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Quantifying regional economic impacts of CO$_2$ intensity targets in China

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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 the current binding provincial CO$_2$ emissions intensity targets. We compare the impact of the provincial targets approach to a single target for China that achieves the same reduction in CO$_2$ emissions intensity at the national level. The national target assumes trading of emissions allowances across provinces, resulting in the least-cost reductions nationwide. We find that the national target results in about 20% lower welfare loss in China 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 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 changing assumptions about the future availability of domestic natural gas resources does not have a large effect.

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1. Introduction

Recent policy developments in China signal 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 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 differentiated CO$_2$ reduction requirements to China's provinces (China State Council, 2012).

Provincial-level allocation of the Twelfth Five-Year Plan's CO$_2$ intensity target is the result of a political negotiation process that reflects

many factors—the cost of abatement for CO$_2$ emissions is only one of them.[1] Since trading of emissions allowances is not set up under the current system, provincial targets will lead to a situation in which the marginal cost of meeting the differentiated policy constraint may vary widely across provinces. A critical question is therefore what incremental cost is associated with relying on the current provincially-based, politically negotiated targets, relative to an approach that allows provinces to trade emissions permits and results in the equalization of marginal cost, i.e. the most economically efficient solution.

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 (China State Council, 2011; Xinhuanet, 2011; Industrial Efficiency Policy Database (IEPD), 2012). Starting in 2013, pilot CO$_2$ emissions trading systems were being implemented in a subset of

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[1] Throughout this analysis, abatement cost refers to the marginal cost of reducing an incremental unit of CO$_2$ emissions. The policy constraint, however, is placed on emissions intensity, which takes into account both the quantity of CO$_2$ emissions and associated adjustments in GDP.

China's provinces (China Securities Journal, 2012). An absolute cap on coal or fossil energy use is also under discussion (Xinhuanet, 2012).

Alongside economic growth and environmental protection, promoting inter-regional equity remains a priority among China's policymakers. Identifying how total welfare costs are distributed requires a modeling framework capable of resolving policy impacts at the provincial level. Here we first describe the development of 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 and an its interaction with the rest of the world by including an aggregate representation of other global regions and international trade flows. The model captures both economic flows and energy quantities in physical units. We apply this new tool to study the impacts of CO_2 intensity targets in China.

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. Many studies apply computable general equilibrium (CGE) models, often with detailed physical accounting for energy, to capture the economy-wide impacts of policy on supply, demand, and relative prices (Alton et al., 2012; Caron et al., 2012; Ferreira-Filho and Horridge, 2012; Lanz and Rausch, 2011, 2012; Paltsev et al., 2009; Rausch et al., 2011). Some of these studies have explicitly focused on the impacts of energy policy in China. Zhang (2000) conducted an economic and political analysis of the effects of capping China's emissions at the national level. A range of other studies have focused on the impact of carbon mitigation and related energy policies in China, including a carbon tax (Cao, 2007; Liang and Wei, 2012), national absolute and intensity-based carbon limits (Dai et al., 2011; Wang et al., 2009), energy subsidies and related reforms (Lin and Jiang, 2011, and border carbon adjustments (BCAs) (Bao et al., 2013).

Previous CGE studies mentioned above have treated China as a single region. Recently, as China has moved to tighten energy intensity (and now also CO_2 intensity) controls through provincial targets, the number of studies that capture sub-national detail in China has increased. Yi et al. (2011) evaluate provincial target allocation schemes based on several indicators related to equity, economic development, and energy intensity, and propose a composite index to guide future allocations. 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. Wei et al. (2011) estimate CO_2 emissions reduction potential and marginal abatement costs by province in a model using a distance function approach. These studies in China build on a long tradition of modeling sub-national impacts of policy in China and elsewhere in the world (Horridge and Wittwer, 2008; Li and He, 2005; Li et al., 2009; Lu et al., 2010; Wang et al., 2006; Xu and Li, 2008).

We perform a sub-national analysis of the impacts of two approaches to climate policy design in China: provincially-disaggregated CO_2 intensity targets and a single national target (with trading across provinces) that achieves the same intensity reduction. This comparison builds on previous studies that have either analyzed provincial allocation of intensity targets or a national carbon constraint. Our study contributes a systematic comparison of the two approaches using a modeling framework that resolves impacts at the provincial level. Specifically, we develop a new CGE model that disaggregates China at the provincial level and includes detailed physical accounting of energy quantities. These features stand in contrast to previous studies, which use models based on older releases of China's input–output data (e.g., China's 2002 input–output tables) and generally do not include physical accounting in the energy sector. Moreover, we have integrated data for China with a comprehensive global trade data set instead of treating China as a small or large open economy as in previous work. While computationally intensive, this integration significantly improves the realism of the analysis.

2.2. Description of the CO_2 intensity targets in the Twelfth Five-Year Plan

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 Five-Year Plan (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 1000 Enterprises Program) and the closure of small, inefficient industrial and power generation facilities (He et al., 2010; Price et al., 2010, 2011).

A CO_2 intensity target was formally introduced for the first time under the Twelfth FYP, with a reduction goal of 17% (China State Council, 2012). The reduction in CO_2 intensity over this period has been 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.

The provincial CO_2 intensity targets are given in Table 1. Provinces are subject to one of nine different levels of CO_2 intensity reduction target stringency. Many researchers have studied how various metrics can be used to inform the allocation of the provincial targets to achieve efficiency or equity goals (Meng et al., 2011; Ohshita et al., 2011; Wang et al., 2012; Wei et al., 2011; Yi et al., 2011), but the actual targets are the result of political negotiations rather than the direct application of one or more clear guiding criteria. One 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 Fig. 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 with allowance trading that would induce reductions 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.
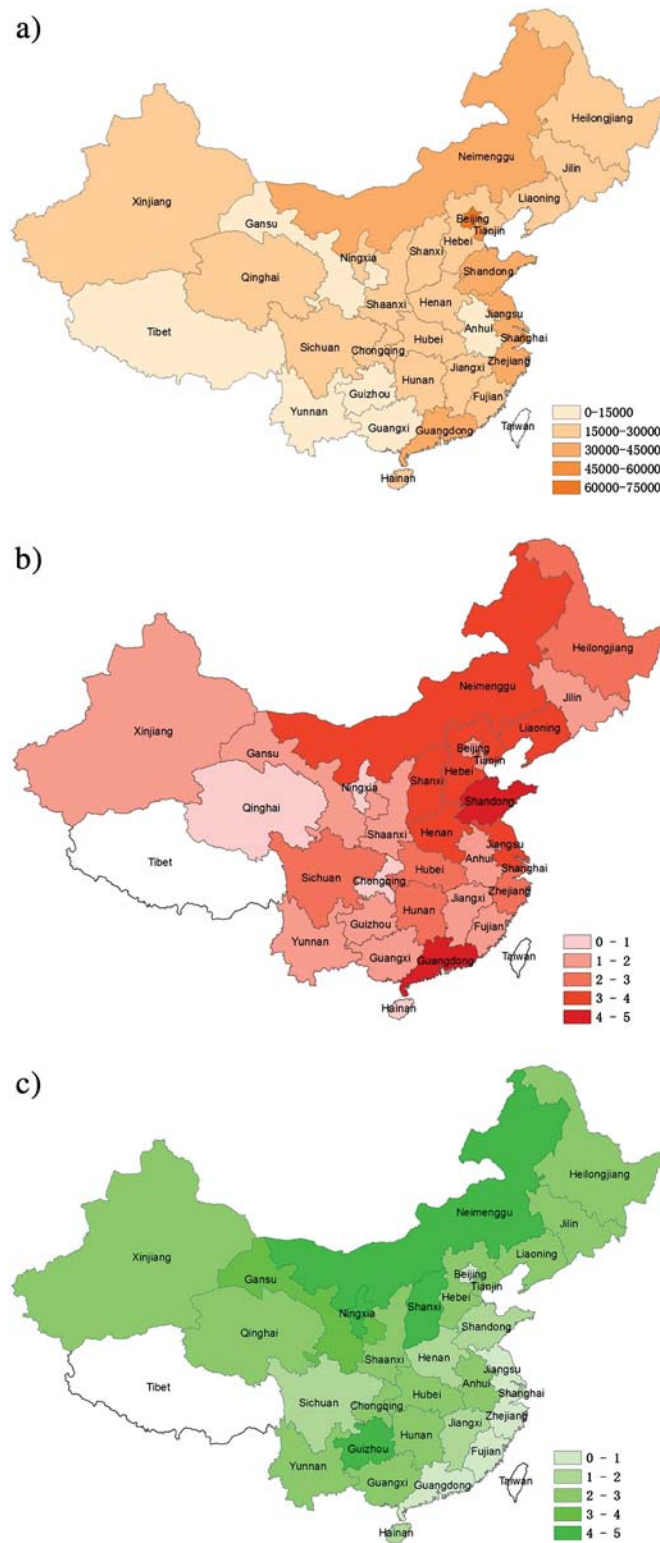
Fig. 1. Per-capita GDP (Chinese Yuan - CNY) (a), CO_2 emission (100 million tons) (b), and CO_2 emission intensity (ton/CNY 10,000) (c) of mainland China's provinces in 2007. Tibet is not included due to data availability in (b) and (c).

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 global economic and energy data, which are used to construct social accounting matrices (SAMs) for all regions. SAMs for every region except China are based on the GTAP database (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 (Statistics Bureau, 2011).[2] Energy use and emissions data is based on data from 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 physical energy flows, energy prices and CO_2 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.[3] We applied the following least-squares optimization problem to obtain the balanced SAM tables for each province p (see Table 2):

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

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.

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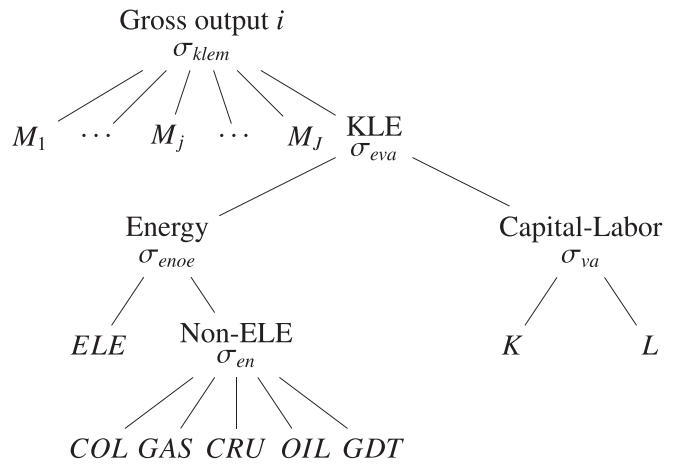$$\sum_p VDXM_{pi} = \sum_p VDIM_{pi} \quad \text{for all } i$$

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

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 subnational detail for China's economy. The key features of the model are outlined below.

3.2.1. Modeling production and household consumption activities

For each industry ($i = 1,...,I, i = j$) in each region ($r = 1,...,R$) 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})[4]:

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

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 Fig. 2.

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[2] 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.

[3] 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.

[4] 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.
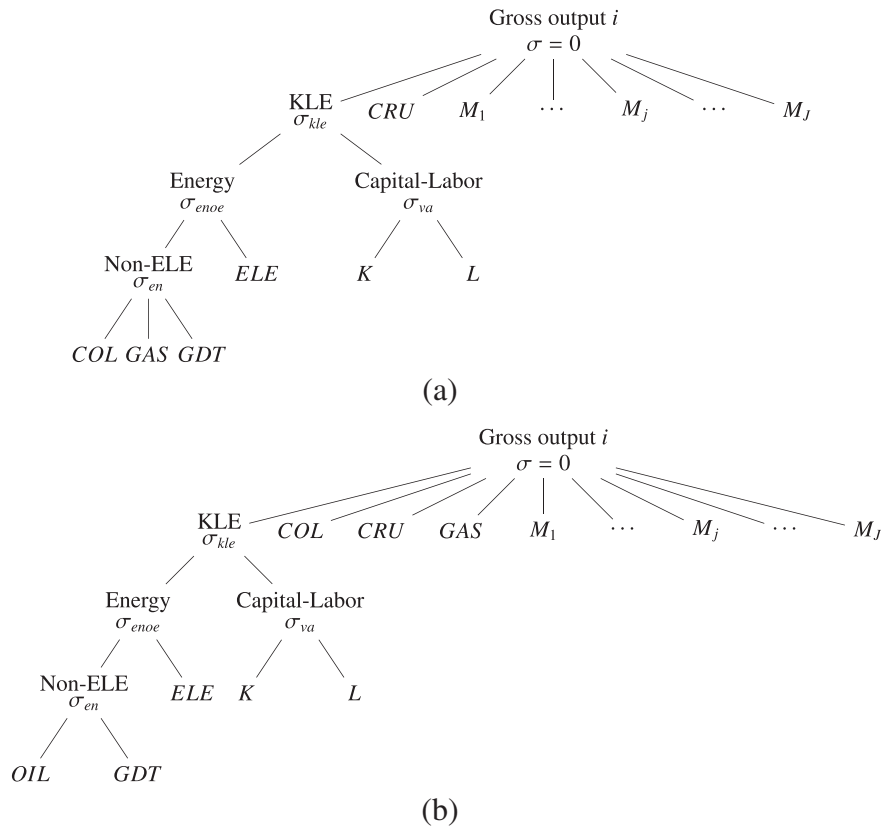
Fig. 3. Structure of production for oil refining $i \in$ {OIL} (a) and gas production and distribution $i \in$ {GDT} (b).

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:

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

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

$$V_{fr} = L_{fr}^{\beta_{fr}} K_{fr}^{1-\beta_{fr}} \tag{3}$$

where β_{fr} and $1 - \beta_{fr}$ are shares of the labor and capital inputs. Oil refining, gas production and distribution production are represented in Fig. 3.

Electricity production is represented in Fig. 4. We distinguish several generation technologies, including conventional fossil, hydro, nuclear and wind. The electricity generation data is collected from China Electric Power Yearbook 2008 (Editorial board of China Electricity Yearbook, 2008), which includes annual electricity generation data by province by type in 2007. In this version of the model, the initial resource endowment of hydro, nuclear, and wind is set to zero in provinces that have no electricity generation from these sources in 2007, and 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 capital with fixed shares of all inputs 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 (Wing, 2006).

In each region r, preferences of representative consumers are represented by a CES utility function (using the Leontief special case with fixed input shares) comprised of consumption goods (C_i) and investment (I):

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

where the function $g(\cdot)$ is a CES composite of all goods. In each region, a single government entity approximates government activities at both the central and local levels.[5]

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

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[5] The structure of government consumption function is also a CES composite as represented in Fig. 5.
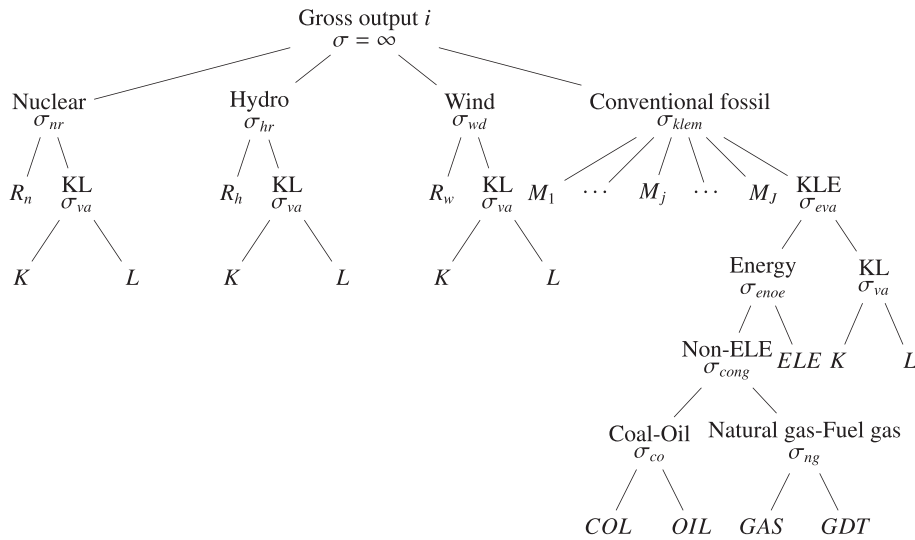
Fig. 4. Structure of electricity production i {ELE}.

supply of good i is a CES composite of a domestically produced variety and an imported variety, as follows:

$$X_{ir} = \left[\psi^z \, ZD_{ir}^{\rho_i^D} + \xi^z \, ZM_{ir}^{\rho_i^D} \right]^{1/\rho_i^D} \tag{5}$$

$$C_{ir} = \left[\psi^c \, CD_{ir}^{\rho_i^D} + \xi^c \, CM_{ir}^{\rho_i^D} \right]^{1/\rho_i^D} \tag{6}$$

$$I_{ir} = \left[\psi^i \, ID_{ir}^{\rho_i^D} + \xi^i \, IM_{ir}^{\rho_i^D} \right]^{1/\rho_i^D} \tag{7}$$

$$G_{ir} = \left[\psi^g \, GD_{ir}^{\rho_i^D} + \xi^g \, GM_{ir}^{\rho_i^D} \right]^{1/\rho_i^D} \tag{8}$$

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 $p = 1,...,P$) and international regions (indexed by $t = 1,...,T$). The nesting structure of the Armington composites is depicted in Figs. 6 and 7.

3.2.3. Elasticities

As customary in applied general equilibrium analysis, we use the exogenous elasticities as the free parameters of the functional forms that capture production technologies and consumer preferences. The elasticities in the production and consumption CES functions are adopted from the MIT EPPA model (Paltsev et al., 2005), see Table 4) and the value of Armington elasticities are adopted from Caron et al. (2012) (see Table 5). We recognize that a robust exercise would require the empirical estimation of these elasticities in a structurally similar framework. Such an exercise is outside the scope of the present study and is left to further research. We conduct a sensitivity analysis with respect to some key parameters in Section 4.4.

3.2.4. Equilibrium and model solution

Consumption, labor supply and savings result from the decisions of the representative household in each model region that maximize its
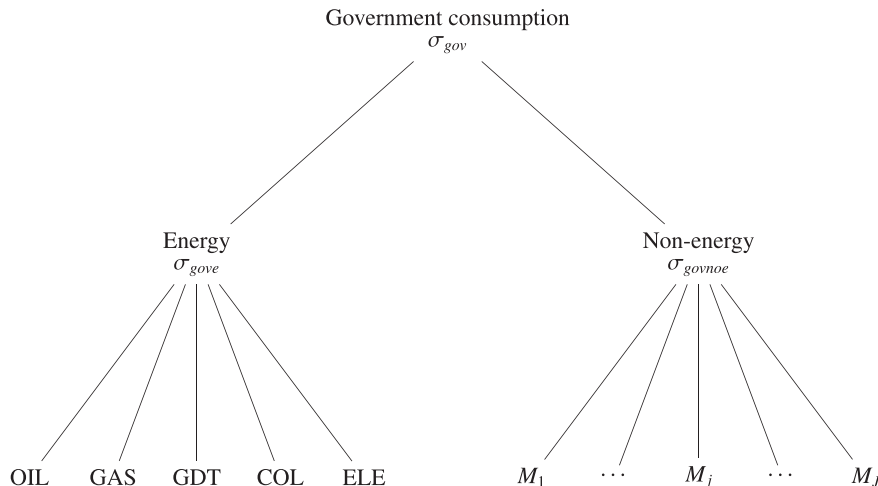

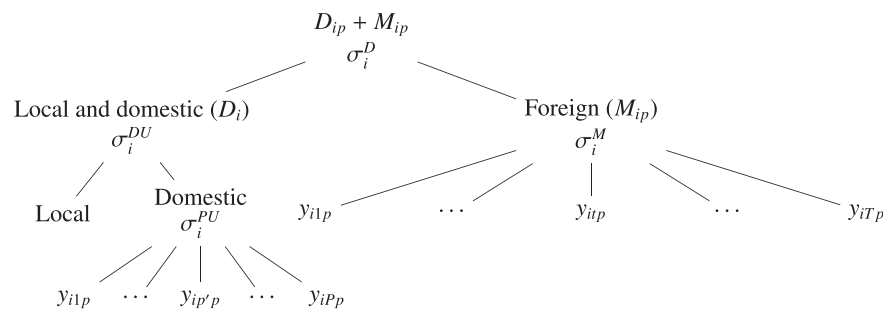**Fig. 5.** Structure of government consumption.

Fig. 6. Aggregation of local, domestic, and foreign varieties of good *i* for China province *p*.

utility subject to a budget constraint that consumption equals income, which includes wage, capital earnings, transfers to/from the government and the value of emissions allowance transfers. 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, Provincial Targets (PT), we simulate provincial-level constraints on CO_2 emissions intensity consistent with current targets specified in China's Twelfth FYP (see Table 1).[6] Reductions taken within each province must be consistent with the assigned goal, and inter-provincial trading of emissions rights is not allowed. Simulation of the Scenario PT results in a 17.4% reduction in emissions intensity at the national level, very close to the announced national target of 17%. In order to compare Scenario PT to a national approach with inter-provincial trading on a consistent basis, we simulate a national targets scenario (Scenario NT) that achieves a CO_2 intensity reduction identical to Scenario PT. In Scenario NT, reductions are not constrained at the provincial level, but instead reflect the most cost-effective opportunities for reducing CO_2 intensity nationwide.

Under Scenario NT, we model the allocation of emissions allowances to provinces based on their benchmark emissions, and a nation-wide allowance trading market is established.[7] We assume that all the allowances are auctioned in our model, and then use lump-sum transfers proportional to benchmark emissions to allocate the revenue of allowances

to representative households across provinces. This approach to revenue recycling is currently reflected in the design of the EU Emissions Trading System Phase III. 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 (provincial or national) is achieved.

We expect that the national and provincial target allocation scenarios will produce different welfare outcomes. Scenario PT is constrained at the provincial level, 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 provincial targets scenario at the national level, our model simulates how emissions and emissions intensity, as well as energy consumption and associated policy cost, 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 with allowance trading) and a regionally-constrained policy that sets provincial targets explicitly.

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. It is not surprising that we find significant variation in impacts across provinces under both policy approaches modeled. Below we discuss the impact of each policy approach (provincial or national targets) at the national level before considering outcomes at the provincial level. We note that the model captures the complex interaction of fuel prices, trade channels, and changes in income at the provincial level, which provide several angles to guide our exploration of national- and provincial-level changes in energy use and welfare.[8]

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.[9] In both scenarios, welfare loss is modest at the national level, 1.5% in Scenario PT and

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[6] 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.

[7] In a competitive setting with full information, the creation of a market for emission allowances will equalize marginal abatement costs across sources, thereby minimizing aggregate compliance costs (Montgomery, 1972). The efficiency property of an emission trading market hinges upon the emissions price signal, so that the initial distribution of allowances can be used to target specific distributional outcomes or promote political support for the policy (Stavins, 2008).

[8] We follow the convention of previous economic modeling studies in which welfare is defined an economic measure that captures the impact on household consumption (equivalent variation) (Paltsev et al., 2005; Weyant et al., 2006). Our analysis is therefore only concerned with the economic costs of a climate policy and does not take into account potentials benefits of reducing carbon emissions.

[9] Welfare costs are measured as the equivalent variation of household income, relative to the no policy benchmark.
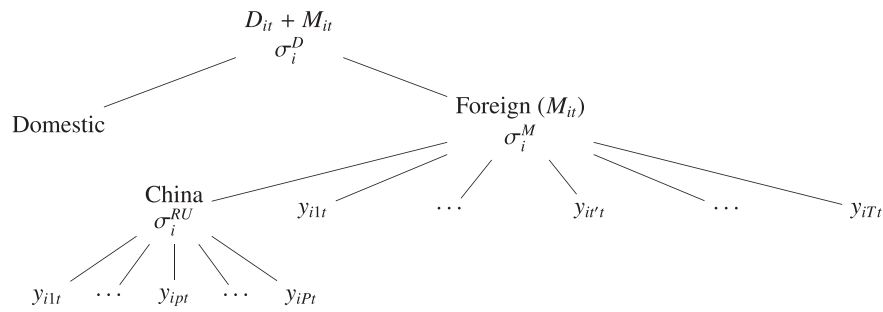
Fig. 7. Aggregation of domestic and foreign varieties of good i for international region t.

1.2% in Scenario NT (see Fig. 8). Relative to Scenario NT, welfare loss is about 20% higher under Scenario PT, the provincial allocation scheme, consistent with the fact that abatement flexibility, and thus the equilibrium allocation, is more constrained by provincial targets. CO_2 intensity reduction under Scenarios NT and PT is 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 PT and 150 mtce in Scenario NT.[10] Very slight differences exist between the two scenarios—slightly more non-fossil energy is brought online in Scenario PT, 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 Fig. 9). 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.

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 Fig. 10). Under the national target, several provinces that had relatively low targets in Scenario PT end up contributing significantly more to overall abatement (in particular Ningxia and Guizhou), as these provinces offer abatement opportunities at lower cost. By contrast, provinces that faced tough provincial targets in Scenario PT contribute less to overall abatement under the national target (see for instance Shanxi, Beijing, and Jiangsu). This result suggests that Scenario

PT is demanding large reductions from provinces where abatement is relatively expensive, while bypassing inexpensive reduction opportunities 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 Fig. 8). Some provinces experience large welfare increases (Ningxia, Guizhou), while some provinces undergo large welfare decreases, e.g., Shanxi province, a major domestic coal exporter, experiences welfare loss of about 11% in Scenario PT and 10% in Scenario NT. In Scenario NT, we find significant welfare losses in provinces such as Beijing, Tianjin, Zhejiang, 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. Given the option they do not undertake significant additional abatement under Scenario NT, continuing their reliance on coal. By contrast, provinces such as Ningxia and Guizhou end up reducing their reliance on coal, and thus contribute disproportionately to achieving the total national reduction. When interpreting the provincial results, it is important to note that impacts are expressed relative to the size of the provincial economies—both Ningxia and Guizhou experience among the largest welfare impacts but have a small economic size, so these impacts are still modest relative to total national welfare. Shanxi's significant welfare decrease is due mainly to its importance as a center of coal production and use. Of the energy sectors, the coal sector is the most severely affected by the policy.

Welfare impacts at the provincial level can be interpreted in terms of how each policy affects prices (especially energy prices), provincial income, and trade patterns. For instance, in the national targets scenario, Ningxia and Guizhou gain because they start with very high carbon intensity and undertake reductions on behalf of other provinces at a lower marginal cost, which allows them to benefit from the income generated through allowance sales. Even in a provincial targets scenario, Ningxia and Guizhou are relatively less constrained by the targets because they face a lower marginal cost of reducing emissions, which prevents large increases in the price of goods with high embodied energy and also improves the competitiveness of these goods in inter-provincial trade. While these factors do not *a priori* lead to welfare increases, relative to other provinces these factors mean that Ningxia and Guizhou face less of a burden in meeting the targets.

Energy use outcomes also differ significantly across provinces under national and provincial targets. Fig. 11 shows the final energy consumption structure of each province in the reference and both policy scenarios. The coal sector is most severely affected by the policy of all energy sectors. The marginal cost of reducing coal is influenced by fuel substitution possibilities (e.g. replacement by natural gas) as well as the cost of improving the efficiency of coal use.

Comparing the carbon prices in individual provinces under each scenario (see Fig. 12) provides some clues as to the relative difficulty of meeting the reduction targets at the provincial level. Under Scenario NT, a single national carbon price of CNY 235 per ton CO_2 (or about

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[10] One million tons of coal equivalent (mtce) is equal to 0.03 exajoules (EJ).
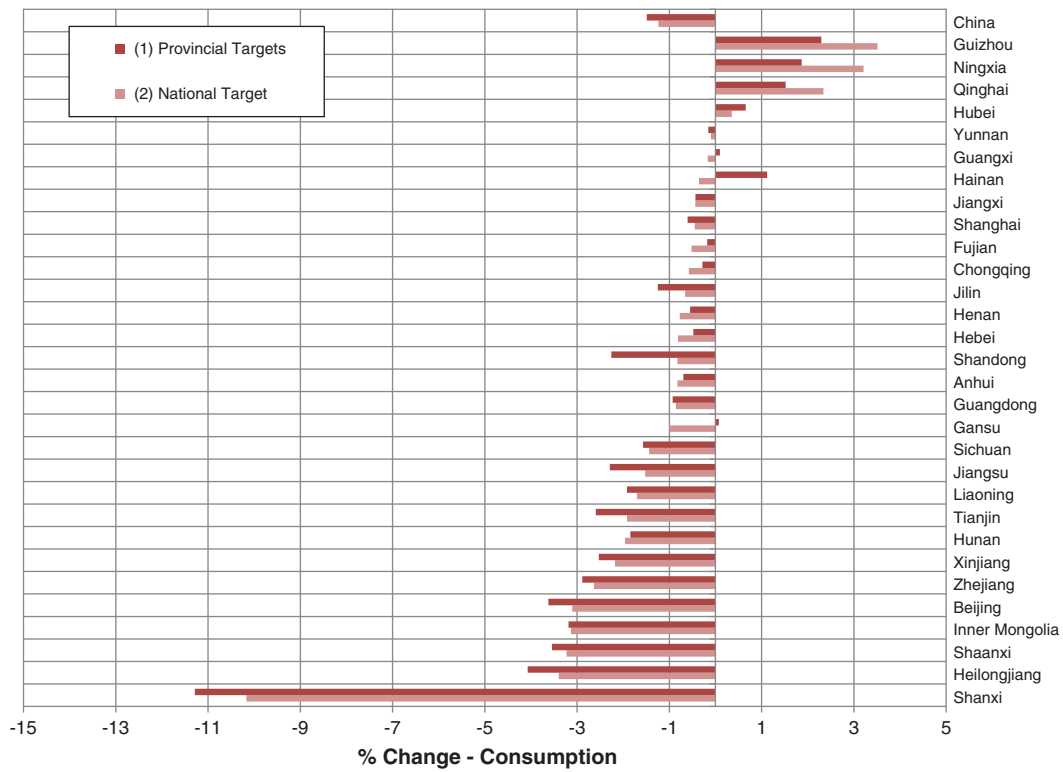
Fig. 8. Provincial welfare change.

U.S. $30 per ton in 2007) is needed to induce the required reduction in CO_2 intensity. Under Scenario PT, there is significant diversity in the provincial carbon price, ranging from CNY 119 to 450 per ton CO_2 (U.S. $ 16 to U.S. $60 per ton in 2007). It is instructive to compare the carbon prices that result in each province under Scenario NT and Scenario PT

to understand whether, under provincial targets, the marginal cost of reductions differs significantly across provinces. We find that provinces with CO_2 prices in Scenario PT in excess of the national CO_2 price undertake more abatement relative to Scenario NT, while the reverse is true for provinces with CO_2 prices in Scenario PT that fall below the national
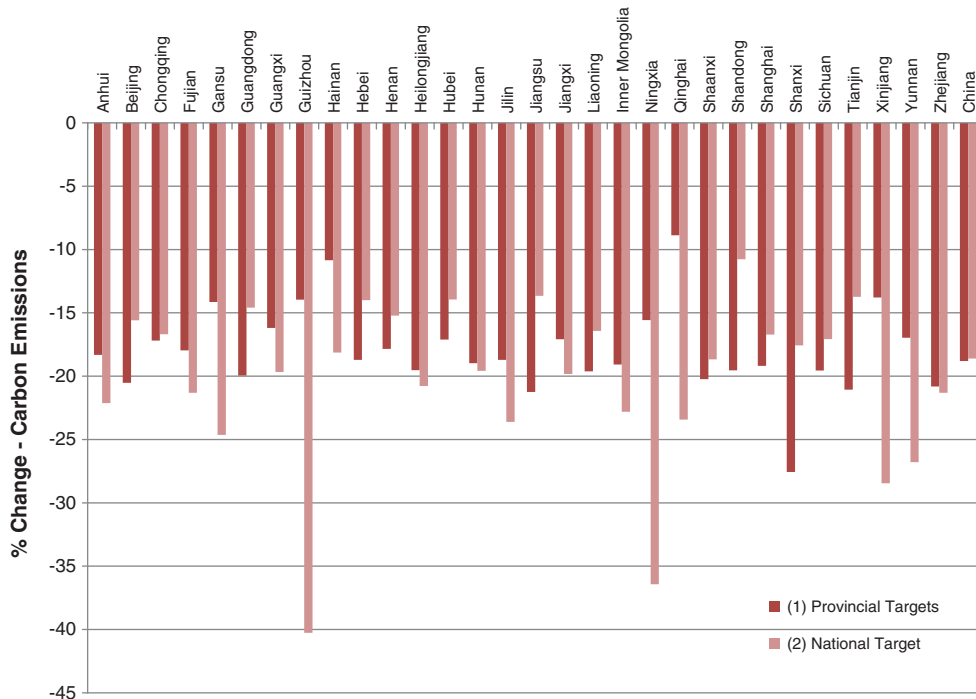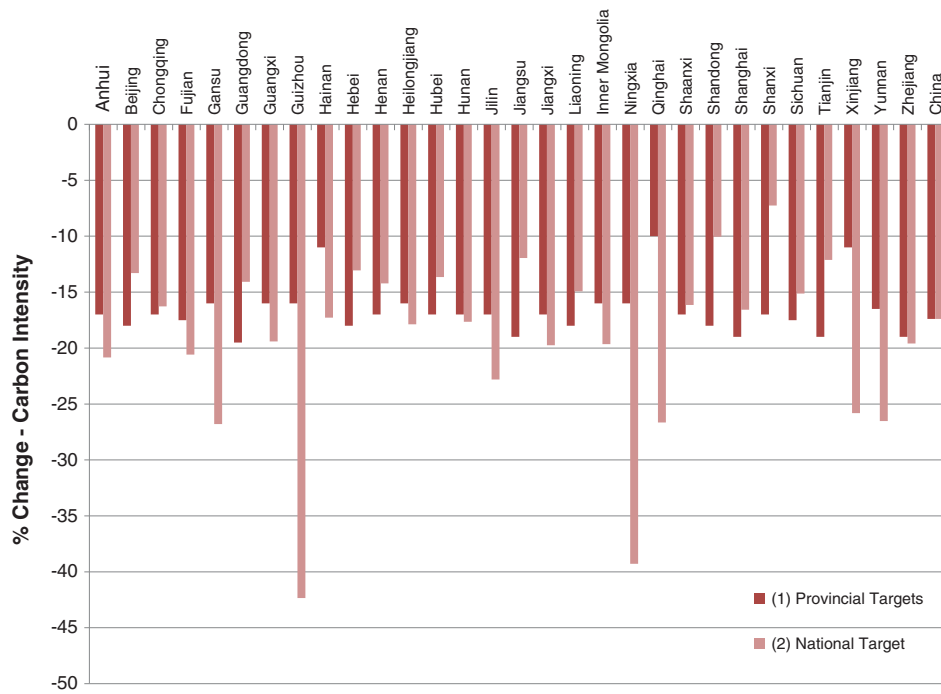

Fig. 9. Provincial carbon emissions reductions.

Fig. 10. Provincial carbon intensity reduction.

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.

Our model captures the international impacts of policies in China. International impacts are modest given that we simulate an intensity-based policy that is not very stringent compared to the long term deep reduction goals associated with global climate stabilization. We find that changes in total CO_2 emissions and CO_2 emissions intensity in the U.S., Europe, and the rest of the world are relatively small. The main difference between Scenarios PT and NT is that total CO_2 emissions in the U.S. and Europe increase slightly more in Scenario PT. Welfare changes outside of China are negligible in both scenarios (see Table 6). However, 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.
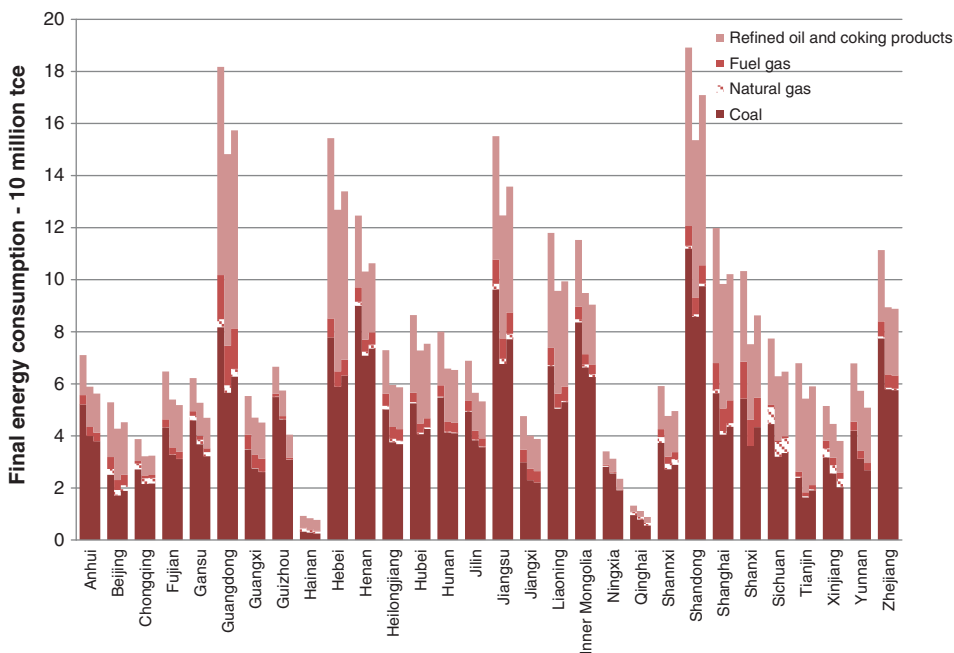

Fig. 11. Provincial energy consumption (from left to right for each province: Reference, Scenario PT, and Scenario NT. Unit: 10 million tons of coal equivalent).
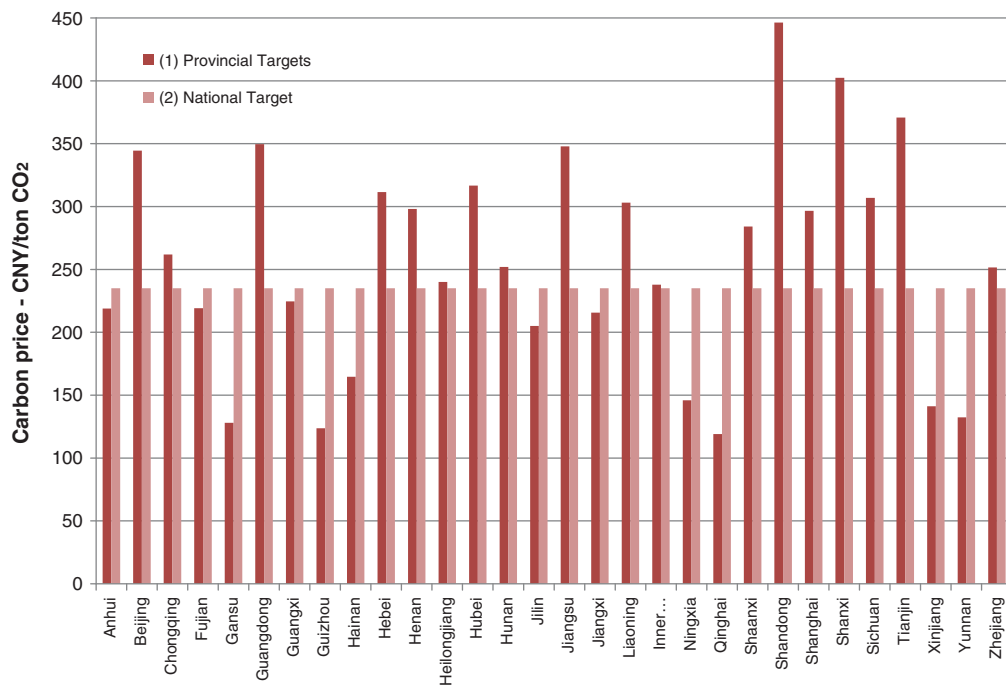
Fig. 12. Provincial carbon price.

4.3. Role of fixed electricity prices

Electricity prices in China are currently managed to keep electricity consumption affordable, and are set at different levels for household and industrial users. To reflect China's current electricity policy, we model prices as fixed for households alone, or for both households and industrial users. We model this type of managed pricing through an endogenous subsidy that maintains electricity prices at a fixed level. In the first scenario, "electricity subsidy for all sectors" (Scenario PT_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 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 PT_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 7. In both scenarios, with fixed electricity prices households experience slightly greater welfare loss relative to the provincial targets scenario in which electricity is not subsidized (-1.5% relative to -1.6% 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 PT_ELERES has higher CO_2 intensity and emissions reduction than Scenario PT, while Scenario PT_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.

4.4. Sensitivity analysis

Since our study is focused on a relatively short (five-year) period covered by the Twelfth FYP, it is reasonable to expect that the limited malleability of the capital stock will play a significant role how the economy responds 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 shares in the model to reflect the limited mobility of capital in the short term. In the high vintaging case, we set the non-malleable fraction of capital ϕ in each sector to be 50% higher than in our base case.

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 (unconventional) gas resource in China could play in national efforts to reduce CO_2 intensity. Although it is difficult to predict the impact of an expanded, inexpensive natural gas supply in China, we take previous work focused on the expected change in the natural gas price elasticity from the literature as our guide (Brown et al., 2010). We set the supply elasticity of natural gas η_{ng} to be four times higher than in our base case in the high natural gas supply case. The (Brown et al., 2010) study assumes an approximately threefold increase in the natural gas supply elasticity due to an expanded shale gas resource in the United States. We are aware of the differences between the natural gas situation in China and the United States and do not believe the two markets will necessarily follow similar development paths,[11] so our assumption of a fourfold increase in the case of China is more aggressive than this assumption and is chosen to provide an upper bound estimate of the potential impact.

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[11] The situation in the U.S. is quite different from China and several previous studies have discussed fundamental differences in the geology, drilling technology needs and capabilities, resource property rights, end-use pricing, and infrastructure availability (Wang et al., 2012; Gao, 2012).

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 PT and Scenario NT are shown in Table 8. 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 in China's primary energy mix is still quite small, its production and use is still carbon intensive relative to other alternatives, and we model limited substitution potential for natural gas in the electric power or industrial sectors in China in the short term.

We further test the robustness of our main results to changes in several key elasticities values. In the sensitivity cases, we double of halve the values of all Armington elasticities, fossil energy supple elasticities and material—energy elasticities in consumption, and compare the changes in the major outputs to the base case in Scenario NT. The results do not deviate significantly from the base case, as shown in Table 8.

Assumptions about labor mobility across provinces could also affect the magnitude and distribution of welfare costs under policy. In our base case scenarios, we assume that labor is completely mobile among different sectors within a region but is immobile across regions. This may not accurately represent the current reality in China because in practice some inter-provincial migration does occur. To check for the robustness of our results with respect to labor migration across provinces, we have implemented an additional set of scenarios that assumes costless mobility of labor across regions. This circumvents the need to rely on an ad-hoc representation (and parametrization) of labor migration in the model and tests the model behavior under the limiting case of a fully integrated national labor market. We find that our results are not very sensitive with respect to the labor mobility assumption. At the national level we find that the welfare loss is 1.4% in Scenario PT (labor mobility leads to smaller welfare loss) and 1.2% in Scenario NT, which shows that a carbon trading market can still significantly reduce the welfare loss. The distributional patterns of welfare impacts across region are not significantly affected by varying the degree of labor mobility.

5. Conclusions

This analysis demonstrates the merits of moving from provincial-level targets for CO_2 control to a fully integrated national emissions trading system. 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 distribution of impacts across provinces. Given that inter-regional equity is an important consideration in the formulation of national energy and climate policy, it is important to understand how impacts are distributed, and to be able to estimate the incremental cost of pursuing reductions through a provincial rather than a single national constraint.

Our results are a clear demonstration of the merits of separating economic efficiency from other considerations (e.g. equity), as an integrated national market is expected to yield the most cost-effective reductions consistent with economic theory (Coase, 1960). Limiting target compliance at the provincial level 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 also a difficult task. It is very challenging (if not impossible) 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. 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 can be applied 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 features of China's economy to determine how they 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 strategies for target allocation. It can also be used to assess alternative approaches for allocating permits under a national emissions trading system. Our model 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 provincial target allocation. Finally, we acknowledge the importance of considering co-benefits of policy, such as air pollution impacts, when setting national climate policy targets. This analysis focuses on the main target of the Twelfth Five-Year Plan—CO_2 intensity—and clearly shows the benefits of moving to a national approach with trading, laying a foundation for future studies that study impacts of alternative policy designs and co-benefits in more detail.

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[11] The situation in the U.S. is quite different from China and several previous studies have discussed fundamental differences in the geology, drilling technology needs and capabilities, resource property rights, end-use pricing, and infrastructure availability (Wang et al., 2012; Gao, 2012).

and participants at the Annual Stakeholders Meeting of the China Energy and Climate Project and EcoMod 2012 Conference for helpful comments and discussion.

Appendix A

Table 1
CO_2 Intensity reduction targets across provinces of mainland China.
Source: (China State Council, 2011).

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

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.

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

Region	Abbreviation	GTAP commodity	Abbreviation of aggregated commodity in model
Beijing	BEJ	Paddy rice	AGR
Tianjin	TAJ	Wheat	AGR
Hebei	HEB	Cereal grains	AGR

Table 3 (continued)

Region	Abbreviation	GTAP commodity	Abbreviation of aggregated commodity in model
Shanxi	SHX	Vegetables, fruit, nuts	AGR
Neimenggu	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	U.S.	Chemical, rubber and plastic products	CRP
Europe Union and other European countries	EUR	Mineral products	NMM
		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

Note: AGR—agriculture products; COL—coal; CRU—crude oil; GAS—natural gas; OMN—mining; B_T—Beverages and tobacco products; CLO—clothes and leather products; LUM—lumber products; PPP—paper products and publishing; OIL—petroleum and coal products; CRP—chemical, rubber, plastic products; NMM—mineral products; MSP—metals; FMP—metal products; TME—transport parts and equipment; ELQ—electronic equipment; OME—machinery equipment; ELE—electricity; GDT—gas manufacture and distribution; WTR—water; CON—construction; TRD—trade; TRP—transport; OTH—other service sectors.

Table 4
Reference values of substitution elasticities in production and consumption.

Parameter	Substitution margin	Value
σ_{en}	Energy (excluding electricity)	1.0
σ_{enoe}	Energy–electricity	0.5
σ_{eva}	Energy/electricity–value-added	0.5
σ_{va}	Capital–labor	1.0
σ_{klem}	Capital/labor/energy–materials	0
σ_{cog}	Coal/oil–natural gas in ELE	Calibrated
σ_{co}	Coal–oil in ELE	0.3
σ_{hnw}	Resource–Capital/labor/energy/materials in hydro/nuclear/wind ELE	1.0
σ_{rklm}	Capital/labor/materials–resource in primary energy	0
σ_{gr}	Capital/labor/materials–resources	0.5
σ_{gov}	Materials–energy in government demand	0.5
σ_{gov}	Energy in government demand	1
σ_{govnoe}	Materials in government demand	1
σ_{ct}	Transportation–Non-transport in private consumption	1.0
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

Note: Substitution elasticity for fossil fuel resource factors are calibrated using estimates for price elasticities of supply are 1 for coal and natural gas and 0.5 for crude oil suggested by from the MIT EPPA model (Paltsev et al., 2005). The same values are assigned for all the regions as we are lack of provincial-specific supply elasticities, and sensitivity analysis is conducted in Section 4.4.

Table 5
Reference values of Armington elasticities in trade aggregation.

Parameter	Substitution margin	Source/Value
σ_i^D	Foreign–domestic (and local)	Based on GTAP, version 8
σ_i^M	Across foreign origins	Based on GTAP, version 8
σ_i^{RU}	Across China's origins for international regions	$2\,\sigma_i^M$
σ_i^{DU}	Local–domestic for China's provinces	$2\,\sigma_i^D$
σ_i^{PU}	Across China's origins for China's provinces	$2\,\sigma_{is}^{DU}$

Table 6
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 PT)	−17.4	−18.8	−1.5
U.S. (Scenario PT)	0.2	0.3	0.0
Europe (Scenario PT)	0.2	0.3	0.0
Rest of world (Scenario PT)	0.5	0.5	0.0
China (Scenario NT)	−17.4	−18.6	−1.2
U.S. (Scenario NT)	0.2	0.2	0.0
Europe (Scenario NT)	0.2	0.2	0.0
Rest of world (Scenario NT)	0.5	0.5	0.0

Table 7
CO_2 intensity, emission and welfare changes (%) of China for alternative electricity policy scenario under provincial CO_2 intensity targets.

	PT	PT_ELEALL	PT_ELERES
CO_2 intensity	−17.4	−17.4	−17.5
CO_2 emission	−18.8	−18.7	−19.2
Welfare change	−1.46	−1.62	−1.56

Table 8
CO_2 intensity, emission and welfare changes (%) of China for alternative vintaged capital share and natural gas supply elasticity (both scenarios) and for alternative Armington elasticities, fossil energy supply elasticities and material–energy elasticities in consumption (Scenario NT).

	Base case	High vintaging capital	High natural gas supply
Scenario PT:			
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
	Base case	**High Armington elasticities**	**Low Armington elasticities**
Scenario NT			
CO_2 intensity	−17.4	−17.4	−17.4
CO_2 emission	−18.6	−18.4	−18.5
Welfare change	−1.2	−1.1	−1.2
	Base case	**High fossil energy supply elasticities**	**Low fossil energy supply elasticities**
Scenario NT			
CO_2 intensity	−17.4	−17.4	−17.4
CO_2 emission	−18.6	−18.6	−18.7
Welfare change	−1.2	−1.2	−1.2
	Base case	**High material–energy elasticities in consumption**	**Low material–energy elasticities in consumption**
Scenario NT			
CO_2 intensity	−17.4	−17.4	−17.4
CO_2 emission	−18.6	−18.7	−18.6
Welfare change	−1.2	−1.1	−1.2

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