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Exploiting complementarity of carbon pricing instruments for low-carbon development in the People's Republic of China

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ADB Working Paper Series

**EXPLOITING COMPLEMENTARITY
OF CARBON PRICING INSTRUMENTS
FOR LOW-CARBON DEVELOPMENT IN
THE PEOPLE'S REPUBLIC OF CHINA**

Jie Wu, Ying Fan, Govinda Timilsina,
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Abstract

There is an urgent need to mitigate global warming for all countries around the world. The People's Republic of China (PRC) has announced a series of energy and climate policy targets in contributing its efforts towards meeting the ambitious goals in the Paris Agreement and the newly pledged carbon-neutral target. While carbon pricing has been considered the first-best policy worldwide to combat climate change, it may not be sufficient for meeting the multiple goals in the PRC, unless it is combined with complementary policies. In an attempt to explore whether this is the case, in this paper we investigate whether a single cost-effective instrument is adequate for developing a low-carbon economy in the PRC or whether a policy portfolio would be more effective. We compare the potential impacts of an emissions trading scheme (ETS), a carbon tax (CT), and a combination of an ETS and a CT. In addition, we further evaluate the economic impacts of two different policy portfolios by combining these approaches with subsidies for energy-efficient vehicles. Our results show that, while a nationwide ETS certainly has advantages over a CT regarding GDP losses, it also performs better in promoting the transfer of labor and capital from the eastern regions to central and western regions. However, a single ETS is less effective in regard to industrial structure adjustments and emission reductions in sectors that are not included in the ETS, such as the transportation sector. The results also show that a policy portfolio could achieve the same emissions reduction target with more moderate impacts. Therefore, it is suggested that implementation of a CT for sectors that are excluded from the ETS or a subsidy for energy-efficient vehicles could be considered as supplementary policies for the ETS in the PRC.

Keywords: carbon pricing, carbon tax, emissions trading scheme, computable general equilibrium model

JEL Classification: C68, O13, Q56

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1. INTRODUCTION

As global emissions have been increasing steadily, there is an urgent need to speed up the process of reducing emissions for all countries around the world. After setting a series of energy and climate policy targets, the Chinese government pledged in the Paris Agreement that its carbon emissions would peak around 2030, while further committing to reach carbon neutrality before 2060 in the 2020 United Nations General Assembly (Ministry of Ecology and Environment of the People's Republic of China 2021). To achieve these goals, two key targets of reducing CO₂ emissions and fossil energy consumption for 2030 were introduced at the Climate Ambition Summit in 2020: a 65% reduction in CO₂ intensity compared to the 2005 level and 25% of the total primary energy supply coming from nonfossil fuels. In addition, in the 14th Five-Year Plan announced in 2021, there is also a goal regarding air quality: The share of days with good air quality in cities at the prefecture level and above should be more than 87.5% by 2025 (State Council of the People's Republic of China 2021). While these targets are interrelated, it seems that it will be difficult to achieve all of them with a single climate policy (Mo et al. 2018; Duan et al. 2021).

Carbon pricing has been considered the first-best policy worldwide to combat climate change, with the carbon tax (CT) and the emissions trading scheme (ETS) being the most common forms. While the CT is a tax levied on the carbon emissions required to produce goods and services, the ETS sets a quantitative cap on the total emissions by all participating emitters and provides a market for emission permit trade. Under emissions trading, emitters with high marginal abatement costs could choose to purchase permits from those with low marginal abatement costs, thereby reducing the total abatement cost (Montgomery 1972; Tietenberg 1985). As a market-based instrument, carbon pricing could lead to effective emissions abatement at the lowest possible costs and therefore is being increasingly implemented by regional, national, and subnational jurisdictions (Borenstein 2012; Mo et al. 2021). According to the World Bank, 67 carbon pricing initiatives have already been in place or are scheduled for implementation in the world by 2021 (World Bank 2021). In the PRC, the emissions trading scheme has been adopted as the most important carbon pricing instrument for emission reductions domestically. Based on a trial run of seven pilot projects at the provincial and city levels since 2013, a nationwide carbon market was announced at the end of 2017. After three years of capacity building, which included the construction of a system for reporting, registration, and trading, the nationwide carbon market finally started operating in July 2021. The nationwide carbon market is planned to cover the following sectors: power generation, petrochemicals, chemicals, building materials, steel and iron, nonferrous metals, paper making, and domestic civil aviation. The average carbon price is 47 yuan/tCO₂, and the accumulated trade volume is 23.44 Mt until November 2021.

The most important purpose of emissions trading is to encourage institutions to reduce their greenhouse gas emissions through a market-based mechanism to optimize resources allocation and achieve maximum ecological and economic benefits at the lowest possible social cost (Coase 1960; Marshall 1998; Kuika and Mulder 2004). Moreover, providing incentives for utilizing low-carbon technologies and improving energy efficiency has been considered a "second aim" of the nationwide carbon market in the PRC. However, there is great uncertainty regarding this additional aim, as the emissions trading scheme is expected to improve energy efficiency and trigger the innovation of low-carbon technologies in an indirect way. In fact, the emissions trading scheme will not always capture all potential emission sources due to high market operation costs, such as emissions from households and some service sectors. For

example, the nationwide carbon market in the PRC only includes the electricity sector in the initial phase, and will cover eight energy-intensive sectors as planned. Furthermore, imperfect market conditions may make the ETS, which is usually a cap-and-trade scheme, fail in terms of the optimal output and social welfare (Geng and Fan 2021).

Some empirical studies of the European Union Emissions Trading Scheme (EU ETS) have shown that the impact of the ETS on low-carbon technology innovation and energy efficiency has not been that significant. For example, it has been found that demand-pull policies like the EU ETS can fail to achieve multiple targets unless they are combined with complementary policies (Fischer and Newell 2008; Acemoglu et al. 2012; Gawel, Strunz, and Lehmann 2014; Borghesi, Cainelli, and Mazzanti 2015; Río 2017). In addition, Rogge, Schneider, and Hoffmann (2011) found that the impact of the EU ETS on renewables and demand-side energy savings has been limited and that the EU ETS may not provide sufficient incentives for low-carbon technology innovation. Schmidt et al. (2012) evaluated the impact of the EU ETS on technological change using novel survey data from the electricity sector in seven EU countries and found that the EU ETS has had limited and even controversial effects. They therefore suggested that other technology policies should be adopted to complement the ETS policy. Calel and Dechezleprêtre (2012) provided a comprehensive empirical assessment of the impact of the EU ETS on low-carbon technological change in both regulated and unregulated companies. Their results showed no evidence of technological change from the EU ETS in non-ETS companies, indicating that a single carbon price by itself is not enough to have a substantial impact on bringing about low-carbon technological change.

In the context of the PRC, there have been a lot of analysis and discussions focusing on the two types of carbon pricing policies—ETS and CT (Cui et al. 2014; Zhang et al. 2014; Zhang 2015; Jiang et al. 2016; Guo et al. 2020; Yu et al. 2020). Guo et al. (2014) applied a computable general equilibrium (CGE) model to investigate the impacts of a carbon tax on the PRC's economy and carbon emissions, and suggested that a carbon tax would be an effective means of reducing carbon emissions. The empirical results in their study indicate that a moderate carbon tax would significantly reduce carbon emissions and fossil fuel energy consumption in the PRC while it would slightly reduce the pace of economic growth. In order to evaluate the economic impacts of the national ETS on different regions, Pang and Timilsina (2021) developed a multiregional CGE model and found that emission-intensive regions experience higher GDP loss in attempting to achieve the PRC's nationally determined contributions in 2030 through an ETS. Based on the comparison of carbon tax and carbon trading under the same GDP effect using a CGE model, Jia and Lin (2020) suggested rethinking the choice of carbon tax and carbon trading in the PRC. They found that the emission reduction efficiency of the carbon tax is higher than that of carbon trading, and this advantage increases over time. From an environmental regulation perspective, Yang, Jiang, and Pan (2020) investigated the employment double-dividend effect of carbon trading policy in the PRC, and suggested that the PRC needs to form a complete set of strict ecological environment protection policies and administrative measures to achieve sustainable development of the economy.

Given the uncertainties surrounding the implementation of a single carbon pricing, complementary policies may provide a hedge against the failure to achieve multiple climate targets (Pizer 1999; Newell and Pizer 2003). For example, a mixture of carbon market and renewable energy policies is necessary in order to achieve both targets of emissions reduction and renewable energy development (Tu and Mo 2017; Fan 2018; Wu et al. 2020; Gugler, Haxhimusa, and Liebensteiner 2021). Lecuyer and Quirion

(2013) argued that the risk of the CO₂ price dropping to zero cannot be excluded from the ETS and that it could be socially beneficial to implement an additional instrument to encourage emission reductions. Hoel (2012) investigated the impact of uncertainty when a subsidy is combined with a CT; he pointed out that regulatory failures may lead to carbon price that is too low, and additional instruments, such as subsidies, may be required in some cases. While carbon pricing is usually considered to be the first-best option, Hepburn, Stern, and Stiglitz (2020) and Rosenbloom et al. (2020) suggested that a mix of policies may best lead to a deep decarbonization at an accelerated pace. An earlier study by Mandell (2008) analyzed whether it is preferable to regulate a portion of the economy through a cap-and-trade program while subjecting the rest to a CT rather than subjecting the entire economy to either a cap-and-trade program or a CT, and he suggested that mixed regulation can be superior in some conditions.

Although a nationwide carbon market is already operating, the most ambitious policy would cover only 50% of the total emissions in the PRC (Cao et al. 2019). For that reason, it is of great importance to assess whether a single cost-effective instrument is enough for developing a low-carbon economy or whether a policy portfolio would be more effective (Duan et al. 2018). There are few studies trying to consider a mixed carbon pricing portfolio in the PRC (Shi et al. 2013; Sun 2014; Bi, Xiao, and Sun 2018; Cao et al. 2019). Using a national CGE model that incorporates short-run unemployment effects, Bi, Xiao, and Sun (2018) compared the impacts of a single ETS, a single CT, and a combination of an ETS and a CT. In the assumption that the ETS will stimulate increased energy-saving innovation while the CT will not, their results showed that a mixed system will lead to lower GDP losses than a single carbon pricing, which is similar to the finding in Zhang et al. (2022). While most studies use a fixed carbon tax in the analysis, Cao et al. (2019) compared the impacts of implementing an ETS and a hybrid system including an ETS and a CT on the national economic costs under the same emissions reduction target at a national level, and the results indicated that the hybrid system would achieve the same CO₂ goals with lower permit prices and GDP losses.

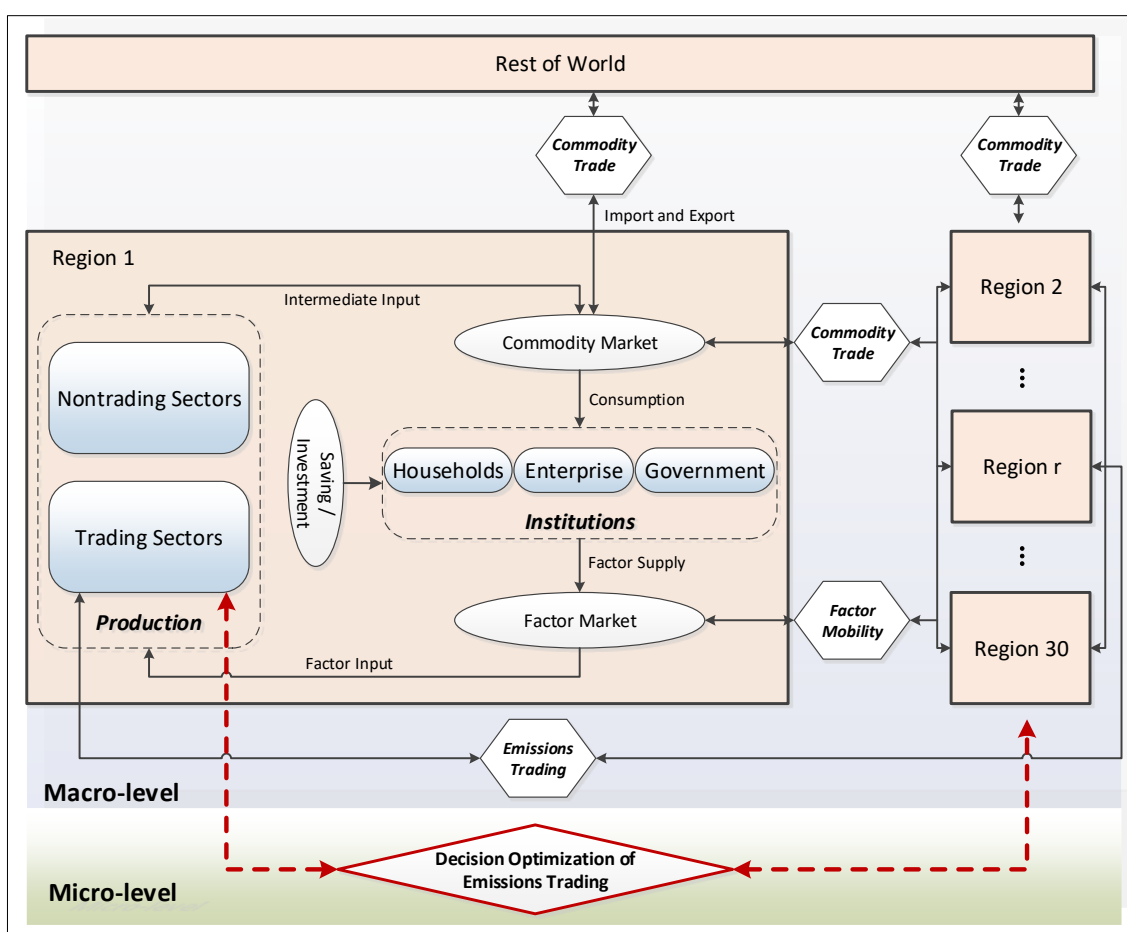
While the above studies explore the impacts of a mixed carbon pricing portfolio in the PRC using a national CGE model, some existing studies have developed multiregional CGE models to discuss the impact of carbon pricing (an ETS or a CT) on regional economies (Zhang et al. 2013; Zhang et al. 2020; Pang and Timilsina 2021; Zhao, Wang, and Cai 2022). However, there is a lack of discussion on the complementarity of different carbon pricing instruments at the regional level. This paper contributes to previous research by investigating the impacts of different carbon pricing portfolios on regional CO₂ emissions, social costs, interregional factor mobility, sectoral outputs, and export and import in the PRC. Using a multiregional CGE model in the PRC, we not only evaluate the ETS and CT policies separately, but we also simulate the combination of an ETS and a CT. Another contribution of this paper is that we further discuss two possible policy portfolios by combining carbon pricing with a subsidy for energy-efficient vehicles, to present the promotion of new energy vehicles in the PRC.

Our paper is organized as follows. Section 2 describes the PRC multiregional CGE model used in this research, Section 3 presents the policy scenarios, Section 4 displays and discusses the numerical results, and our conclusions are presented in Section 5.

2. METHODOLOGY

In this paper, we adopt the CEEP Multi-Regional Energy-Environment-Economy Modeling System (CE³MS) to analyze the economic impacts of different policies, which is based on a PRC multiregional CGE model. The CE³MS was first introduced by Wu, Fan, and Xia (2016a) and has been used in various climate policy analyses (e.g., ETS, renewable energy policy, etc.) (Fan et al. 2016; Wu et al. 2016b; Wu et al. 2020). The overall framework of the proposed model is described in Section 2.1, and the modeling of the ETS and CT will be introduced in Section 2.2. Finally, Section 2.3 presents the recycling of auction revenues in an ETS and CT revenues under the CT policy, and Section 2.4 explains how we can implement subsidies for energy-efficient vehicles in the model.

Figure 1: Framework for CE³MS



Sources: Fan et al. (2016).

2.1 Framework of the CGE Model

The CE³MS includes 30 regions in accordance with the administrative structure of the PRC (excluding Tibet due to a lack of data). Each region consists of production sectors, rural and urban households, a representative enterprise, and a local government. The production sectors are aggregated as 17 representative sectors: one agriculture sector, five energy sectors, seven nonenergy industrial sectors, and four

service sectors (Table 1). The model includes six modules: production module, emissions trading module, commodity trading module, institution module, labor and capital mobility module, and macro closure. Details of the different modules are provided in one of our earlier papers that has been published as a World Bank Policy Research Working Paper (Fan et al. 2017).

Table 1: Sector Declarations and Descriptions

Sector	Description
Agriculture	Agriculture, forestry, animal husbandry, and fishery
Coal	Coal
Oil and natural gas	Crude oil and natural gas
Mining	Mining
Food	Manufacture of foods, beverages, tobacco, textiles, wearing apparel, leather, wood, paper and publishing
Petroleum	Coking, gas, and processing of petroleum
Chemical	Chemical industry
Nonmetallic	Manufacture of nonmetallic mineral products
Metal	Manufacture and processing of metals and metal products
Other manufacturing	Other manufacturing
Electricity	Production and supply of electricity, heat power
Gas	Production and supply of gas, water
Construction	Construction
Transportation	Transport, storage, post, information transmission, computer services and software
Wholesale	Wholesale and retail trades, hotels and catering services
Real estate	Real estate, leasing, business services and financial intermediation
Other services	Other services

Sources: Wu, Fan, and Xia (2016a); Fan et al. (2016).

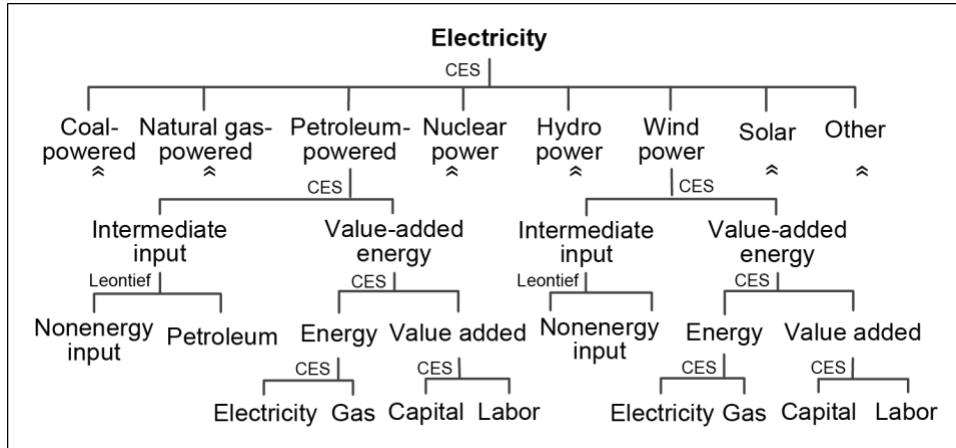
The production module describes the production activities of different sectors under the assumption of cost minimization. We use a nested structure of the constant elasticity substitution (CES) function to formulate the production structure. Generally, the total output of sectors (excluding electricity) is composed of nonenergy intermediate inputs and capital-labor-energy inputs.

$$QA_{j,r} = \alpha_{j,r} [\delta_{j,r} QVAE_{j,r}^{\rho_{j,r}} + (1 - \delta_{j,r}) QINTA_{j,r}^{\rho_{j,r}}]^{\frac{1}{\rho_{j,r}}}, \quad j \notin ele, \quad (1)$$

where $PA_{j,r}$ and $QA_{j,r}$ are the producer price and output of sector j in region r , $QINTA_{j,r}$ and $QVAE_{j,r}$ are the quantity of intermediate input and the value added and energy input, respectively, $\alpha_{j,r}$ and $\delta_{j,r}$ are the efficiency parameter and share parameter of the CES function, and $\rho_{j,r}$ is the substitution elasticity parameter.

The structure of electricity production is given in Figure 2, which shows that power generation is represented by eight generation technologies: coal (*Coa*), natural gas (*Ngs*), petroleum (*Pet*), nuclear (*Nuc*), hydropower (*Hyd*), wind (*Win*), solar (*Sol*), and other renewable technologies (*Oth*). In particular, coal, natural gas, and petroleum are raw material inputs of coal-, natural gas-, and petroleum-powered generation and thus are considered to be intermediate inputs rather than value-added or energy inputs for coal-, natural gas-, and petroleum-powered generation.

Figure 2: Production Structure of Electricity Sector in CE³MS



Source: Fan et al. (2017).

In the commodity trading module, we adopt the Armington assumption to describe the imperfect substitutions between domestic commodities (including local commodities and commodities from other regions) and foreign commodities. With regard to exports, we use the constant elasticity transformation function (CET) to distribute the domestic products between exports and domestic sales.

$$QA_{j,r} = \alpha_{j,r}^{cet} \left[\delta_{j,r}^{cet} QDS_{j,r}^{\rho_{j,r}^{cet}} + (1 - \delta_{j,r}^{cet}) QE_{j,r}^{\rho_{j,r}^{cet}} \right]^{\frac{1}{\rho_{j,r}^{cet}}}, \quad \rho_{j,r}^{cet} > 1 \quad (2)$$

$$QDS_{j,r} = \alpha_{j,r}^{ds} \left[\delta_{j,r}^{ds} QRRE_{j,r}^{\rho_{j,r}^{ds}} + (1 - \delta_{j,r}^{ds}) QRD_{j,r}^{\rho_{j,r}^{ds}} \right]^{\frac{1}{\rho_{j,r}^{ds}}}, \quad \rho_{j,r}^{ds} > 1 \quad (3)$$

$$QQ_{j,r} = \alpha_{j,r}^{am} \left[\delta_{j,r}^{am} QDC_{j,r}^{\rho_{j,r}^{am}} + (1 - \delta_{j,r}^{am}) QM_{j,r}^{\rho_{j,r}^{am}} \right]^{\frac{1}{\rho_{j,r}^{am}}} \quad (4)$$

$$QDC_{j,r} = \alpha_{j,r}^{dc} \left[\delta_{j,r}^{dc} QRRM_{j,r}^{\rho_{j,r}^{dc}} + (1 - \delta_{j,r}^{dc}) QRD_{j,r}^{\rho_{j,r}^{dc}} \right]^{\frac{1}{\rho_{j,r}^{dc}}} \quad (5)$$

Equations (2) and (3) describe the allocation of the total output of commodity j between domestic market ($QDS_{j,r}$) and export ($QE_{j,r}$), where $QRD_{j,r}$ and $QRRE_{j,r}$ are the supply of commodity j in region r and the total supply to other regions, respectively. Equations (4) and (5) describe the total supply of commodity j , which is from domestic market ($QDC_{j,r}$) and import ($QM_{j,r}$). And the supply from the domestic market includes the supply of local production ($QRD_{j,r}$) and production in other regions of the PRC ($QRRM_{j,r}$).

The institution module describes the income, expenditures, and savings of institutions—such as rural and urban households, a representative enterprise, and the local government—in each region. The utility functions of households and local government are assumed as Cobb-Douglas functions in this model. The income of the central government is partly from tax revenue from the various regions, and its expenditures are fixed transfers to the regional governments.

In the labor and capital mobility module, labor and capital are assumed to flow across sectors and regions due to changes in relative wages and returns on capital. Finally, the neoclassical closure is adopted in the macro-closure of CE³MS.

2.2 Modeling of ETS and CT

The costs of carbon pricing, either via the ETS or a CT, would directly affect production in the sectors covered by the policy by increasing their total production costs. As shown in Equation (6), the production costs of ETS sectors or CT sectors include not only intermediate input costs and costs of energy and value added, but also the costs of carbon pricing ($TC_{j,r}$).

$$PA_{j,r}QA_{j,r} = PVAE_{j,r}QVAE_{j,r} + PINTA_{j,r}QINTA_{j,r} + TC_{j,r}, j \in ETS \text{ or } CT \quad (6)$$

$PVAE_{j,r}$ and $PINTA_{j,r}$ are the price of value added and energy input and the intermediate input, respectively.

When there is an ETS, $TC_{j,r}$ is the total costs of abatement cost and permit trading cost in ETS sectors. Equation (7) shows that by comparing its marginal abatement cost and carbon price, each trading sector can determine its actual emission reduction and trading volume under the objective of total cost minimization. A decision to reduce emissions will directly affect the production of trading sectors through changes in production costs (Eq. (6)). In the ETS setting of this study, eight energy and energy-intensive sectors in all regions are regulated as trading sectors.

$$Min TC_{j,r} = AC_{j,r}(\overline{COE}_{j,r} - COEE_{j,r}) + CP_1 \times (COEE_{j,r} - \overline{COQ}_{j,r}) \quad (7)$$

$$s. t. \sum_{j,r} COEE_{j,r} = \sum_{j,r} \overline{COQ}_{j,r} \quad (8)$$

where $TC_{j,r}$ is the total cost, which includes the abatement cost and trading cost of trading sector j in region r . $COEE_{j,r}$ is the actual emissions under the ETS policy, while $\overline{COE}_{j,r}$ is the emissions in the benchmark. $\overline{COQ}_{j,r}$ is the initial emission quota allocated to sector j in region r , and the “grandfathering” approach is adopted in this study, which means that initial quotas are distributed across sectors based on historic emission levels. CP_1 is the CO₂ price of the nationwide carbon market.

When there is a CT, $TC_{j,r}$ in Equation (6) is the costs of a CT for the sectors on which the CT is imposed.

2.3 Recycling of Auction and CT Revenues

So that we can compare the different policies, we recycle the auction revenues and CT revenues in the same way in this paper. In the ETS, we assume a perfect auction, such that the auction price is equal to the carbon price. To maintain government revenue neutrality, we assume that the auction revenues or CT revenues are returned to households under both the ETS and CT policies. When we adopt an additional subsidy for energy-efficient vehicles, we assume that the auction revenues or CT revenues will be used as subsidies rather than being returned to households.

2.4 Subsidies for Energy-Efficient Vehicles

In this paper, we also consider scenarios that include subsidies for energy-efficient vehicles as a way to encourage emissions reductions in the transportation sector. Similarly to Imhof (2011), we implement a subsidy on capital that is used to provide transportation services. The purpose of this subsidy is to encourage consumers to substitute capital for fuel in transportation services, as a way of representing subsidies for energy-efficient vehicles.

3. SCENARIOS

This study utilizes five policy scenarios to assess the impact of different climate policy portfolios in the PRC (Table 2), and we set the national CO₂ emission reduction target at 10%.¹ An ETS scenario refers to a nationwide carbon market covering energy and energy-intensive sectors. A CT scenario refers to a unified CT for all sectors. In the ETS_CT scenario, both ETS and CT policies are adopted when the ETS refers to energy and energy-intensive sectors, and the CT policy refers to the rest of the sectors. A subsidy for energy-efficient vehicles is implemented in the ETS_SUB and CT_SUB scenarios in combination with the ETS and CT policies, respectively. As stated previously, we set the subsidy rate at 10%, which means that 10% of the capital price used in the transportation sector is subsidized.

Table 2: Scenarios under Different Policies

Scenario	Scenario Description
Scenario S0	The base case without any policies
Scenario ETS	ETS policy for energy and energy-intensive sectors
Scenario CT	CT policy for all sectors
Scenario ETS_CT	ETS policy for energy and energy-intensive sectors and CT policy for the remaining sectors
Scenario ETS_SUB	ETS policy for energy and energy-intensive sectors combined with subsidies for energy-efficient vehicles
Scenario CT_SUB	CT policy for all sectors combined with subsidies for energy-efficient vehicles

In order to present the results clearly, we classified the 30 regions into three areas (eastern, central, and western) based on the regional divisions used by the National Bureau of Statistics of China (Table 3).

Table 3: Classification of Regions

Category	Regions
Eastern regions	Beijing (BJ), Tianjin (TJ), Hebei (HB), Liaoning (LN), Shanghai (SH), Jiangsu (JS), Zhejiang (ZJ), Fujian (FJ), Shandong (SD), Guangdong (GD), Hainan (HAN)
Central regions	Shanxi (SX), Jilin (JL), Heilongjiang (HLJ), Anhui (AH), Jiangxi (JX), Henan (HEN), Hubei (HUB), Hunan (HUN)
Western regions	Inner Mongolia (IM), Guangxi (GX), Chongqing (CQ), Sichuan (SC), Guizhou (GZ), Yunnan (YN), Shaanxi (SaX), Gansu (GS), Qinghai (QH), Ningxia (NX), Xinjiang (XJ)

Source: Fan et al. (2016).

¹ An earlier study by Cao, Ho, and Timilsina (2016) shows that achieving the PRC's Intended Nationally Determined Contribution (INDC) would require a 9.8% reduction in emissions over the period 2015–2030. In order to evaluate the profound economic impacts that may be caused by carbon pricing, we simply adopt 10% as the emissions reduction target in this study.

4. RESULTS

4.1 CO₂ Emissions

The total emissions rate is decreased in all scenarios, but the results show differences in the magnitudes of emission reduction among the different scenarios (Table 4). The total emission reductions under the ETS and ETS_SUB scenarios are a little more than we expected (10%) due to extra emission reductions in sectors that are not covered by the ETS (non-ETS sectors). The main reason for this is that the non-ETS sectors are affected by the rising costs of energy and energy-intensive products, reduced final demand for goods under ETS, etc. Therefore, the output of these non-ETS sectors—or the intermediate input of energy and energy-intensive products in these sectors—is reduced, leading to a slight decline in emissions. On the other hand, total emissions decrease by 9.35% under the ETS_CT scenario, in which 90% of the emissions reduction target is allocated to the ETS and 10% is expected to be accomplished by the CT. However, our results show that while 90% of the target can be achieved by the ETS under a CO₂ price of 55.26 yuan/ton, it is still too difficult for non-ETS sectors to achieve the 10% target under a CT of 100 yuan/ton, as most of these non-ETS sectors are service sectors. Given that the 100 yuan/ton CT is already quite high for these non-ETS sectors, we have not imposed a further higher CT to force non-ETS sectors to achieve the 10% of the total emission reduction target. For that reason, the emission reduction rate under the ETS_CT scenario is 9.35%, which is less than 10%.

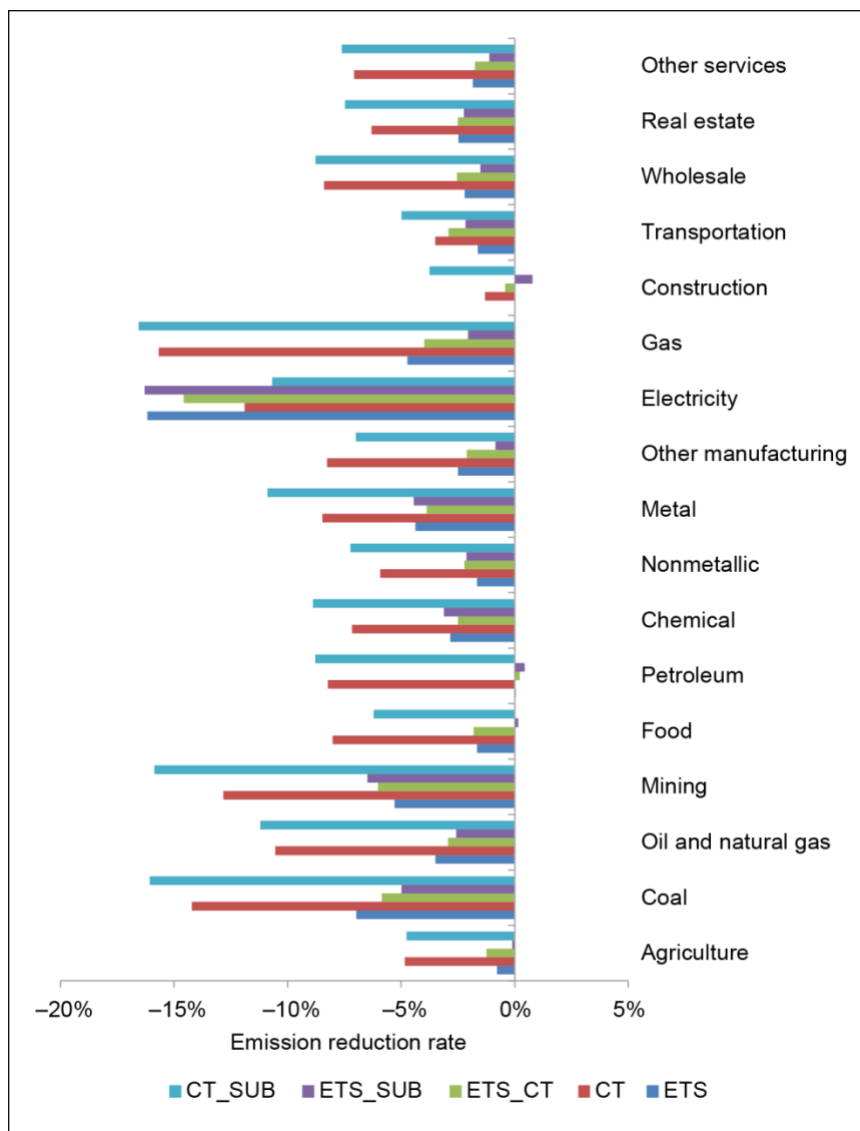
Table 4: Emission Reduction Rate and CO₂ Prices^a

Scenario	Emission Reduction Rate (%)	CO ₂ Price (yuan/ton)	Carbon Tax (yuan/ton)
S1: ETS	10.25	64.81	-
S2: CT	10.00	-	77.18
S3: ETS_CT	9.35	55.26	100
S4: ETS_SUB	10.20	50.14	-
S5: CT_SUB	10.00	-	58.07

^a Due to differences in scenario settings, the CO₂ prices under the scenarios ETS and ETS_CT are quite different to that in the study by Cao et al. (2019). For example, all energy and energy-intensive sectors are covered by the ETS in this study, while only the electric power and cement sectors are included in the ETS in Cao et al. (2019).

By comparing emissions in different sectors, we find that the impact of the ETS policy on the energy sectors is more significant than on the other sectors. Our results show that the emissions in the coal and electricity sectors decrease by 7.0% and 16.2%, respectively, under the ETS scenario, while the service sectors only experience a 1.8% to 2.5% emissions reduction (Figure 3). However, the differences in the emission reductions among the various sectors are relatively smaller under the CT policy than the ETS. These results show that the emissions in the energy and energy-intensive sectors decrease by 5.9% to 15.7% under the CT scenario and that the service sectors experience a 3.5% to 8.4% emissions reduction. The reason for this difference is that although both the ETS and CT are market-based instruments for emissions reduction, the quota allocation scheme of the ETS, which is based on sectoral historic emissions, takes into account the differences in the emission reduction potential across sectors and also allows for higher flexibility in the trading sectors in seeking to meet the emission reduction targets through self-emission reductions or quota purchases. Therefore, the energy and energy-intensive sectors have a higher degree of responsibility than the other sectors for reducing their rates of emission under the ETS and ETS_SUB scenarios.

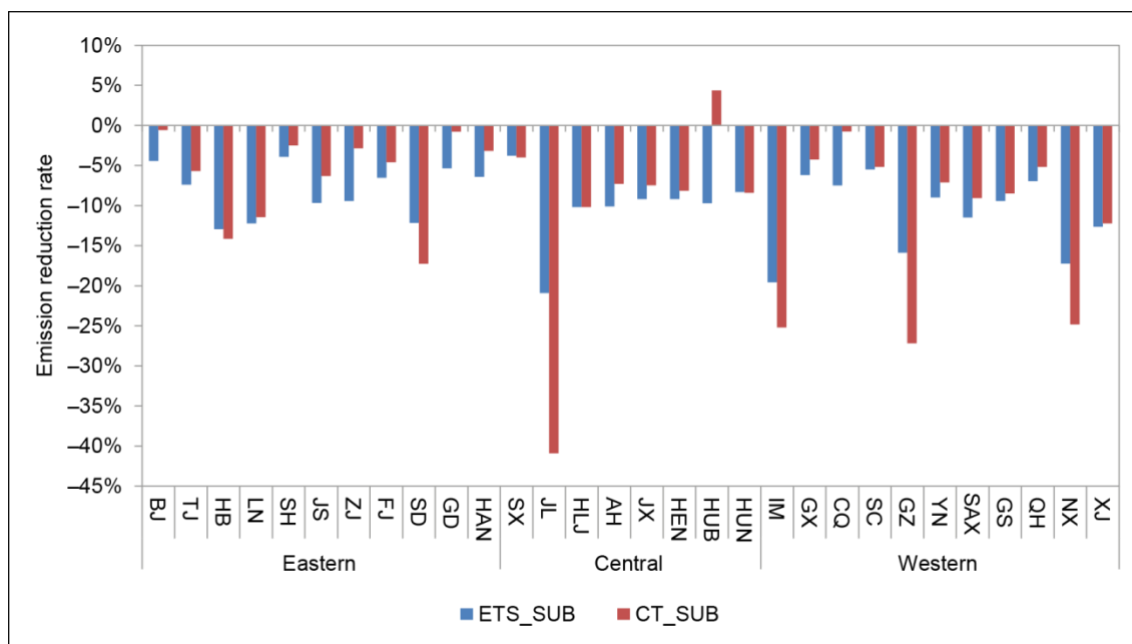
Figure 3: Sectoral Emission Reductions under Different Scenarios



We propose that an additional policy of providing subsidies for energy-efficient vehicles will lead to more emission reductions in the transportation sector and energy-intensive industries. The results in Figure 3 show that the emissions from the chemical, nonmetallic, and metal sectors are reduced by 7.2%, 5.9%, and 8.5%, respectively, under the CT scenario, and they experience further reductions of 8.9%, 7.2%, and 10.9%, respectively, under the CT_SUB scenario. The results are similar under both ETS and ETS_SUB scenarios. The main reason for these results is that subsidies for energy-efficient vehicles reduce the demand for energy or energy-intensive products. On the other hand, the subsidies, which are from auction revenues or CTs, are returned to households under the ETS and CT scenarios and thus increase the consumption of energy-intensive products to some extent.

Figure 4 displays the differences in emission reductions across regions under the ETS_SUB and CT_SUB scenarios. The results show significant differences between the two policies and that the emission reductions present larger differences across regions under the CT_SUB scenario. Under the CT_SUB scenario, regions such as Jilin, Guizhou, Ningxia, and Inner Mongolia need to reduce emissions much more in order to achieve the same emission reduction target. As there is no emission trading in the CT_SUB scenario, these regions will definitely suffer from greater economic loss. Compared with CT_SUB, the emission reductions under the ETS_SUB scenario are more evenly distributed across regions and seem to be more reasonable.

Figure 4: Regional Emission Reductions under Different Scenarios



4.2 GDP and Welfare

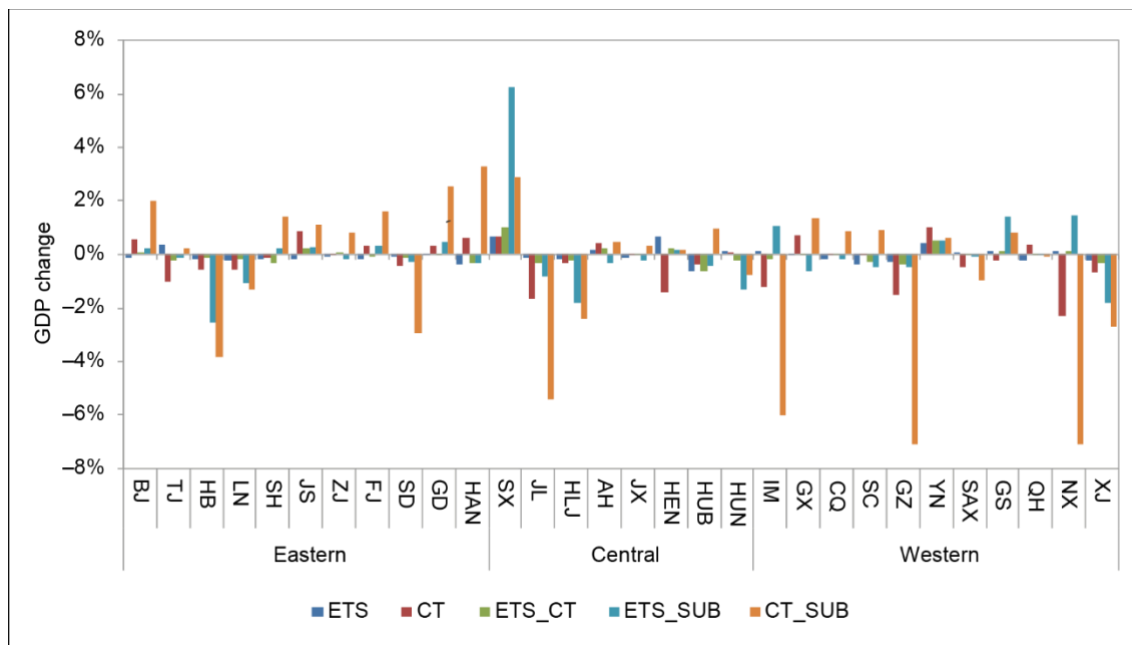
Table 5 summarizes GDP and welfare changes under different scenarios. In the five different scenarios we present, the PRC would experience GDP losses of 0.07%, 0.13%, 0.05%, 0.13%, and 0.16%, respectively, compared with the base case scenario. As expected, the policies that include the ETS (except ETS_SUB) face lower economic costs than others. It is confirmed that the ETS is more cost-effective than the CT policy. In addition, the combination of ETS and CT policies has a lower GDP cost than the single ETS policy. When subsidies for energy-efficient vehicles are included in the plan, the distortion on consumption and investment increases, thus leading to higher social costs under the ETS_SUB scenario.

Table 5: GDP and Welfare Changes under Different Scenarios

Indicators	ETS	CT	ETS_CT	ETS_SUB	CT_SUB
National GDP Change (%)	-0.07	-0.13	-0.05	-0.13	-0.16
— Eastern Regions	-0.13	0.03	-0.04	-0.20	0.19
— Central Regions	0.09	-0.46	-0.04	-0.01	-0.33
— Western Regions	-0.08	-0.248	-0.11	-0.09	-1.12
Welfare Change (Billion Yuan)	36.7	147.2	56.9	-24.6	16.8
— Eastern Regions	8.0	80.9	26.2	-13.4	24.5
— Central Regions	18.6	30.5	17.0	-7.4	-2.7
— Western Regions	10.1	35.8	13.7	-3.8	-5.0

Figure 5 shows the GDP changes across regions under different scenarios. In regard to policy impacts at the regional level, four central and western regions—Jilin, Inner Mongolia, Guizhou, and Ningxia—experience more significant GDP losses than other regions under the CT and CT_SUB scenarios. This indicates that the ETS policy could better reflect regional equity than the CT policy. The results in Figure 5 show that the GDPs in all regions are affected less under the ETS and ETS_CT scenarios. Compared with a single ETS policy, the combination of subsidies for energy-efficient vehicles and the ETS has a larger impact on regional GDPs, especially in Shanxi, Hebei, Heilongjiang, and Xinjiang.

Figure 5: Regional GDP Changes under Different Scenarios

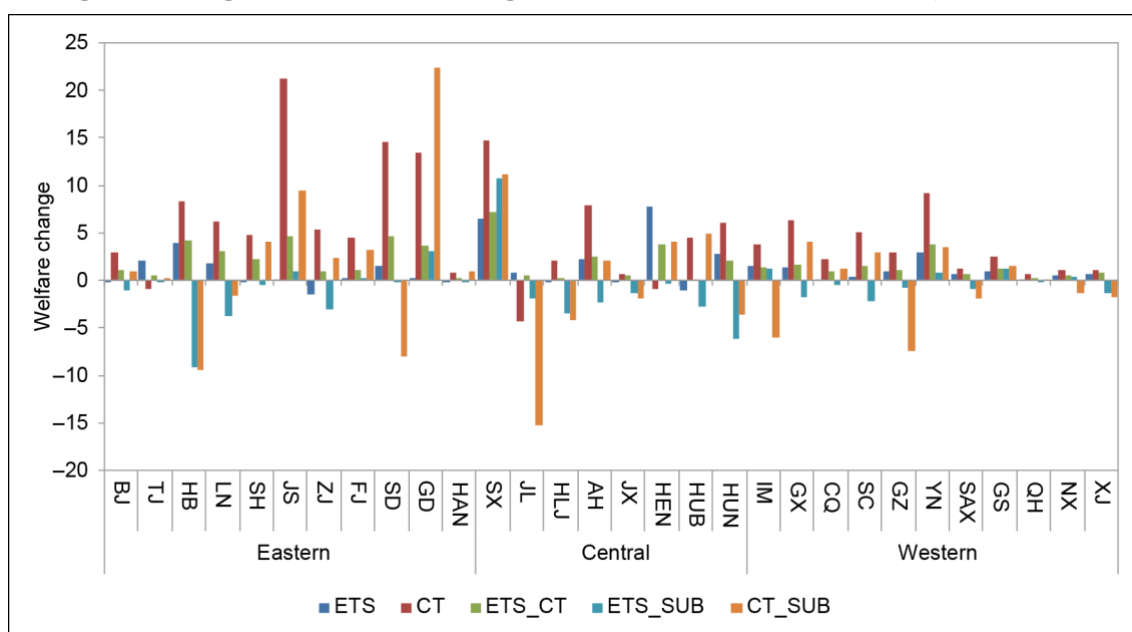


As shown in Table 5, the total welfare in the PRC increases by 36.7, 147.2, 56.9, and 16.8 billion yuan under the ETS, CT, ETS_CT, and CT_SUB scenarios, respectively, while it decreases by 24.6 billion yuan under the ETS_SUB scenario. As we have assumed that either the auction revenues from the ETS or the revenues from the CT are all returned to households in this paper, the disposable incomes of households increase; thus, our results show welfare benefits in various regions, especially in the eastern regions. However, when the auction revenues and the CT are used as subsidies for energy-efficient vehicles, the disposable income of households is directly

reduced. Therefore, the total welfare increases less under the CT_SUB scenario and even experiences a loss under the ETS_SUB scenario. By comparing the ETS, CT, and ETS_CT, we find that the ETS_CT improves the welfare in all regions. Shanxi, the province with the most coal resources in the PRC, experiences the biggest welfare increase compared to the other regions under the ETS_CT scenario.

Although we show that the welfare increase under the CT scenario is much higher than under the other scenarios, we find that there are wide gaps among the welfare increases across regions (Figure 6). Regions with high emissions, such as Jiangsu, Shandong, Guangdong, and Shanxi, have much higher welfare increases than the other regions. The main reason is that these regions have more CT revenue if they implement a uniform CT, and this leads to a higher income for the local households. Regional coordinated development is an important focus in the PRC, and our results show that the CT policy might deepen gaps in the welfare of households across regions.

Figure 6: Regional Welfare Changes under Different Scenarios (Billion Yuan)



4.3 Interregional Labor and Capital Mobility

Different policy portfolios have different impacts on the reallocation of production factors—both labor and capital—across regions. Table 6 presents regional labor and capital changes under all scenarios. The results show that the ETS policy and CT policy have opposite effects on interregional labor and capital mobility. The ETS policy performs better in promoting the transfer of labor and capital from eastern regions to the central and western regions. For instance, labor decreases by 0.11% in the eastern regions and increases by 0.20% and 0.07% in the central and western regions under the ETS scenario. At the same time, labor in the central and western regions transfers to the eastern regions under the CT scenario. The results for capital are similar. The main reason is that the central and western regions usually have lower marginal abatement costs for emissions reduction than the eastern regions, and therefore they are major emission permit sale regions in the ETS. Compared with the eastern regions, which have high abatement costs, the central and western regions can choose to

reduce emissions and get trading benefits through the ETS, which would increase their relatively higher rates of capital return and wages. This would cause interregional labor and capital mobility from the eastern regions to the central and western regions under the ETS policy.

The labor and capital both indicate mobility from the central and western regions to the eastern regions under the CT and CT_SUB scenarios. These findings indicate that the CT policy would probably exacerbate the imbalanced allocation of production factors between the eastern regions and the central and western regions. With the same cost per unit of emission reduction under the CT policy, the rate of capital return and wages in the eastern regions are less affected than in the central or western regions due to higher levels of economic development in the eastern regions. For that reason, both labor and capital in the eastern regions show increases of 0.11% to 0.44%, compared with decreases of 0.02% to 1.50% in the central and western regions.

Table 6: Labor and Capital Changes under Different Scenarios

Indicators		ETS	CT	ETS_CT	ETS_SUB	CT_SUB
Labor changes (%)	Eastern	-0.11	0.17	0.00	0.04	0.26
	Central	0.20	-0.39	-0.01	-0.10	-0.24
	Western	0.07	-0.02	0.03	0.02	-0.45
Capital changes (%)	Eastern	-0.07	0.11	-0.02	-0.16	0.44
	Central	0.17	-0.29	0.08	0.40	-0.12
	Western	-0.12	-0.26	-0.16	0.05	-1.50

4.4 Sectoral Output and Industrial Structure

The total output of the PRC decreases under all policy scenarios, as the emissions reduction policies increase total production costs. Our estimation shows that the total output decreases by 1.53%, 2.38%, 1.77%, 1.84%, and 2.53%, respectively, under the ETS, CT, ETS_CT, ETS_SUB, and CT_SUB scenarios. When comparing ETS and CT policies, we can see that the CT policy leads to increased reduction in total output due to a higher price level for all sectors. Figure 7 displays the sectoral output changes under the different scenarios. It shows significant differences in the impacts of the ETS and CT policies on sectoral outputs, with most sectors experiencing more reduction in outputs under the CT and CT_SUB scenarios.

When an ETS policy is included in a scenario, the energy and energy-intensive sectors (except for petroleum) have higher rates of reduction in output than other sectors. As energy and energy-intensive sectors are the targeted industries for emissions reduction in the PRC and are also the main sectors included in the carbon market, these sectors are assigned clear emission reduction targets and are thus facing more output reductions. By comparing the ETS, ETS_CT, and ETS_SUB scenarios, the electricity industry, which is the largest CO₂ emitter, experiences the biggest reduction in output under the ETS scenario. The main reason is that the adoption of a CT or subsidies for energy-efficient vehicles will reduce the CO₂ emissions from nontrading sectors, especially the transportation sector, leading to a reduction in the demand for emission permits in the carbon market. Therefore, the electricity industry will struggle to reduce their excessive output under the ETS_CT and ETS_SUB scenarios. The output of the petroleum sector experiences increases of 1.50% and 1.63% under the ETS and ETS_SUB scenarios, which could be explained by the substitution of petroleum and coal. Another explanation for this is the slight increase in the demand of households as the auction revenues are returned to households. Our results show that the household

consumption of petroleum slightly increases (0.47% and 0.79%, respectively) under the ETS and ETS_SUB scenarios.

Figure 7: Sectoral Output Changes under Different Scenarios

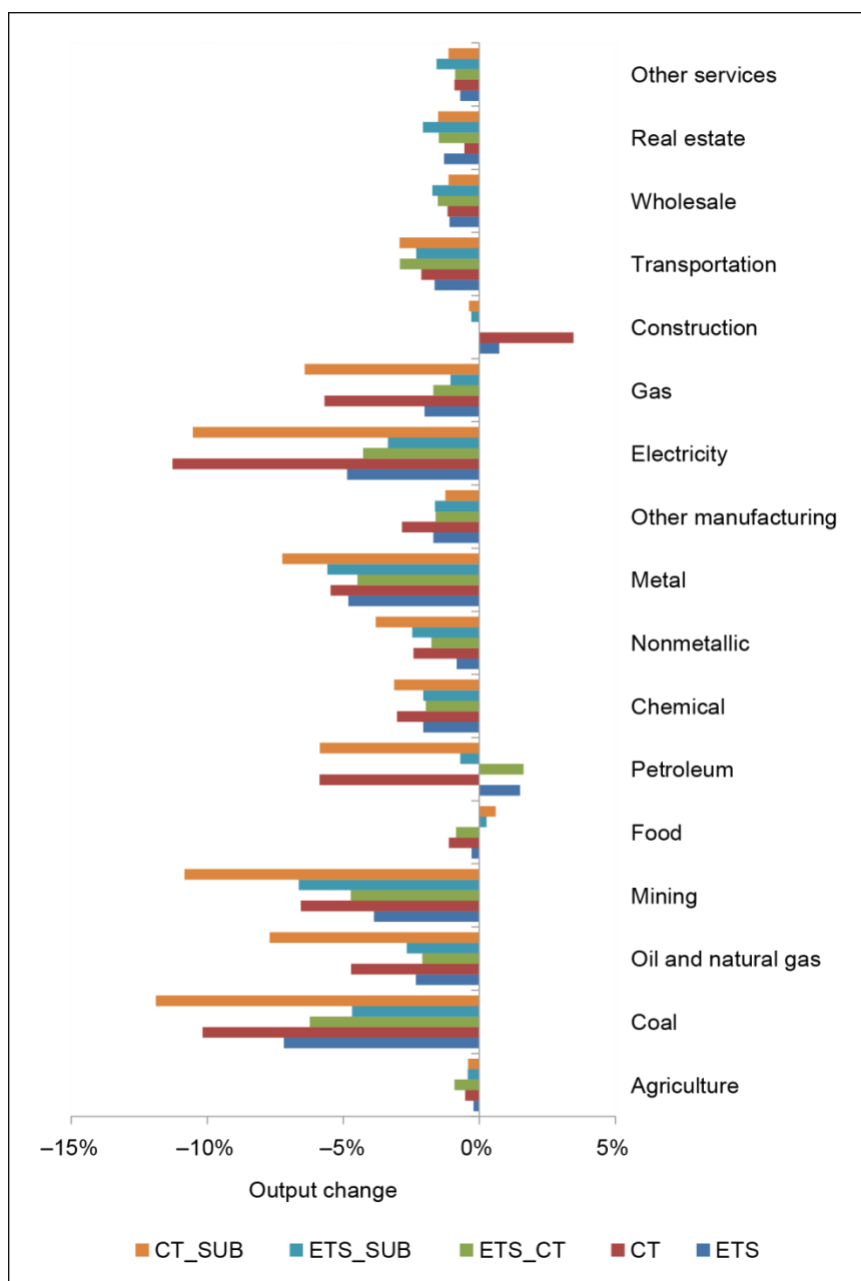


Table 7 presents the industrial structure under the base case scenario and all policy scenarios. As expected, the percentage of energy and energy-intensive products in the total output experiences declines of 0.34% to 1.10% under all scenarios compared to the base case. This indicates that all policy portfolios are effective in reducing the output of high-emission industries. When comparing the ETS and CT policies, the industrial structure adjustment is more significant due to its implementation of a CT. One reason for this is that to reduce emissions, the industries with high rates of emission usually choose to change their energy input structures or reduce their output

under a CT policy. However, they have more flexibility in achieving reduction targets by purchasing emission permits under an ETS policy, thus avoiding having to reduce their output. Therefore, the ETS, ETS_CT, and ETS_SUB policies are less effective than the CT and CT_SUB policies in promoting changes to the industrial structure.

Table 7: Industrial Structures under Different Scenarios

	S0	ETS	CT	ETS_CT	ETS_SUB	CT_SUB
Agriculture	6.20%	6.28%	6.32%	6.26%	6.29%	6.34%
Energy	8.57%	8.44%	8.03%	8.50%	8.50%	8.01%
Energy-intensive	19.63%	19.30%	19.28%	19.36%	19.24%	19.09%
Other	40.39%	40.66%	40.85%	40.64%	40.77%	41.12%
Service	25.21%	25.32%	25.52%	25.25%	25.20%	25.44%

4.5 Export and Import

Table 8 presents the impacts of different policy portfolios on the total export of goods and services. The total export of goods and services decreases compared to the base case. The results show that the export of energy-intensive goods (i.e., nonmetallic mineral products, metals, and chemicals) significantly decreases under all scenarios. Compared with the ETS and CT scenarios, however, the decline in total exports is more significant under the ETS_SUB and CT_SUB scenarios. This indicates that while the implementation of an ETS or CT decreases the export of energy-intensive goods, subsidies for energy-efficient vehicles cause further drops in the export of energy-intensive goods. In contrast to energy-intensive goods, the export of coal increases by 11.82% to 29.80% under all scenarios. This could be explained by the decreased domestic demand for coal, as most industries would reduce their coal input to control their CO₂ emissions during production.

Table 8: Sectoral Export Changes under Different Scenarios (%)

	ETS	CT	ETS_CT	ETS_SUB	CT_SUB
Total	-0.96	-3.31	-1.02	-0.42	-0.09
Agriculture	1.35	0.20	1.69	5.85	5.20
Coal	21.32	29.80	19.90	15.97	11.82
Oil and natural gas	2.49	5.72	3.22	-1.12	-2.68
Mining	23.91	19.54	17.75	1.42	-6.53
Food	0.08	-1.99	-0.57	2.85	4.31
Petroleum	10.75	-6.46	12.95	1.66	-6.54
Chemical	-2.95	-5.84	-1.08	-3.25	-8.01
Nonmetallic	-3.54	-9.55	-2.79	-6.89	-16.49
Metal	-9.25	-12.72	-7.43	-10.08	-13.01
Other manufacturing	-1.08	-3.04	-1.01	-0.98	0.22
Electricity	-3.87	-16.39	-2.98	1.95	6.46
Gas	-3.65	-11.57	-2.63	-0.99	-10.55
Construction	-3.17	-12.34	-4.37	-3.91	-11.54
Transportation	0.80	-1.48	-6.57	4.53	2.95
Wholesale	1.33	1.12	1.01	2.15	7.64
Real estate	1.11	10.80	3.05	0.80	14.88
Other services	1.98	4.03	2.62	5.41	10.84

Table 9 presents the impacts of different policy portfolios on the total import of goods and services. This also experiences a decrease, which is mainly caused by the decreased domestic demand. As expected, the import of fossil fuels also experiences a decline, which is conducive to reducing the PRC's energy dependence. The results show that the import of coal and crude oil would decrease by 4.23% to 6.74% and 1.70% to 10.09%, respectively, under all scenarios. As compared with the CT policy, the import of coal decreases more under the ETS, ETS_CT, and ETS_SUB scenarios. However, the import of crude oil has a much more significant decrease under the CT and CT_SUB scenarios.

Table 9: Sectoral Import Changes under Different Scenarios (%)

	ETS	CT	ETS_CT	ETS_SUB	CT_SUB
Total	-1.57	-1.43	-1.68	-1.55	-1.13
Agriculture	-0.35	-0.09	-0.79	-0.73	-0.33
Coal	-6.74	-4.90	-6.00	-6.61	-4.23
Oil and natural gas	-2.71	-10.09	-2.69	-1.70	-6.43
Mining	-9.66	-8.28	-9.67	-12.20	-14.31
Food	-0.46	0.22	-0.78	-1.04	-0.55
Petroleum	-2.29	-4.18	-2.45	-1.81	-3.36
Chemical	-1.17	-1.09	-1.65	-1.20	-0.16
Nonmetallic	1.82	4.77	0.08	-0.18	1.29
Metal	-0.30	0.46	-0.95	0.01	1.34
Other manufacturing	-1.38	-1.00	-1.30	-1.05	-0.40
Electricity	1.83	12.45	1.07	-2.03	11.38
Gas	-1.43	-2.21	-1.45	-1.36	-2.83
Construction	-0.50	7.41	-0.30	-0.18	-0.06
Transportation	-1.18	-1.11	-0.86	-2.67	-2.35
Wholesale	-1.55	-1.56	-1.90	-1.94	-2.13
Real estate	-0.90	0.06	-1.00	-1.13	-2.04
Other services	-0.55	-1.01	-1.02	-2.10	-1.14

4.6 Comparison of Results with Previous Research

It is important to compare the results in this study with those of previous studies, as it helps to check the robustness of our findings. We find that due to differences in the model structure, database, and setting of policy scenarios, the values of results vary across existing studies. For example, Pang and Timilsina (2021) developed a multiregional CGE model and found that the ETS would cause a national GDP loss of 0.3% – 0.5% in 2030 under a reduction target of 13%, in which all the production sectors are included in the ETS. With a sectoral coverage of seven energy and energy-intensive industries in the national ETS, Jia and Lin (2020) found that the national GDP would reduce by 0.08% – 0.13% in 2030. In this study, eight energy and energy-intensive industries are included in the ETS and we find that the national GDP experiences a 0.05% – 0.13% reduction under the ETS, ETS_CT, and ETS_SUB scenarios under a 10% reduction target. However, both Pang and Timilsina (2021) and this study have found that from a regional perspective, some regions would benefit from a national ETS whereas other regions would lose out. In terms of the existing studies on a hybrid policy of carbon pricing that are national-level analyses, the findings in Cao et al. (2019) and Zhang et al. (2022) show that a hybrid policy including emissions trading and carbon tax may be the most efficient way to reduce emissions

with lower economic cost than a single ETS or CT. This finding is comparable to that of this study.

5. CONCLUSION AND POLICY RECOMMENDATIONS

To achieve its climate change mitigation targets by 2030 and 2060, the PRC is seeking to implement a variety of measures to reduce emissions. The emissions trading scheme has been adopted by the Chinese government as the most important emissions reduction policy in the PRC, and a nationwide carbon market was established in 2017. However, a single policy instrument such as an emissions trading scheme might not be sufficient to reduce all emissions, as it does not encompass all greenhouse gas sources. Therefore, to improve the efficiency of emissions reduction in the PRC, it is necessary to examine whether a single policy could work well or whether it would be better to adopt a policy portfolio.

From regional and industry perspectives, we have compared the impacts of a separate emissions trading scheme, a carbon tax, and the combination of an emissions trading scheme and a carbon tax. We have further evaluated the economic impacts of two policy portfolios by combining these two instruments with subsidies for energy-efficient vehicles.

Our analysis shows that under the emissions reduction target of 10% from the base case, the actual total emissions will be slightly reduced by more than 10% with a nationwide emissions trading scheme due to the additional emissions reduction in sectors that are excluded from the carbon market. Compared with a separate carbon tax, the GDP losses caused by a separate emissions trading scheme or the policy portfolio of an emissions trading scheme and a carbon tax are lower, especially in some central and western regions. The adoption of subsidies for energy-efficient vehicles on top of an emissions trading scheme or a carbon tax will lead to greater GDP loss. In terms of regional welfare, our analysis shows that although the total welfare increase under a separate carbon tax is much higher than with other policy portfolios, there are wider gaps in welfare increases across regions.

As regards interregional labor and capital mobility, the separate carbon tax policy or the policy mix of a carbon tax and subsidies for energy-efficient vehicles will probably exacerbate the imbalanced allocation of production factors between the eastern regions and the central and western regions. Our analysis shows that a separate emissions trading scheme performs better in promoting the transfer of labor and capital from the eastern regions to central and western regions. When a carbon tax or subsidies for energy-efficient vehicles are implemented, the labor and capital both follow the opposite trend of transferring from the central and western regions to the eastern regions.

While implementing a carbon tax increases social costs in the PRC, it also causes a higher decrease in total output compared with the emissions trading scheme. In addition, although all policy portfolios are effective in reducing the output of high-emission industries, the industrial structure adjustment is more significant when a carbon tax is put in place, especially when combined with subsidies for energy-efficient vehicles. We saw a similar situation in the export of goods and services. While the implementation of an emissions trading scheme or a carbon tax decreases the export of energy-intensive goods, the subsidies for energy-efficient vehicles cause further drops in the export of energy-intensive goods.

In conclusion, as the most important emissions reduction policy in the PRC, a nationwide emissions trading scheme certainly has its advantages compared with a carbon tax, such as cost-effectiveness and regional equity. However, compared to other policies, such as a policy portfolio of a carbon tax and subsidies for energy-efficient vehicles, it is less effective in regard to industrial structure adjustment and emissions reduction in sectors that are excluded from the emissions trading scheme, such as the transportation sector. For that reason, policy portfolios could be adopted to improve the efficiency of emissions reduction in the PRC. In terms of social costs, a carbon tax for sectors that are excluded from the emissions trading scheme or subsidies for energy-efficient vehicles could be seen as a supplementary policy for the emissions trading scheme in the PRC. As more and more countries in Asia and beyond have developed and are developing carbon pricing mechanisms, the findings of this paper represent an important reference.

The limitations of this study should be noted when interpreting our findings. Due to the limitation of industry classification in the database, the sectors covered by the emissions trading scheme in this paper are not completely consistent with the sectors included in the national carbon market of the PRC. For example, domestic civil aviation is included in the transportation sector in this study rather than as a trading sector in the emissions trading scheme. In addition, this paper lacks a discussion on the long-term impact of carbon pricing because of the static model. These should be considerations for future research.

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