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Quantifying Regional Economic Impacts of CO_2 Intensity Targets in China

Da Zhang[*†§], Sebastian Rausch[*], Valerie Karplus[*], and Xiliang Zhang[†]

Abstract

To address rising energy use and CO_2 emissions, China's leadership has enacted energy and CO_2 intensity targets under the Twelfth Five-Year Plan (2011–2015), which are defined at both the national and provincial levels. We develop a computable general equilibrium (CGE) model with global coverage that disaggregates China's 30 provinces and includes energy system detail, and apply it to assess the impact of provincial CO_2 emissions intensity targets. We compare the impact of the provincial targets approach to a single national target for China that achieves the same reduction in CO_2 emissions intensity at the national level. We find that at the national level, the national target results in 25% lower welfare loss relative to the provincial targets approach. Given that the regional distribution of impacts has been an important consideration in the target-setting process, we focus on the changes in provincial level CO_2 emissions intensity, CO_2 emissions, energy consumption, and economic welfare. We observe significant heterogeneity across provinces in terms of the energy system response as well as the magnitude and sometimes sign of welfare impacts. We further model the current policy of fixed end-use electricity prices in China and find that national welfare losses increase. Assumptions about capital mobility have a substantial impact on national welfare loss, while assumptions about natural gas resource potential does not have a large effect.

Contents

1. INTRODUCTION

In recent years policy in China has signaled strong intentions to reduce the country's growing energy and CO_2 emissions footprint. Sustained rapid growth in China over the past three decades has brought great benefits but has also intensified concerns about energy security, air quality and global climate change. China's comprehensive Five-Year Plans, which lay out the government's

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priorities and program of work every five years, have increasingly reflected these concerns. Most recently, China's Twelfth Five-Year Plan (FYP) (2011–2015) has, for the first time, introduced a national target for reducing the nation's CO_2 intensity by 17% over the period 2011 to 2015, in line with the nation's commitment at the 2009 Copenhagen Summit to reduce its CO_2 emissions intensity by 40–45% over the period 2005 to 2020. This national carbon intensity target has been disaggregated at the provincial level, assigning responsibility for different levels of CO_2 intensity reduction to China's provinces (State Council, 2012).

While meeting these targets is mandatory, their existence does not by itself create incentives for firms and households across China to reduce CO_2 emissions intensity. To meet these short- and medium-term policy targets, China's policy makers have announced a range of programs to support target attainment. These include an industrial energy efficiency mandate, targets for the deployment of renewable and nuclear electricity generation, and reduced subsidies to China's energy-intensive, export-oriented sectors (State Council, 2011; Xinhuanet, 2011; Industrial Efficiency Policy Database (IEPD), 2012). Also in the early stages of development is a pilot cap-and-trade system for CO_2 emissions to be deployed in a subset of China's provinces (China Securities Journal, 2012). An energy cap is also under discussion (Xinhuanet, 2012).

Alongside economic growth and environmental protection, promoting inter-regional equity remains a priority among China's policy makers. Identifying the total welfare cost and its distribution under each policy requires a modeling framework capable of resolving policy impacts at the provincial level. In this paper, we first describe how we have developed a new computable general equilibrium (CGE) model that includes a detailed representation of the economy and energy system of China's 30 provinces connected by inter-provincial trade as well as to the rest of the world through international trade flows and an aggregate representation of other global regions. The model includes economic flows and energy quantities in physical units. We apply this new tool to perform an analysis of China's CO_2 intensity targets.

This paper is organized as follows. In Section 2, we summarize previous studies and identify the contribution of this work. We also provide background on China's CO_2 intensity target policy and the assignment of reduction targets in each of China's provinces. In Section 3, we describe the new model, including the model structure, data preparation, representation of inter-provincial trade and integration with a global data set, the 2007 edition of the Global Trade Analysis Project (GTAP 8) data base. In Section 4, we describe the results of our policy scenarios and investigate the sensitivity of our results to electricity pricing policies, capital mobility assumptions, and the availability of natural gas as a potential low carbon substitute fuel. Section 5 discusses some preliminary conclusions and topics for future investigation.

2. BACKGROUND AND LITERATURE REVIEW

2.1 Previous Work

Energy-economic modeling approaches have been widely applied to study prospects for emissions reduction at the sub-national or sectoral level in many countries (Rausch *et al.*, 2011; Lanz and Rausch, 2011; Lanz and Rausch, 2012; Caron *et al.*, 2012; Paltsev *et al.*, 2009; Alton *et al.*, 2012; Ferreira-Filho and Horridge, 2012). Many of these studies have been conducted for China. For instance, Wei *et al.* (2011) estimate CO_2 emissions reduction potential and marginal abatement costs by province in a model using a distance function approach. Yi *et al.* (2011) evaluate provincial target allocation schemes based on several indicators related to equity, economic development, and energy intensity, which are used to construct a comprehensive index for policy evaluation. Our study contributes to efforts to evaluate both the economic and distributional impacts of target allocation schemes. For this study we use a new CGE model that disaggregates China at the provincial level. CGE models have been widely used in China to investigate energy and climate policy proposals. Previous research has employed single-region models of China to focus on the impacts of carbon mitigation measures (Cao, 2007; Wang *et al.*, 2009; Lin and Jiang, 2011; Dai *et al.*, 2011). Other analyses have used models with various levels of regional disaggregation to investigate a wide range of energy policy questions (Horridge and Wittwer, 2008; Li *et al.*, 2009; Wang *et al.*, 2006; Li and He, 2005; Xu and Li, 2008; Lu *et al.*, 2010). Li and He (2010) are among the few to analyze carbon mitigation policy in a regionally-disaggregated CGE model. However, these models are mostly based on older input-output data (e.g., China's 2002 input-output tables) and do not include physical accounting in the energy sector. Moreover, they are not integrated with any global trade data set, treating China as a small or large open economy, which can significantly affect the reliability of simulation results.

2.2 Description of the Twelfth Five-Year Plan CO_2 Intensity Targets

China's primary policy approach to reduce energy and CO_2 emissions takes the form of intensity targets, defined as the allowable energy consumption or emissions per unit of GDP. Prior to the Twelfth FYP (2011–2015), policy was focused on energy intensity. The Eleventh FYP included an energy intensity reduction target of 20% nationwide. This target was not formally allocated to provinces, although provinces made non-binding pledges to undertake a certain level of reductions at the outset of the policy (World Bank, 2009). At the conclusion of the Eleventh FYP, China's leaders officially declared that a 19.1% reduction in energy intensity had been achieved (Industrial Efficiency Policy Database (IEPD), 2012). The reduction achieved during the Eleventh FYP has been attributed to energy efficiency improvements in industry (much of it claimed to be achieved through an initiative called the 1,000 Enterprises Program) and the closure of small, inefficient industrial and power generation facilities (He *et al.*, 2010; Price *et al.*, 2010; Price and et.al., 2011).

A CO_2 intensity target was formally introduced for the first time under the Twelfth FYP, with a reduction goal of 17% (State Council, 2012). The reduction in CO_2 intensity over this period is expected to come from reductions in energy intensity (through further improvements in industrial energy efficiency and a shift in economic structure away from energy-intensive industries), as well as the further introduction of low carbon electricity sources into China's electric power generation mix. For the first time, binding targets for CO_2 emissions reductions were assigned at the provincial level. These targets are given in **Table 1**.

Table 1. CO_2 Intensity reduction targets across provinces of mainland China.

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	Inner Mongolia, Heilongjiang, Guangxi, Guizhou, Gansu, Ningxia
11	Hainan, Xinjiang
10	Qinghai, Tibet

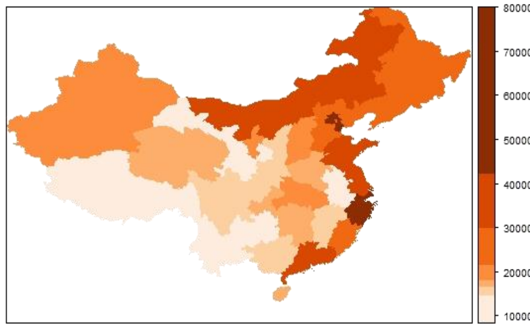
A driving principle behind the allocation is to assign reduction burdens according to provincial wealth, which is intended to ease pressure on less affluent regions or regions targeted for accelerated development. Presently China is characterized by significant heterogeneity across provinces in terms of per-capita GDP, total emissions rates, and emissions intensities (see **Figure 1**). In general, the eastern coastal provinces have higher per-capita GDP and higher total emissions rates but low emission intensities compared to the western provinces in China, and thus have been assigned higher intensity reduction targets. An alternative to provincial targets is to set a single national reduction target that would induce reductions at least cost nationwide. Our modeling framework allows us to compare national and provincial target allocation approaches, and to understand how each leads to heterogeneous energy, emissions, and economic outcomes across provinces.

3. MODELING FRAMEWORK

3.1 Data

For this study we develop a comprehensive energy-economic data set that includes a consistent representation of energy markets in physical units as well as detailed accounts of regional production and bilateral trade for the year 2007. The data set is based on detailed provincial-level data for China and a global economic and energy data set, which are used to construct social accounting matrices (SAMs) for all regions. SAMs for every region except China are based on the GTAP data base (GTAP, 2012), while data for China is based on the full set of China's recently published 2007 provincial input-output tables and China's national input-output table (National Information Center, 2011).[1] Energy use and emissions data is based on data from

[1] In preparing our data we noted substantial discrepancies between the sum of economic flows in the provincial data and the national totals. To achieve consistency with the national totals, which are used in the preparation of the GTAP database, we scale the provincial data by the national total, holding fixed the provincial and sector shares of output.



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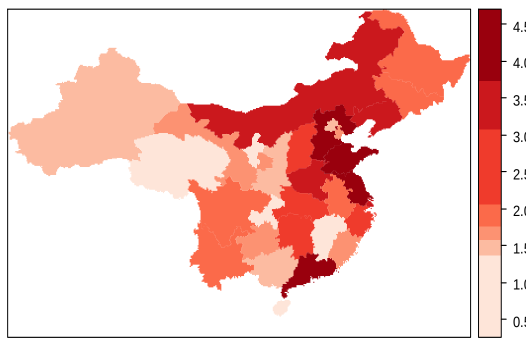

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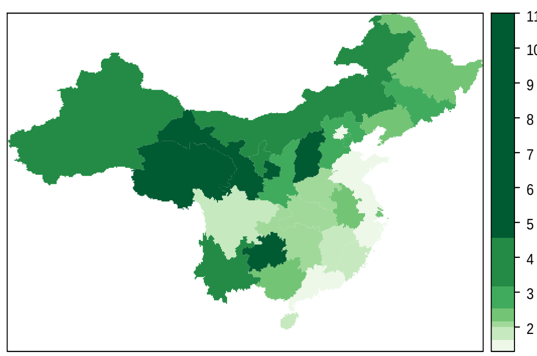


(c)

Figure 1. Per-capita GDP (yuan) (a), CO_2 emission (100 million tons) (b), and CO_2 emission intensity (ton/10,000 yuan) (c) of mainland China's provinces in 2007. Tibet is not included due to data availability in (b) and (c).

GTAP and the 2007 China Energy Statistical Yearbook (National Statistics Bureau, 2008). 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 in the year 2007, and identifies 129 countries and regions and 57 commodities (GTAP, 2012).

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). The data set consists of input-output tables for each province. Each table identifies the forward and backward linkages associated with production of 42 commodities and existing taxes. Based on these input-output tables, we established our SAM tables for each province after some minor adjustments and updates for balancing.[2] We applied the following least-squares optimization problem to obtain the balanced SAM tables for each province p (see **Table 2**).

$$\begin{gathered} \min_{\{x_{pij}\}} \sum_{i,j}(x_{pij} - \overline{X}_{pij})^2 + PEN \sum_{i \in E \ or \ j \in E}(x_{pij} - \overline{X}_{pij})^2 \\ s.t. \ \sum_j x_{pij} = \sum_j x_{pji} \quad \textit{for all } i \\ VXM_{pi} \leq VOM_{pi} \quad \textit{for all } i \end{gathered}$$

where i and j represent row and column indices of the SAM table, and x_{pij} is the value of elements of the SAM table for province p. E represents rows or columns related to energy sectors (energy production, use and trade), and PEN is the penalty term associated with changing elements related to the energy sector. VOM_{pi} and VXM_{pi} are output and total outflows (domestic outflows and international exports) of sector i in province p.

The objective function minimizes the extent to which the value of SAM elements can be altered, especially in the case of elements related to the energy sectors, given that we have already modified the energy data to improve its quality. Constraints in the optimization problem force all accounts in the SAM table to be balanced and require output of every sector to be greater than the total outflow for each province to satisfy the Armington assumption (Armington, 1969).

We then construct another least-squares optimization problem to balance all the SAM tables for each province simultaneously to ensure that the domestic trade flows for each sector in China are balanced. Prior to this optimization, bilateral province-to-country trade flows are estimated by disaggregating China's bilateral international trade data in GTAP according to each province's value share in China's import/export flows by sector. These trade flows are fixed in the optimization.

$$\begin{gathered} \min_{\{x_{pij}\}} \sum_{p,i,j}(x_{pij} - \overline{X}_{pij})^2 + PEN \sum_{i \in E \ or \ j \in E}(x_{pij} - \overline{X}_{pij})^2 \\ s.t. \ \sum_j x_{pij} = \sum_j x_{pji} \quad \textit{for all } p, i \\ VXM_{pi} \leq VOM_{pi} \quad \textit{for all } p, i \\ \sum_p VDXM_{pi} = \sum_p VDIM_{pi} \quad \textit{for all } i \end{gathered}$$

[2] We set all subzero entries in the input-output tables to zero. The number of subzero entries was very small relative to the total number of entries (about 0.001%). To improve the characterization of energy markets, we merged input-output data with data on physical energy quantities from both national and provincial energy balance tables in China's Energy Statistical Yearbook 2007 and energy price data supplied by the Energy Research Institute of the National Development and Reform Commission (NDRC), China.

Table 2. Structure of SAM tables for each province in China.

	A	**C**	**F**	**H**	**G1**	**G2**	**T**	**DX**	**X**	**I1**	**I2**	**M**
A		AC					SA					
C	CA			CH		G2D		DER	ER	CS1	CS2	VDST
F	FA											
H			HF			HG2		DHR	HR			
G1						G1G2				CG1S		
G2					G2G1		TR					
T	TA											
DX		DRC		DRH								
X		RC		RH								
I1			DP	PSV1	G1SV							
I2		IC		PSV2								
M		MG										

Note: AC – sector output; SA – sector subsidy; CA – intermediate use; CH – household consumption; G2D – local government; DER – domestic outflow; ER – export; CS1 – investment; CS2 – inventory addition; VDST – domestic transportation service use; FA – factor input; HF – Factor earning; HG2 – transfer from central government to household; DHR – domestic trade deficit; HR – international trade deficit; G1G2 – transfer from local government to central government; CG1S – Balancing term for central government; G2G1 – transfer from central government to local government; TR – tax revenue for local government; TA – production tax; DRC – domestic inflow; DRH – domestic trade surplus; RC – import; RH – international trade surplus; DP – capital depreciation; PSV1 – balancing term for investment; G1SV – balancing term for investment; IC – inventory deletion; PSV2 – balancing term for inventory; MG – domestic trade margin.

The optimization problem for balancing trade flows is similar to the previous one. $VDXM_{pi}$ and $VDIM_{pi}$ are domestic exports and imports, respectively, from sector i for province p. Using the balanced provincial SAM data, bilateral inter-provincial trade data is estimated using the least-squares approach under the assumption that the import source composition of each sector is the same as the source composition of the total imports for each province.

For this study, we aggregate the data set to 30 provinces in China and to three regions in the rest of the world (the United States, the European Union and other European countries, and the rest of world), and into 26 commodity groups (see **Table 3**). However, we maintain the flexibility to aggregate the regions as desired for other studies. Our commodity aggregation identifies six energy sectors and 20 non-energy composites. The mapping of GTAP commodities and sectors identified in our study is provided in Table 3. Primary factors in the data set include labor, capital and natural resources. Labor, capital earnings and natural resource rents represent gross earnings denominated in 2007 U.S. dollars.

3.2 The Numerical Model

Our modeling framework is a multi-commodity, multi-region static numerical general equilibrium model of the world economy with sub-national detail for China's economy. The key features of the model are outlined below.

Table 3. Regions, commodity classifications and mappings in the model.

Region	Abbreviation	GTAP commodity	Aggregated commodity
Beijing	BEJ	Paddy rice	AGR
Tianjin	TAJ	Wheat	AGR
Hebei	HEB	Cereal grains	AGR
Shanxi	SHX	Vegetables, fruit, nuts	AGR
Inner Mongolia	NMG	Oil seeds	AGR
Liaoning	LIN	Sugar cane, sugar beet	AGR
Jilin	JIL	Plant-based fibers	AGR
Heilongjiang	HEL	Crop	AGR
Shanghai	SHH	Bovine cattle, sheep and goats, horses	AGR
Jiangsu	JSU	Animal products	AGR
Zhejiang	ZHJ	Raw milk	AGR
Anhui	ANH	Wool, silk-worm cocoons	AGR
Fujian	FUJ	Forestry	AGR
Jiangxi	JXI	Fishing	AGR
Shandong	SHD	Coal	COL
Henan	HEN	Oil	CRU
Hubei	HUB	Gas	GAS
Hunan	HUN	Minerals	OMN
Guangdong	GUD	Bovine meat products	AGR
Guangxi	GUX	Meat products	AGR
Hainan	HAI	Vegetable oils and fats	AGR
Chongqing	CHQ	Dairy products	AGR
Sichuan	SIC	Processed rice	AGR
Guizhou	GZH	Sugar	AGR
Yunnan	YUN	Food products	AGR
Shanxi	SHX	Beverages and tobacco products	B_T
Shannxi	SHA	Textiles	TEX
Gansu	GAN	Wearing apparel	CLO
Qinghai	QIH	Leather products	CLO
Ningxia	NIX	Wood products	LUM
Xinjiang	XIN	Paper products, publishing	PPP
		Petroleum, coal products	OIL
United States	USA	Chemical, rubber, plastic products	CRP
Europe Union and		Mineral products	NMM
other European countries	EUR	Ferrous metals	MSP
Rest of world	ROW	Metals	MSP
		Metal products	FMP
		Motor vehicles and parts	TME
		Transport equipment	TME
		Electronic equipment	ELQ
		Machinery equipment	OME
		Manufactures	OMF
		Electricity	ELE
		Gas manufacture and distribution	GDT
		Water	WTR
		Construction	CON
		Trade	TRD
		Transport	TRP
		Water transport	TRP
		Air transport	TRP
		Communication	OTH
		Financial services	OTH
		Insurance	OTH
		Business services	OTH
		Recreational and other services	OTH
		Public Administration, defense, education, health	OTH
		Dwellings	OTH

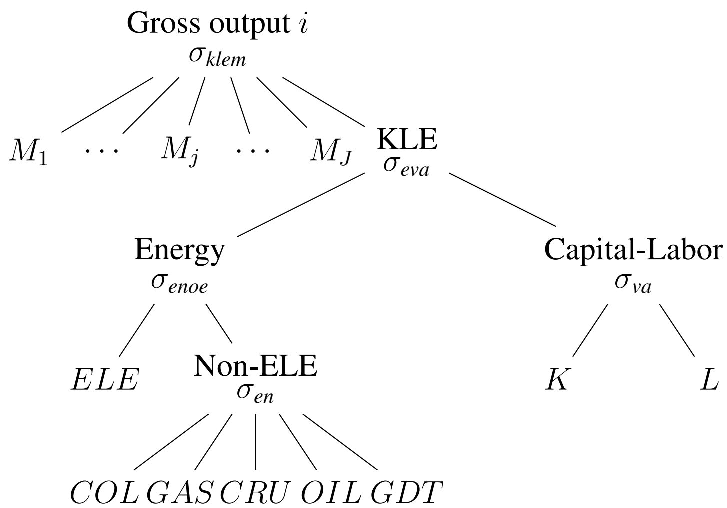


Figure 2. Structure of production for all the industries except fossil fuels and OIL, GDT, ELE.

3.2.1 Modeling Production and Household Consumption Activities

For each industry ($i = 1, \ldots, I$, $i = j$) in each region ($r = 1, \ldots, R$) gross output (Y_{ir}) is produced using inputs of labor (L_{ir}), capital (K_{ir}), natural resources including coal, natural gas, crude oil, and land (R_{ir}), and produced intermediate inputs (X_{jir})[3].

$$Y_{ir} = F_{ir}(L_{ir}, K_{ir}, R_{ir}; X_{1ir}, \ldots, X_{Iir}) \tag{1}$$

We employ constant-elasticity-of-substitution (CES) functions to characterize the production technologies. All industries are characterized by constant returns to scale and are traded in perfectly competitive markets. Nesting structures for the production systems of all industries except for fossil fuel and petroleum and coal products (OIL), gas manufacture and distribution (GDT), electricity (ELE) are depicted in **Figure 2**.

Fossil fuels f (coal, crude oil and natural gas) are produced according to a nested CES function combining a fuel-specific resource, capital, labor, and intermediate inputs.

$$Y_{fr} = \left[\alpha_{fr}\, R_{fr}^{\rho^R_{fr}} + \nu_{fr}\, min\,(X_{1fr}, \ldots, X_{ifr}, V_{fr})^{\rho^R_{fr}}\right]^{1/\rho^R_{fr}} \tag{2}$$

where α, ν are share coefficients of the CES function and $\sigma^R_{fr} = 1/(1-\rho^R_{fr})$ is the elasticity of substitution between the fuel-specific resource and the composite including primary factors, energy and materials. σ^R_{fr} is determined by the resource input share and price elasticity of supply η_{fr}. The primary factor and energy composite is a Cobb-Douglas function of the energy input,

[3] For simplicity, we abstract from the various tax rates that are used in the model. The model includes *ad valorem* output taxes and import tariffs.

labor and capital.

$$V_{fr} = L_{fr}^{\beta_1} K_{fr}^{\beta_2} E_{1_{fr}}^{\beta e1} \ldots E_{i_{fr}}^{\beta ei} \tag{3}$$

where β_1, β_2, $\beta_{e1}, \ldots, \beta_{ei}$ are shares of the labor, capital and energy inputs. Oil refining, gas production and distribution production are represented in **Figure 3**.

Electricity production is represented in **Figure 4**. We distinguish several generation technologies, including conventional fossil, hydro, nuclear and wind. In this version of the model, the resource input share is calibrated using the benchmark data. As we lack estimates of price elasticities for supply of nuclear, hydro, and wind in individual provinces in China, we adopt the corresponding elasticities from the MIT Emissions Prediction and Policy Analysis model (Paltsev *et al.*, 2005).

For each sector, the capital mobility feature is represented by following a putty-clay approach. A fraction ϕ of previously-installed capital becomes non-malleable in each sector, and vintaged production in this sector uses this part of capital with fixed shares of all the inputs which are identical to those installed in the base year. The fraction $1 - \phi$ of capital is malleable and can be shifted to other sectors in response to input price changes. All the sectors except electricity have the same ϕ value, while ϕ for the electricity sector is higher because capital tends to be less mobile when invested in electricity generation (Sue Wing, 2006).

In each region r, preferences of representative consumers are represented by a CES utility function comprised of consumption goods (C_i) and investment (I):

$$U_r = \mathit{min}\left[g(C_{1r}, \ldots, C_{Ir}), g(I_{1r}, \ldots, I_{Ir})\right] \tag{4}$$

where the function $g(\cdot)$ is a CES composite of all goods. In each region, a single government entity approximates government activities at both central and local levels.

3.2.2 Supplies of Final Goods and Treatment of Domestic and International Trade

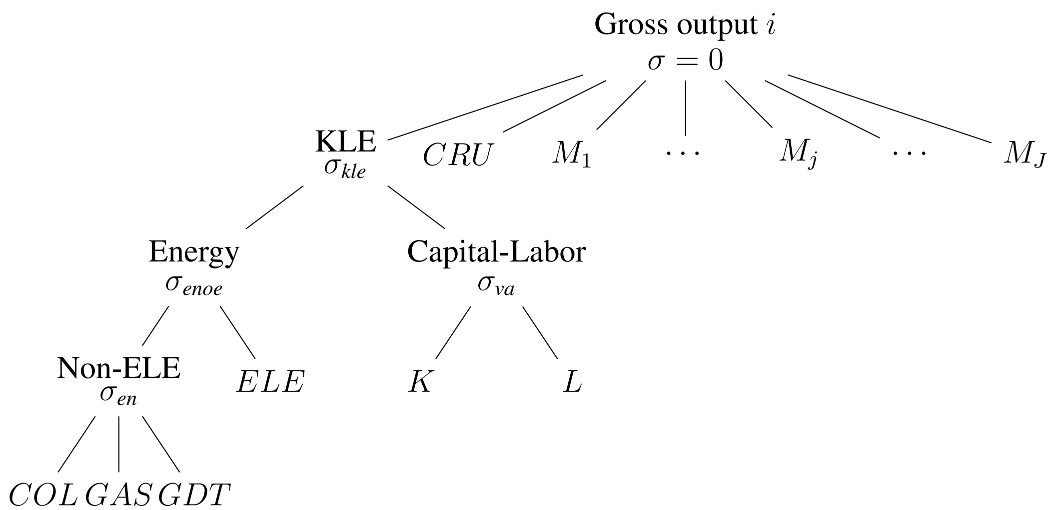
All intermediate and final consumption goods are differentiated following the Armington assumption. For each demand class, the total supply of good i is a CES composite of a domestically produced variety and an imported variety, as follows:

$$X_{ir} = \left[\psi^z \, \mathit{ZD}_{ir}^{\rho_i^D} + \xi^z \, \mathit{ZM}_{ir}^{\rho_i^D}\right]^{1/\rho_i^D} \tag{5}$$

$$C_{ir} = \left[\psi^c \, \mathit{CD}_{ir}^{\rho_i^D} + \xi^c \, \mathit{CM}_{ir}^{\rho_i^D}\right]^{1/\rho_i^D} \tag{6}$$

$$I_{ir} = \left[\psi^i \, \mathit{ID}_{ir}^{\rho_i^D} + \xi^i \, \mathit{IM}_{ir}^{\rho_i^D}\right]^{1/\rho_i^D} \tag{7}$$

$$G_{ir} = \left[\psi^g \, \mathit{GD}_{ir}^{\rho_i^D} + \xi^g \, \mathit{GM}_{ir}^{\rho_i^D}\right]^{1/\rho_i^D} \tag{8}$$



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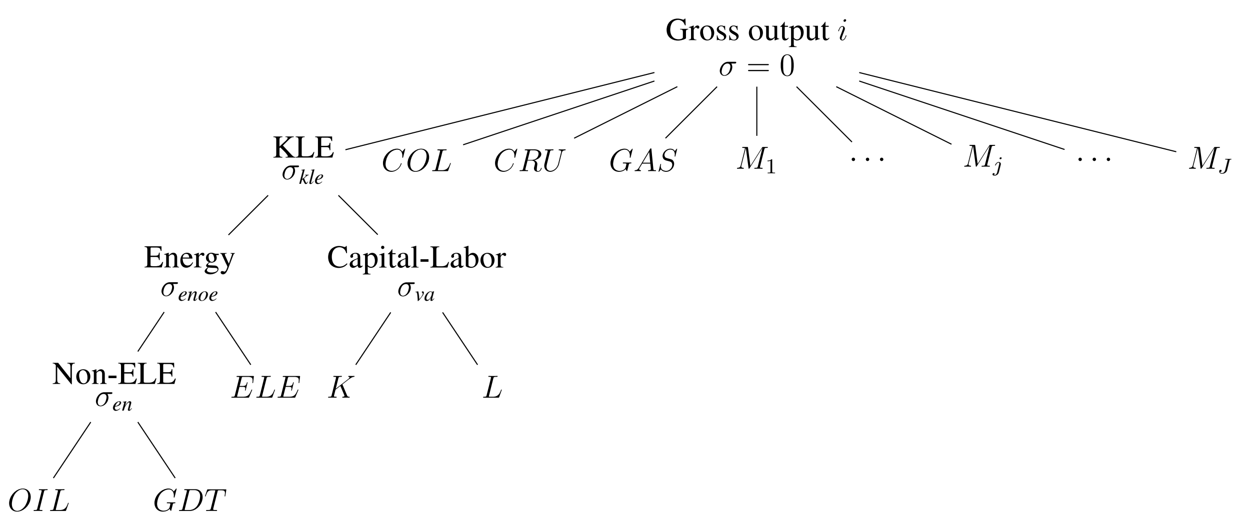

(b)

Figure 3. Structure of production for oil refining $i \in \{\text{OIL}\}$ (a) and gas production and distribution $i \in \{\text{GDT}\}$ (b).

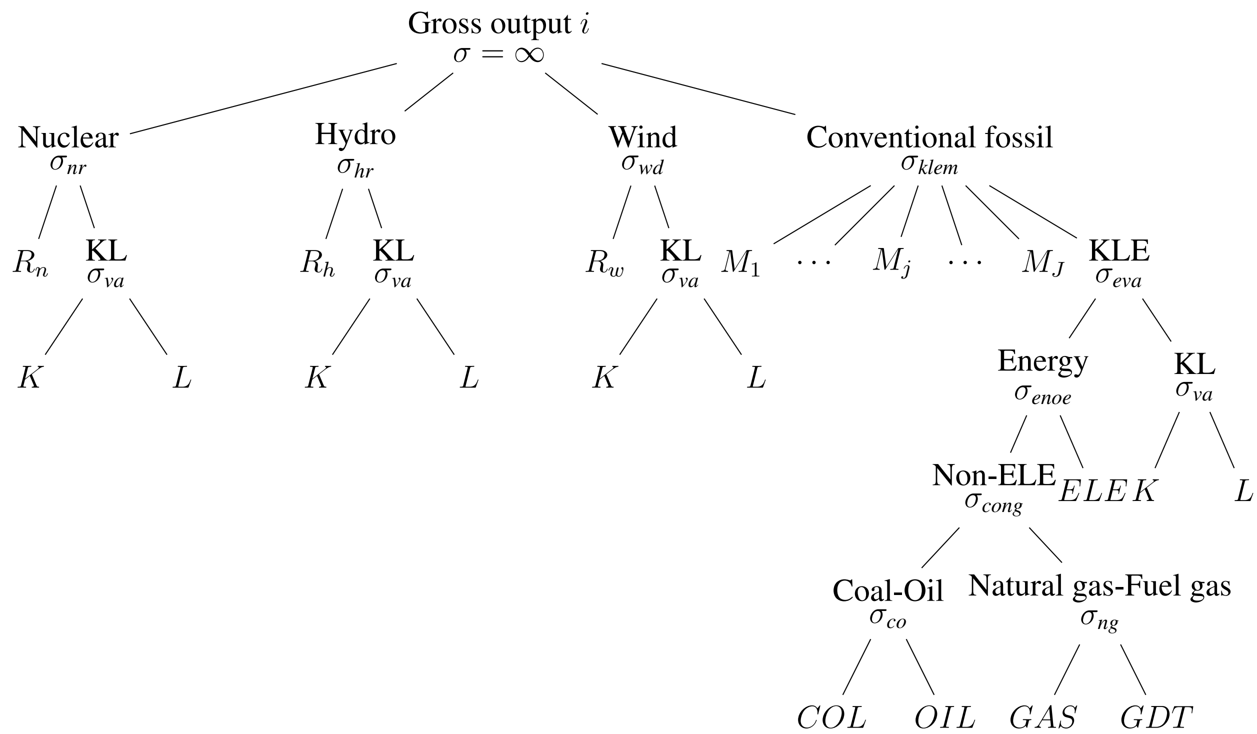

Figure 4. Structure of electricity production $i \in \{\text{ELE}\}$.

where Z, C, I and G are inter-industry demand, consumer demand, investment demand, and government demand for good i, respectively; and *ZD*, *ZM*, *CD*, *CM*, *ID*, *IM*, *GD*, *GM* are domestic and imported components of each demand class, respectively. The ψ's and ξ's are the CES share coefficients. The Armington substitution elasticities between domestic and imported varieties in these composites are given by $\sigma_i^D = 1/(1 - \rho_i^D)$.

The domestic and imported varieties of goods are represented by nested CES functions. We replicate a border effect within our Armington import specification by assuming that goods produced within China are closer substitutes than goods from international sources. We include separate import specifications for China's provinces (indexed by $p = 1, \ldots, P$) and international regions (indexed by $t = 1, \ldots, T$). The nesting structure of the Armington composites are depicted in **Figures 5 and 6**.

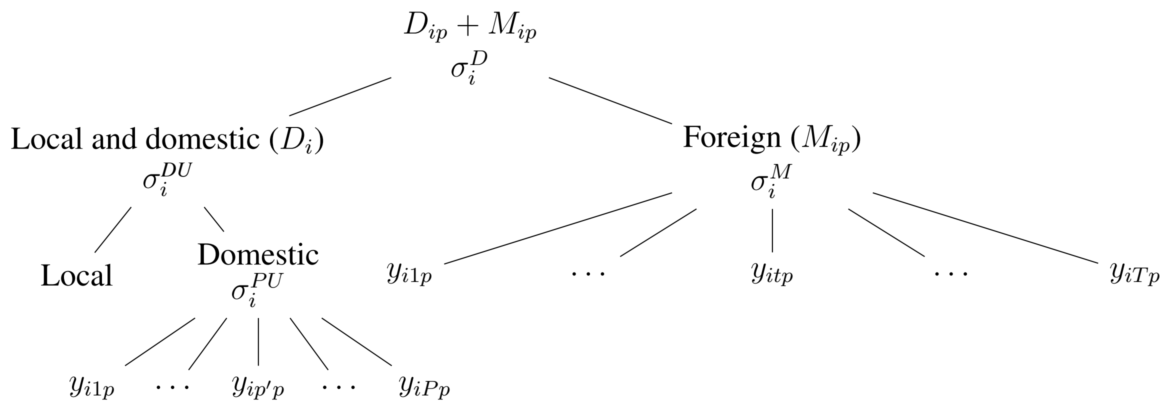

Figure 5. Aggregation of local, domestic and foreign varieties of good i for China province p.

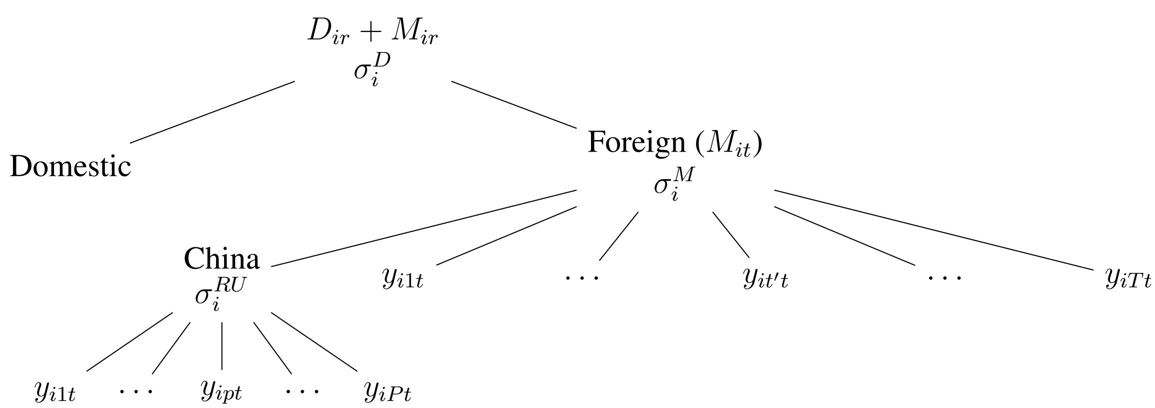

Figure 6. Aggregation of domestic and foreign varieties of good i for international region t.

3.2.3 Equilibrium and Model Solution

Consumption, labor supply and savings result from the decisions of the representative household in each model region that maximize its utility subject to a budget constraint that consumption equals income. Given input prices gross of taxes, firms maximize profits subject to the technology constraints. Firms are assumed to operate in perfectly competitive markets (an assumption that can be relaxed in specific applications) and maximize profit by selling products at a price equal to the marginal cost of production. Numerically, the equilibrium is formulated as a mixed complementarity problem (MCP) (Mathiesen, 1985; Rutherford, 1995). A model solution must satisfy zero profit and market clearance conditions, with the former condition determining a vector of activity levels and the latter a vector of market-clearing prices. The problem is formulated in GAMS and solved using the mathematical programming system MPSGE (Rutherford, 1999) and the PATH solver (Dirkse and Ferris, 1995) to obtain non-negative prices and quantities.

3.3 Scenarios

We design two scenarios to compare the impact of different approaches to setting CO_2 intensity targets in China. In the first scenario, Regional Targets (RT), we require compliance with CO_2 intensity reduction targets set at the provincial level, based on the Twelfth FYP (see Table 1).[4] In the second scenario, National Target (NT), we impose a single CO_2 intensity reduction target at the national level that is equivalent to the national carbon intensity reduction achieved in Scenario RT, which we find to be a reduction of 17.4%. We model the allocation of emissions allowances to provinces based on their benchmark emissions, and a nation-wide allowance trading market is established. We implement both policies as an endogenous tax on CO_2 embodied in energy used across the range of economic activities. The tax is adjusted until the CO_2 intensity target is achieved. The tax revenue collected in each province is returned to the representative household in the same province.

We expect that the national and regional target allocation scenarios will produce different welfare outcomes. The provincial target scenario is regionally constrained, and the reductions required vary across provinces, while under a single national target least cost opportunities can be chosen from across the economy as a whole. While we design the national target to equal the CO_2 intensity reduction achieved under the regional target at the national level, our model simulates how emissions and emissions intensity, as well as energy consumption and associated policy cost, will vary by province. Understanding how each policy design induces changes in the energy consumption profile, emissions and economic welfare in each province will lend insight into the trade-offs between the efficient policy design (a single national cap) and a regionally-constrained policy that sets provincial targets explicitly.

[4] We caution that our simulation is not intended to simulate the future impact of the Twelfth FYP, particularly given that we are using a static framework based on 2007 data. Nevertheless, this framework allows us to understand the relative merits of alternative policy approaches and develop intuition about the relationship between provincial characteristics and localized welfare changes as a result of policy.

4. RESULTS

China is characterized by significant regional heterogeneity in per-capita income, energy demand, CO_2 emissions and CO_2 emissions intensity as described above. We therefore anticipate that policy impacts will vary across provinces, and also expect different responses under the two policy approaches modeled. Below we discuss the impact of each policy approach (regional or national targets) at the national level before considering in depth heterogeneity in terms of CO_2 intensity, total CO_2 emissions, energy consumption and welfare outcomes at the provincial level.

4.1 Comparing Policy Impact at the National Level

By design both scenarios achieve a reduction in CO_2 emissions intensity of 17.4%, but at different national welfare costs.[5] In both scenarios, welfare loss is modest at the national level, 1.5% in Scenario RT and 1.2% in Scenario NT (see Figure **7**). More welfare loss occurs at the national level under Scenario RT, the provincial allocation scheme (a 25% greater reduction relative to Scenario NT), consistent with the fact that abatement flexibility, and thus the equilibrium allocation, is more constrained by the provincial-level reductions required. CO_2 intensity reduction under Scenarios NT and RT are achieved by reducing coal use by around 25%, while total final consumption of fossil energy falls by 18%. At the same time, generation from non-fossil sources (hydro, nuclear and wind) increases from 120 million tons of coal equivalent (mtce) to about 160 mtce in Scenario RT and 150 mtce in Scenario NT.[6] Very slight differences exist between the two scenarios—slightly more non-fossil energy is brought online in Scenario RT, while coal use is reduced more under Scenario NT. It is interesting that the outcomes are similar, despite the fact that under the provincial targets, cost effective opportunities to reduce coal are regionally constrained—for instance, a more modest reduction in CO_2 intensity may be required within a province that has a large opportunity to cost-effectively reduce coal use, while a province facing a more aggressive target may have limited opportunities to improve coal use efficiency and instead needs to rely on adoption of non-fossil sources.

In both scenarios CO_2 emissions reductions are slightly larger in percentage terms than CO_2 intensity reductions at the national level (see **Figure 8**). We observe a reduction in emissions in the static model framework because the intensity target reduces China's GDP, and so a CO_2 intensity reduction consistent with the new level of GDP results in a disproportionately larger reduction in CO_2 emissions. We would expect the effect to be the opposite if the policy were modeled in a dynamic framework that captured increases in GDP over the same period—i.e. total emissions may decrease less or increase if the economy is growing over the period covered by the intensity target. As this analysis is aimed at understanding the relationship between policy design and the distribution of impacts, we adopt a static approach to build intuition, acknowledging that in practice emissions outcomes are a function of the intensity target stringency and the rate of GDP growth.

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[5] Welfare costs are measured as the equivalent variation of household income, relative to the no policy benchmark.

[6] One million tons of coal equivalent (mtce) is equal to 0.03 exajoules (EJ).

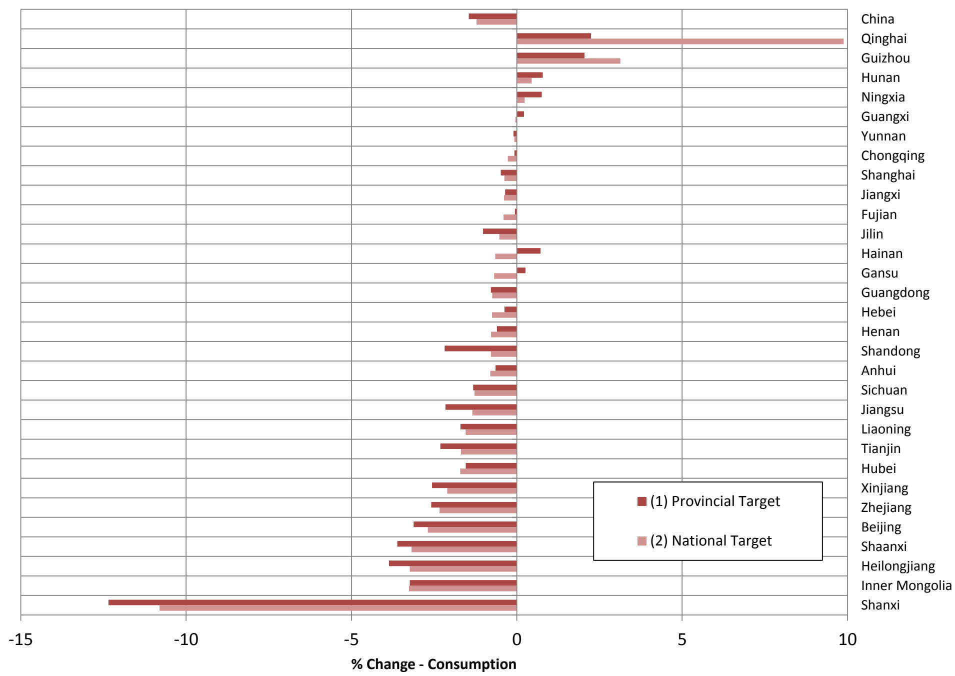

Figure 7. Regional welfare change.

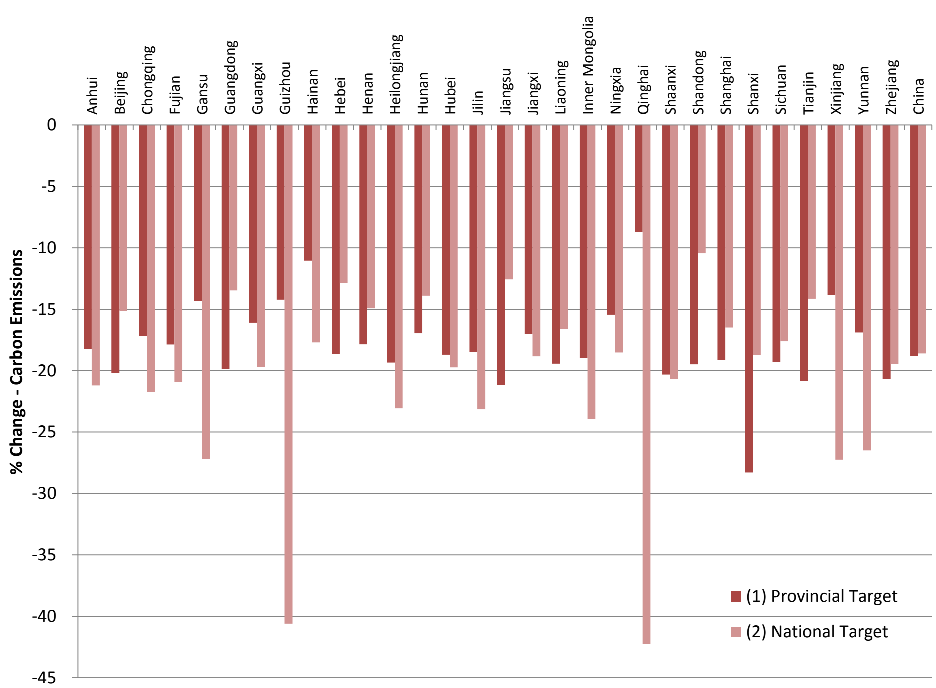

Figure 8. Regional carbon emissions reductions.

4.2 Comparing Policy Impact at the Provincial Level

A comparison of the CO_2 intensity reduction undertaken in each of China's provinces under the two scenarios reveals some significant differences (see **Figure 9**). Under the national target, several provinces that had relatively low targets in Scenario RT end up contributing significantly more to overall abatement (in particular Qinghai and Guizhou), suggesting that these provinces offer abatement opportunities at lower cost. By contrast, provinces that faced tough provincial targets in Scenario RT contribute less to overall abatement under the national target (see for instance Shaanxi, Beijing and Jiangsu). This result suggests that the Scenario RT target allocation is demanding large reductions from provinces where abatement is relatively expensive, while bypassing opportunities to make reductions inexpensively in other provinces.

The modest welfare loss at the national level also masks large variation in the welfare impacts across provinces under both scenarios (see Figure 7). Some provinces experience large welfare increases (Qinghai, Guizhou), while some provinces undergo large welfare decreases, e.g., Shaanxi province, a major domestic coal exporter, experiences welfare loss of about 12% in Scenario RT. In general the pattern of welfare change is similar in both scenarios. Interestingly, consumption gains incurred in some provinces, e.g., Qinghai and Guizhou, are larger in the national target allocation (Scenario NT), suggesting that a single national constraint is not only good for efficiency, but can increase welfare gains in provinces with large potential to reduce emissions. **Figure 10** shows the final energy consumption structure of each province in the reference and both policy scenarios. In the national target allocation (Scenario NT), energy use

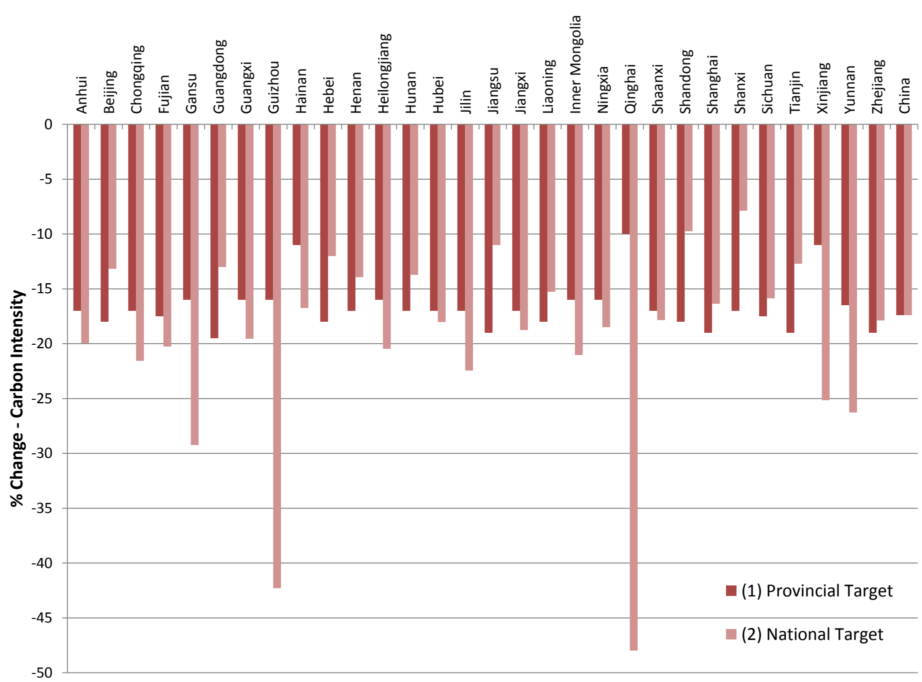

Figure 9. Regional carbon intensity reduction.

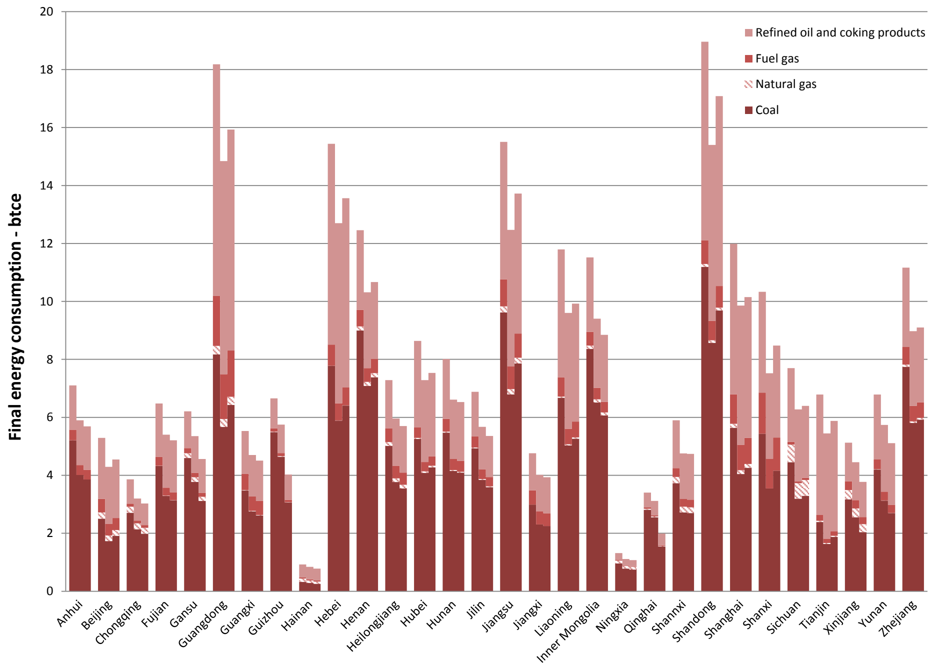

Figure 10. Regional energy consumption. From left to right for each province: Reference, Scenario RT, and Scenario NT. Unit: Billion tons of coal equivalent.

patterns reflect a less constrained response to achieve reductions in emissions intensity. We find that provinces such as Guangdong, Shandong and Jiangsu that have already achieved lower CO_2 intensity (given a higher level of development and adoption of efficient technology). These provinces face more costly abatement opportunities at the margin and so given the option they do not undertake significant additional abatement under Scenario NT, continuing their reliance on coal. By contrast, provinces that have high energy intensity and face relatively low cost opportunities to cut coal use (Qinghai and Guizhou) end up reducing their reliance on coal, and thus contribute disproportionately to achieving the total national reduction. By selling allowances to provinces that face more costly abatement opportunities, these provinces benefit relative to the provincial target scenario.

Comparing the carbon prices in individual provinces under each scenario (see **Figure 11**) provides some clues as to the relative stringency of the reduction targets at the provincial level. Under Scenario NT, a single national carbon price of 225 yuan per ton CO_2 (or about U.S. $30 per ton in 2007) is needed to induce the required reduction in CO_2 intensity. Under Scenario RT, there is significant diversity in the provincial carbon price, ranging from 40 to 440 yuan per ton CO_2 (U.S. $5 to U.S. $58 per ton in 2007). It is instructive to compare the carbon prices that result in each province under Scenario NT and Scenario RT to understand whether, under regional targets, provinces undertake more or less reduction relative to the national targets scenario. We find that provinces with carbon prices in Scenario RT in excess of the national carbon price undertake more abatement relative to Scenario NT, while the reverse is true for provinces with

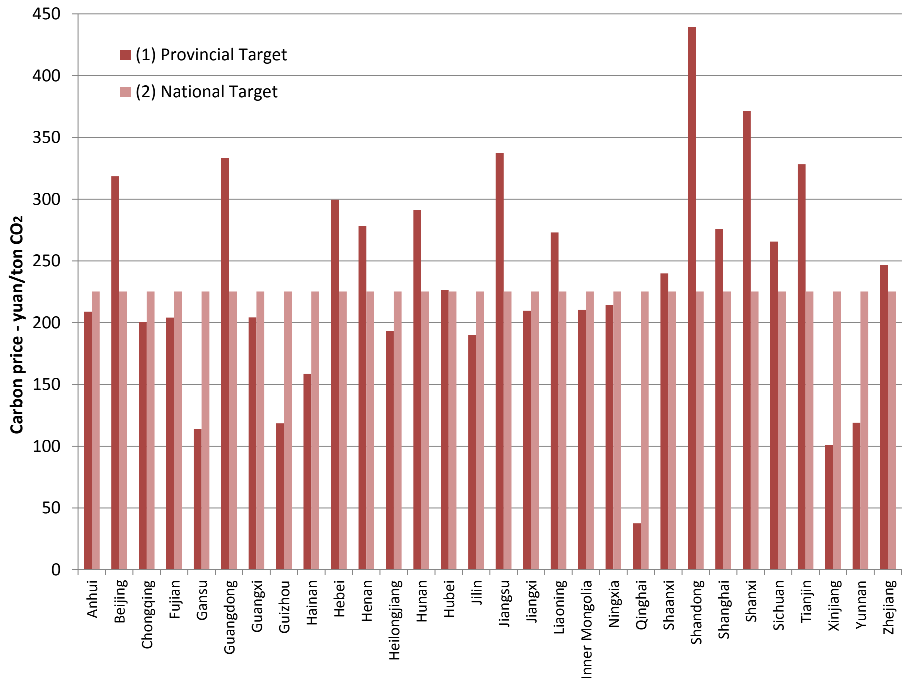

Figure 11. Regional carbon price.

carbon prices in Scenario RT that fall below the national price in Scenario NT. An example is Qinghai province, which has large opportunities to reduce CO_2 emissions intensity by reducing coal use, but these opportunities are essentially bypassed because the CO_2 intensity reduction required of Qinghai (10%) is one of the lowest. As discussed above, Qinghai's welfare gain under Scenario NT is partly related to the fact that it can undertake reductions cheaply on behalf of other provinces, reducing the burden elsewhere in the economy to reduce CO_2 intensity.

For China as a whole, as well as for the U.S., Europe and the rest of world, CO_2 emissions intensity and total CO_2 emissions changes are small, while the welfare change is negligible in both scenarios (see **Table 4**). However, even small changes are notable given that policy is not directly imposed in these regions. Moreover, should China choose to adopt more stringent policies in the future, the effects on non-target regions may be substantial given China's size and its role as an energy consumer in global markets.

4.3 Role of Fixed Electricity Prices

Electricity prices in China are currently managed to keep end-use prices at affordable levels, and are set at different levels for household and industrial users. To reflect China's current electricity policy, we model prices as fixed to households alone, or to both households and industrial users. We model this type of managed pricing through a endogenous subsidy that maintains electricity prices at a fixed level. In the first scenario, "electricity subsidy for all sectors" (Scenario RT_ELEALL), a subsidy is provided to electricity consumers in all sectors, and the subsidy rate is endogenously determined by the model to hold the electricity price at the level

Table 4. Results for China, U.S., Europe and rest of world in the two scenarios in percentage terms.

	Carbon intensity change	Carbon emission change	Welfare change
China (Scenario RT)	−17.4	−18.8	−1.5
China (Scenario NT)	−17.4	−18.6	−1.2
U.S. (Scenario RT)	0.2	0.3	0.0
U.S. (Scenario NT)	0.2	0.2	0.0
Europe (Scenario RT)	0.2	0.3	0.0
Europe (Scenario NT)	0.2	0.2	0.0
Rest of world (Scenario RT)	0.5	0.5	0.0
Rest of world (Scenario NT)	0.5	0.5	0.0

of the reference year (e.g., the price is not adjusted to reflect increases in underlying costs of generating electricity). We assume that local governments fund the subsidy with transfers from households. In the "cross electricity subsidy" scenario (Scenario RT_ELERES), we only model a subsidy to residential users to maintain the residential electricity price at the reference level, and the subsidy is financed by a tax levied on all other electricity consumers. This tax rate is endogenously determined by the model to ensure that household electricity price remains fixed, and the tax revenue is equal to the subsidy to the household.

CO_2 intensity, emissions and welfare changes (%) in China as a whole for the above scenarios are presented in **Table 5**. In both scenarios, with fixed electricity prices households experience slightly greater welfare loss relative to the regional intensity targets scenario in which electricity is not subsidized (Scenario RT) (−1.45% relative to −1.60% or 1.55% at the national level). The additional welfare loss results from the economic distortion created by the subsidy. With fixed prices, consumers' electricity demand does not reflect the penalty imposed on carbon-intensive energy sources, and so demand is higher relative to a case in which prices are passed through. Interestingly, Scenario RT_ELERES has higher CO_2 intensity and emissions reduction than Scenario RT, while Scenario RT_ELEALL has lower intensity and emission reduction but even greater welfare loss. These differences reflect the fact that economic activity also changes when a subsidy to maintain fixed electricity prices is imposed.

Table 5. CO_2 intensity, emission and welfare changes (%) of China for alternative electricity policy scenario under region carbon intensity targets.

	RT	RT_ELEALL	RT_ELERES
CO_2 intensity	−17.43	−17.42	−17.45
CO_2 emission	−18.83	−18.72	−19.17
Welfare change	−1.45	−1.60	−1.55

4.4 Sensitivity Analysis

Since our study is focused a relatively short (five-year) period covered by the Twelfth FYP, it is reasonable to expect that the malleability of the capital stock will play a significant role in the response to the CO_2 intensity targets. We therefore investigate a case in which capital is less malleable than in the reference scenarios by setting high capital vintaging share in the model to reflect the limited mobility of capital in the short term. In the high vintaging (HVTG) case, we set the non-malleable fraction of capital ϕ in each sector to be 50% higher than in our base case (BASE).

We also consider sensitivity to the assumption of the supply elasticity of natural gas. In recent years regional natural gas prices in Asia have remained high and supply is currently limited. There is much speculation about the role that an expanded domestic (potentially unconventional) gas resource in China could play in national efforts to reduce CO_2 intensity. The price elasticity of natural gas supply η_{ng} is set to be four times higher than in our base case in the high natural gas potential (HNGS) case.

The results of changing capital vintaging and natural gas availability assumptions on CO_2 intensity, emission and welfare changes (%) in China as a whole under both Scenario RT and Scenario NT are shown in **Table 6**. In both scenarios a high fraction of non-malleable capital leads to greater welfare loss, especially in Scenario NT, which reflects the difficulty of adjusting the input structure of production in the short term. Increasing the supply elasticity of natural gas has almost no impact on the model results because the share of natural gas of China's primary energy mix is still quite small, its production and use is still carbon intensive relative to other alternatives, and the model captures the fact that there is limited substitution potential for natural gas in the electric power or industrial sectors in China in the short term.

Table 6. CO_2 intensity, emission and welfare changes (%) of China for alternative vintaged capital share and natural gas supply elasticity assumptions.

	BASE	**HVTG**	**HNGS**
Scenario RT:			
CO_2 intensity	-17.4	-17.5	-17.4
CO_2 emission	-18.8	-19.7	-18.8
Welfare change	-1.5	-2.4	-1.5
Scenario NT:			
CO_2 intensity	-17.4	-17.4	-17.4
CO_2 emission	-18.6	-19.0	-18.6
Welfare change	-1.2	-1.7	-1.2

5. CONCLUSIONS

This paper described a new provincial-level CGE model of China and applied it to assess the impact of alternate approaches to achieving the Twelfth FYP CO_2 intensity targets. The main goal of this analysis was to compare two CO_2 intensity target allocation scenarios: one policy scenario that matches China's Twelfth FYP targets imposed at the provincial level, and one policy scenario in which China faces a single national target that achieves an equivalent national intensity reduction. While we find that the single national carbon intensity reduction target results in less consumption loss at the national level (1.2%) than current provincially-disaggregated targets (1.5%), we also find great disparities in the regional impacts. Given that regional impacts are an important consideration in the formulation of national energy and climate policy, it is important to understand how these impacts are distributed, and to be able to estimate the incremental cost of pursuing reductions through provincial rather than a single national constraint.

Our results suggest that assigning provincial targets may miss cost-effective opportunities to reduce emissions in less-constrained provinces, while demanding more costly reductions from highly-constrained provinces. Assigning the appropriate intensity target level for each province is a difficult task. It is very difficult in advance to perform an exhaustive assessment of abatement costs across provinces, not least because it requires knowledge of these costs (which are often proprietary, difficult to estimate or otherwise unavailable). A national target creates incentives to undertake reductions where they are most cost effective, independent of where they are located in China. However, we note that the challenges of implementing a national intensity target may be significant in practice, as provincial governments are currently held accountable for target implementation, and it is less clear how this responsibility would be assigned (and achievement verified) under a national target. Nevertheless, as China's policymakers consider design of a carbon market that integrates several or all provinces, models such as the one developed in this work will be able to estimate the impacts of alternative design approaches as an input to the policy process. As we demonstrate for the case of fixed electricity prices, it is possible to incorporate specific non-market features of China's economy to capture aspects of the response to policy that may affect the magnitude and direction of simulated policy outcomes.

Our model can help to make equity and efficiency trade-offs clear by serving as a platform to evaluate alternative target allocation scenarios. Our results provide some first insights into the impact of reducing energy intensity in China in a static regional energy-economic modeling framework. An important caveat is that we assume in our model that China's economy is characterized by perfectly competitive markets, which may have important implications for welfare loss. We model one feature of China's electricity market—subsidized end-use prices—and find that welfare losses increase when costs are not passed through. This is consistent with the absence of a price signal that would otherwise encourage electricity conservation or spur the adoption of more efficient technology and practices. We further find that the magnitude of the welfare change is sensitive to our assumption about capital mobility, but we also find that it does not change our main result, which is that a single national target imposes a smaller welfare burden on the national economy than the regional target allocation.

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