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A Comparative Analysis of Separate and Joint Environmental Rights Trading Markets in China

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Abstract: The structuring of effective market-based environmental rights instruments can help to achieve energy efficiency and emission reduction goals while minimizing economic costs. As part of the global drive for sustainable development, pollution rights, carbon emission permits, and white certificates have become widely used as environmental rights trading schemes in many countries. However, interactions between environmental rights can create challenges. For instance, China has established a national carbon market, which it aims to connect with the energy consumption permit trading market. The effectiveness of separate and joint markets in achieving win-win outcomes is an area that requires further research. To address this question, we employed a mixed-integer linear programming model to simulate the potential incremental outputs and energy savings of 16 high-energy-consuming and high-emission industries in China from 2010 to 2019. Our findings indicate that the joint energy consumption permits and the carbon emission permits market yield the greatest economic benefits, but they lack a distinct advantage compared to the separate carbon market. Additionally, industries face less pressure to ensure energy savings in the joint market. The energy saving ratio of the joint market is 0.1% lower than that of the separate carbon market. We also found that the construction of a joint market will incur additional costs for firms and governments. Based on our benefit and cost analysis, we propose that governance subjects of pilot cities prioritize the establishment of the carbon market and not the rapid expansion of the pilot-level scope of energy consumption permits.

Keywords: carbon emission permit; energy consumption permit; trading scheme; linear programming

1. Introduction

China is currently under unprecedented pressure to shift its energy composition towards low-carbon sources, as it is the world's largest energy consumer and carbon dioxide emitter [1]. To promote energy conservation and emission reduction, the development of environmental rights trading markets, including energy consumption permits (ECPs) and carbon emission permits (CEPs), is seen as an important measure [2]. Many countries have already established reimbursable use and trading systems for ECPs or CEPs. For instance, the European Union (EU) launched its market-based emissions trading system in 2005 to reduce carbon emissions and proposed an energy market strategy in 2015 to construct an EU energy market. Despite the different contributions of EU member states, there is agreement on core topics regarding policies such as green trading [3]. The EU emissions trading system has provided valuable experience for the establishment of emissions trading markets in other countries, such as the Regional Greenhouse Gas Initiative (RGGI) in the US and the NSW Greenhouse Gas Reduction Scheme (NSW-GGAS) in Australia [4]. It has also spurred the establishment of China's own carbon emissions trading scheme (CETS).

Since 2013, the National Development and Reform Commission has been promoting pilot carbon emissions trading schemes in seven locations, including Shanghai, in response to the global low-carbon initiative. In 2021, China officially launched its national carbon market. Additionally, in 2016, China began to explore energy consumption permits trading

in four pilot regions, including Fujian Province. By 2021, the Chinese government had come to recognize the importance of market-based trading for pollution rights, energy consumption permits, water rights, and carbon emissions permits. The ECPTS involves the trading of energy consumption indicators by enterprises based on national total energy-consumption control. This scheme shares similarities with the white certificate program implemented in Europe and the United States, as both guide the spontaneous trade of energy consumption units and, ultimately, aim to achieve optimal resource allocation based on energy saving goals. Table 1 shows that the ECPTS in China has similarities with the CETS, according to which the latter directly limits the total emissions or their intensity, while the former limits the total energy consumption or its intensity. However, the dual use of these two policy instruments has raised concerns among the government and scholars [5]. When firms are involved in both trading schemes, their energy consuming behaviors will be subject to the dual constraints of the ECPTS and CETS, which may increase production costs, resulting in controversy regarding policy overlap [6].

Table 1. Comparison of the ECPTS and CETS.

Policy Content	Energy Consumption Permit Trading Scheme	Carbon Emissions Trading Scheme	Comparison
Governance subjects	National Development and Reform Commission	Ministry of Ecology and Environment	Different authorities
Trading subjects	Taking Shanghai as an example: 1. Enterprises involved: 322 enterprises. 2. Industry coverage: steel, petrochemical, non-ferrous metal, automobile manufacturing, cement building materials and other industries.	Firstly, covering 2162 key emission units in the power generation industry, including 7 industries: petrochemical, chemical, building materials, iron and steel, non-ferrous, paper and aviation.	Industry coverage overlap
Trading mechanism	1. The allocation methods include bench marking, historical trends, and emissions reduction potential. 2. The ECPs are freely allocated to companies. 3. Transaction form: offered or repurchased by the government and transactions between enterprises.	1. The allocation methods include bench marking, historical trends, and emissions reduction potential. 2. The CEPs are freely allocated to companies, possibly being paid in the near future. 3. Transaction form: public transactions and agreed transfers.	Similar cap and trading scheme

In practice, China's carbon market has developed relatively quickly, and the operation of the national carbon market has begun. The ECPTS, however, is still in the preliminary stage of exploration. In light of this, our objective is to explore whether a joint market or a separate market is more helpful in achieving the goal of cost-optimal sustainable development and to provide policy recommendations to local governments in pilot regions in order to promote sustainable urban development.

In order to address this issue, we selected 16 typical industries in China with high energy consumption and high emission characteristics. Next, we employed a mixed-integer linear programming model to simulate four policy combinations that include ECPs and CEPs. Based on the simulation results, we compared China's output growth ratios and energy savings based on a separate carbon market, a separate energy consumption permit trading market, and a joint market. Finally, we conducted a comprehensive analysis of the impacts of constructing a joint market on both the benefit and cost sides for enterprises and the government. The findings of this study will encourage more enterprises to participate in green trading and provide valuable policy references for China to promote its carbon-neutral strategy.

This study offers two significant contributions to the literature. Firstly, we optimized the computational method proposed by Färe et al. [7] by constructing a mixed-integer linear programming model that incorporates industry decision variables. This approach allows each trading subject to freely choose one market based on its unique characteristics,

rendering the model more suitable for the research problem. Secondly, by simulating the changes in economic output and energy conservation in different scenarios, such as separate and joint environmental rights trading schemes, the conclusions provide important references for the future development of environmental rights markets in each pilot city.

The paper is structured as follows. Section 2 provides a brief review of the previous studies on CETS and ECPTS in China. Section 3 explains the model framework and data, while Section 4 presents the allocation results and provides further discussion. Lastly, Section 5 concludes this study and provides policy recommendations.

2. Literature Review

Policy tools such as CEPs, pollution rights, water rights, and renewable energy certificates have become increasingly critical for countries in addressing environmental and climate change issues [8]. The establishment of an environmental rights trading scheme is conducive to directing capital towards more environmentally friendly areas [9]. Scholars have focused on two main categories of related topics. The first category examines the environmental and economic impacts of the CETS or ECPTS on regions or firms. The second category examines various environmental rights instruments and analyzes how they can be coordinated in a joint market, as well as the potential impacts of coordination.

To date, numerous research studies have been conducted on the CETS. They have focused on several key areas including the allocation of carbon emission allowances [10], economic and environmental effects [11,12], enterprise value [13], carbon equity [14], and carbon leakage [15]. Stuhlmacher et al. [16] highlighted that there is currently a high level of carbon emissions aggregation in the EU; however, this is expected to decline as the trading mechanism matures. Tang et al. [17] found that carbon trading pilot policies have the potential to effectively reduce carbon emissions through technological innovation and industrial restructuring. Additionally, Zhao et al. [18] noted that a well-established CETS could be instrumental in promoting green innovation within the power sector in China's pilot regions.

The tradable ECPs have been shown to achieve a balance between economic and environmental considerations, with studies focusing on their energy-saving effects and cost-effectiveness. Zhang and Zhang [19], as well as Luo and Zhang [20], demonstrated that the ECPTS can achieve economic growth and energy conservation, as compared to command control policies. Wang et al. [21] and Che and Wang [22] pointed out that the ECPTS has significant curbing effects on the total energy consumption and intensity. Yang et al. [23] and Xue and Zhou [24] found that the construction of an ECPTS can improve efficiency.

Scholars have found evidence of interactions between different environmental rights by simulating joint markets that include multiple environmental instruments. Much research on CEPs and environmental rights has explored the coupling effect between the economy and the environment. The primary environmental rights that show synergy with CEPs are white certificates, green certificates, carbon taxes, and ECPs.

Sorren et al. [25] examined the economic and environmental implications of introducing a tradable white certificate scheme in a country already participating in the EU ETS. Similarly, Yi et al. [26] argued that there are strong inner linkages between the tradable green certificate system and the national carbon market. Yu et al. [27] and Feng et al. [28] suggested that the implementation of a tradable green certificate system and CETS can optimize the power supply structure and control carbon emissions in the power sector. In terms of carbon taxes, Zhang et al. [29] found that hybrid systems combining carbon taxes and CETS can accelerate the decline in energy and carbon intensity. Jia and Lin [30] argued that the carbon tax has a slightly greater long-term emission reduction capacity than the carbon emissions trading scheme.

Last, but not least, scholars have paid significant attention to the setting of allowances and interconversion factors for CEPs and ECPs, while also empirically examining their potential impact. Li and Zhu [31] found that the ECPTS and CETS are highly interrelated, and if CEPs and ECPs complement and engage in exchange with each other, this will

promote the synergistic development of the two markets. Zhang et al. [32] prioritized the allocation efficiency of ECPs over carbon allowances, the former being more conducive to energy saving and emission reduction. Wang et al. [6] pointed out that the joint trading system generates more economic-environmental benefits. Liu and Wang [2] agreed on the construction of a mechanism in which ECPs and CEPs can be traded simultaneously. In this market, both energy saving and emission reduction effects, as well as green total factor productivity, will be significantly enhanced. Yu et al. [33] considered the impact of shadow prices and proposed that it is more cost-effective to construct a separate ECPTS.

In order to accurately evaluate the impacts of different energy policies, scholars have employed various methods, including the difference-in-differences model (DID), general equilibrium model (CGE), and data envelopment analysis (DEA). These methods offer different perspectives on the impacts of energy policies. DID, for instance, enables the easy comparison of policy impacts before and after implementation [34], while CGE is suited to the evaluation of the impacts of a policy within an integrated system [35]. DEA, on the other hand, is better suited to the measure of efficiency.

Most scholars use DEA to determine optimal energy consumption or CO_2 emissions and assess economic and environmental effects. Wang et al. [21], for instance, used DEA to measure the optimal desired output and energy input for the ECPTS. Zhang and Zhang [19] adopted DEA to compare the optimal decisions of firms in a command control scenario and an ECP trading scenario. Liu and Wang [2] employed non-parametric DEA to compare the command control scenario with the free trade scenario. Yang et al. [23] designed an energy allocation scheme along with the ECPTS based on the ZSG-DEA and CAT models. While DEA is widely applied to study CEPs and ECPs, traditional DEA cannot incorporate the cost of market overlap or include decision variables in the modeling process. To accurately simulate the trading decisions of different subjects, we introduce industry decision variables based on the modeling concept proposed by Färe et al. [7,36] and solve it by constructing a mixed-integer linear programming model.

In summary, the previous literature has examined the impacts of the CETS and ECPTS but has also identified several deficiencies. Since the mechanism of the ECPTS is still yet to be fully determined, few quantitative studies have explored the effectiveness of ECPs, particularly with regard to the similarities between the ECPTS and CETS. To effectively synergize different environmental rights markets in China, further examination is needed to determine whether the coexistence of the ECPTS and CETS is necessary. While many previous studies have compared the policy combination of command control and free trade, arguing that allowing environmental rights to be traded in the market can help to achieve win-win goals, few scholars have discussed whether a separate or joint scheme should be constructed based on free trade.

Therefore, we constructed three different markets to evaluate the potential benefits of separate and joint markets for sustainable development in each pilot city. These markets included a separate carbon market, a separate energy consumption permits market, and a joint market. Our goal was to compare the potential output changes and energy savings of each industry in order to determine which type of market would be the most beneficial.

In our study, a separate market refers to a situation where only one type of environmental right (i.e., carbon emission rights or energy-consumption permits) can be traded in the pilot area. In contrast, a joint market allows for the coexistence of both the CETS and the ECPTS in the pilot area. However, they remain independent of each other and cannot be offset against one another.

3. Methodology and Data

3.1. Model

Based on previous studies, we utilized the calculation method proposed by Färe et al. [7,36] and we choose good output increment maximization as the industry's objective function. We compute the maximal good output increment all industries may achieve given

that the emissions of bad output and energy input can be reallocated among them in a separate carbon market, a separate energy consumption permit market, and a joint market.

In order to estimate the potential output increment, we first model the environmental production technology. Suppose there are k = 1, ..., and K decision-making units representing the different industries involved in the transaction. Furthermore, assume non-energy inputs vector by $x = (x_1, \ldots, x_N) \in R_+^N$, energy inputs vector by $e = (e_1, \ldots, e_S) \in R_+^S$, good outputs by $y = (y_1, \ldots, y_M) \in R_+^M$, and bad outputs by $b = (b_1, \ldots, b_J) \in R_+^J$. Good outputs refer to industrial output and bad outputs refer to environmental pollutants, which is the amount of carbon dioxide emission in this paper. According to the environmental production technology, each decision-making unit uses input vector to produce both good and bad outputs. Therefore, the environmental production technology can be modeled as follows:

$$P(x) = \{(y, b) : x \text{ can produce } (y, b)\}, x \in R_+^N \tag{1}$$

It is often assumed that P(x) satisfies the standard properties of the production technology theory, including $P(0) = \{0\}$. Furthermore, we assume that the bad output are weakly disposable and nulljoint with the good output [7,37], and that the non-energy input and good output are strongly disposable [7]. Weak disposability implies that reducing carbon emissions and energy consumption will come at the cost of giving up a portion of the good output. Assumption of weak disposability is expressed as:

$$\text{If } (y, b) \in P(x) \text{ and } 0 \leq \theta \leq 1 \text{ then } (\theta y, \theta b) \in P(x) \tag{2}$$

Meanwhile, the null-jointness assumption indicates that the consensual output must be zero, when carbon emissions are zero, i.e., the company will inevitably emit a certain amount of carbon dioxide when carrying out its daily production and operation activities. Assumptions of nulljoint is expressed as:

$$\text{If } (y, b) \in P(x) \text{ and } b = 0 \text{ then } y = 0 \tag{3}$$

Here we only have one good output, potential output increment, and its maximum is estimated using a linear programming model. We assume that at each time period t = 1, ..., T there are k = 1, ..., K observations of inputs, good output (y), and bad output (b). The non-energy inputs were the capital stock (x_1) and the number of employees (x_2), while the energy consumption (e) was the energy input.

Due to the length of the article, the model for Scenario 2 is shown below. The difference lies in the fact that in Scenarios 1, 3, and 4, the carbon and energy markets have industry-specific coverage, and each industry is not at liberty to choose which market to trade in.

$$\omega^t = \max \sum_{k=1}^{K} a_k^t \tag{4}$$

Industry 1:

$$\text{s.t.} \sum_{k=1}^{K} z_{k1}^t \times y_k^t \geq y_1^t + a_1^t \tag{5a}$$

$$\sum_{k=1}^{K} z_{k1}^t \times b_k^t = b_1^t + \delta_1^t \tag{5b}$$

$$\sum_{k=1}^{K} z_{k1}^t \times e_k^t = e_1^t + \beta_1^t \tag{5c}$$

$$\sum_{k=1}^{K} z_{k1}^t \times x_{kn}^t \leq x_{1n}^t, \ n = 1, 2 \tag{5d}$$

$$z_k^t \geq 0, \ k = 1, \ldots, K \tag{5e}$$

$$-BMC_1^t \leq \delta_1^t \leq BM \times SC_1^t \tag{5f}$$

$$-BME_1^t \leq \beta_1^t \leq BM \times SE_1^t \tag{5g}$$

$$SC_1^t + SE_1^t = 1 \tag{5h}$$

In Equation (4), a_k^t represents the potential incremental output of industry k in period t and ω^t is the sum of the maximum potential output increments, representing the optimization condition required to maximize the potential output increment.

In Equation (5a), y_1^t is the pre-trade output of industry 1, and a_1^t is the potential post-trade output increment of industry 1. $y_1^t + a_1^t$ denotes the optimal output after the transaction.

Equation (5b) denotes the free allocation of CEPs among industries. Since bad outputs are weakly disposable, the carbon constraint formula in Equation (5b) is equality. c_k^t is the observed levels of the bad outputs, denoting the carbon emissions of industry k. δ_1^t is the slack variable, denoting the difference between post-trade carbon emissions and historical carbon emissions, representing the degree of change in the carbon emissions of industry 1.

Equation (5c) reflects the free allocation of ECPs among industries. Since energy inputs are weakly disposable, the energy constraint formula in Equation (5c) is also equality. e_k^t is the energy input variable, which denotes energy consumption. β_1^t is the slack variable, which indicates the degree of change in the energy consumption of industry 1.

Equation (5d) represents the constraints on non-energy inputs. Since non-energy inputs are strongly disposable, the non-energy constraint is inequality. x_{11}^t and x_{12}^t are capital stock and human capital, respectively.

Moreover, we assume constant returns to scale, so that the decision variable, z_{k1}^t, is set to be non-negative. In Equation (5h), SC_1^t and SE_1^t are 0–1 decision variables, which indicate the market choice of each industry. If the carbon market is chosen, $SC_1^t = 1$.

In Equation (5f), BMC_1^t denotes the carbon allowance of industry 1 in period t. Each industry can sell all of its initial carbon allowances; thus, the minimum values are set for BMC_1^t. BM is a large number, which shows that if industry 1 chooses the carbon market, there will be no cap on the carbon allowances acquired through purchase. In Equation (5g), we also set the upper and lower limits of the trading volume of ECPs for industry 1, based on the same principle as the trading scheme of the carbon market in Equation (5f).

Industry k:

$$
\begin{aligned}
\text{s.t. } & \sum_{k=1}^{K} z_{kK}^t \times y_k^t \geq y_K^t + a_K^t \\
& \sum_{k=1}^{K} z_{kK}^t \times b_k^t = b_K^t + \delta_K^t \\
& \sum_{k=1}^{K} z_{kK}^t \times e_k^t = e_K^t + \beta_K^t \\
& \sum_{k=1}^{K} z_{kK}^t \times x_k^t \leq x_{Kn}^t,\ n = 1,\ 2 \\
& z_{kK}^t \geq 0,\ k = 1,\ \dots,\ K \\
& \sum_{k=1}^{K} \delta_{kK}^t \leq 0 \\
& \sum_{k=1}^{K} \beta_{kK}^t \leq 0 \\
& -BMC_k^t \leq \alpha_k^t \leq BM * SC_k^t \\
& -BME_k^t \leq \beta_k^t \leq BM * SE_k^t \\
& SC_k^t + SE_k^t = 1
\end{aligned} \tag{6}
$$

Model (6) represents the trading behavior of the kth industry in the CETS or ECPTS, based on the same principle as model (5). We set non-positive constraints for the slack variables, β_k^t and δ_k^t, indicating that the pilot city needs to achieve energy efficiency and emission reduction targets. $\sum_{k=1}^{16} \delta_k^t \leq 0$ and $\sum_{k=1}^{K} \beta_k^t \leq 0$ denote the total carbon emission constraints of the CETS and the total energy input constraint of the ECPTS, respectively. We stipulate that the total amount of resources after reallocation may be the historical total, at most.

3.2. Data Sources and Scenario Setting

Here, the proposed models are used to compare the separate and joint trading systems of the CETS and ECPTS for 2010–2019. We take 16 specific industries in China as an example. The input elements include capital stock (x_1), human capital (x_2), and energy consumption (e). The good output (y) is the gross product of each industry, and the bad output (b) is CO_2 emissions. Data were collected from the China Statistical Yearbook, the China Industry Statistical Yearbook, and the China Energy Statistical Yearbook, while carbon emissions data and energy consumption were collected from the CEADs database [38–40]. The labor force was measured using the number of employed people at year-end. The capital stock data and output data were expressed as 2010 constant prices. Table 2 presents summary statistics for all of the variables.

Table 2. Variable setting and descriptive statistics.

Type	Variable	Unit	Mean	Std. Dev.	Min	Max
Summary statistics (2010)						
	Energy consumption	Tons (in millions)	10,532.15	17,943.75	101.43	69,574.97
Input	The number of employees	Workers (in 10 thousands)	475.99	482.77	79.19	1991.00
	The capital stock	RMB (in billions)	6523.58	7812.14	691.51	30,074.50
Good output	Industrial output	RMB (in billions)	26,461.00	15,434.63	3655.03	55,255.61
Bad output	CO_2	Tons (in millions)	434.10	853.66	2.16	3198.84
Summary statistics (2019)						
	Energy consumption	Tons (in millions)	13,244.07	25,896.51	64.83	101,365.17
Input	The number of employees	Workers (in 10 thousands)	630.72	1064.04	80.76	4296.10
	The capital stock	RMB (in billions)	13,334.79	16,090.71	535.46	66,017.23
Good output	Industrial output	RMB (in billions)	34,042.10	19,058.63	5490.59	74,750.22
Bad output	CO_2	Tons (in millions)	554.62	1209.39	1.22	4646.59

To make the separate and joint trading system feasible, we firstly establish four scenarios, as shown in Table 3. The difference between these four scenarios lies in the different coverage of the industry. In the expected scenario (S1), we simulate the mechanisms that will develop in each pilot city in the short term. As per the latest policy, the initial phase of CETS will cover eight industries, including the electric power and construction sectors. Hence, we included these eight industries in the CETS and the remaining eight energy-intensive industries in the ECPTS. In the optimal scenario (S2), each industry has the freedom to choose between the two trading schemes. Additionally, we established a separate environmental rights trading market in both the CETS (S3) and ECPTS (S4) but allowed for free trading between individual entities. By comparing the results of the simulations of the four scenarios, we could determine which environmental rights trading scheme can achieve the energy saving and emission reduction goals at the lowest cost.

Table 3. Description of scenarios and industry allocation.

Scenarios	CETS	ECPTS
Scenario 1 (based on expected policy)	Papermaking and Paper Products Petroleum Processing and Coking Raw Chemical Materials and Chemical Products Smelting and Pressing of Ferrous Metals Smelting and Pressing of Nonferrous Metals Electric Power, Steam, and Hot Water Production and Supply Construction Transport, Storage, Postal, and Telecommunications Services	Food Production Textile Industry Printing and Record Medium Reproduction Medical and Pharmaceutical Products Nonmetal Mineral Products Metal Products Ordinary Machinery Transportation Equipment
Scenario 2 (based on free choice)	The above 16 industries are free to choose 1 market under the constraint of meeting environmental regulations.	
Scenario 3 (only CETS)	The above 16 industries can only participate in the CETS.	
Scenario 4 (only ECPTS)	The above 16 industries can only participate in the ECPTS.	

Furthermore, in the cap-and-trade mechanism, the two control targets commonly adopted in the CETS are the absolute cap and intensity cap [41,42]. The intensity cap is more widely used in China [43–45]. Given this fact, we intended to use the historical intensity to delineate the baseline of the ECPs and carbon allowances [46]. The quantitative relationships are as follows.

$$BME_k^t = b_k^{t-1}/y_k^{t-1}*y_k^t*rfBME_k^t = e_k^{t-1}/y_k^{t-1}*y_k^t*rf \qquad (7)$$

In Equation (7), BMC and BME represent the carbon allowances and initial limit of energy use, respectively. b_k^{t-1} and e_k^{t-1} denote the CO_2 emissions and energy consumed by industry k in period t−1, respectively, while y_k^{t-1} denotes the total output of industry k in period t−1. rf indicates the ratio between the free quota and the total quota. Additionally, we assume that both the initial limit of energy consumption and carbon allowances are currently allocated to energy-consuming enterprises for free [47,48].

Lastly, we propose a non-overlapping market for the CETS and ECPTS, meaning that each industry can only participate in one of the two markets. Since, in China, the ECPTS is still in the pilot stage and the trading mechanism for energy consumption permits requires further improvement, it is difficult to scientifically determine the replacement coefficient of the two indicators. Meanwhile, an enterprise facing the constraints of these two markets will probably observe increases in its operating costs and administration costs, which will be detrimental to the sustainable development of the economy.

4. Results and Discussion

In this section, we first analyze the empirical results, namely, the benefits of separate and joint markets. Then, we conduct a cost analysis of the construction of a joint market. Due to the amount of computation involved, we use Matlab to identify the optimal solution.

4.1. The Benefits Analysis

4.1.1. Comparisons of the Output Growth

Firstly, we analyze the economic impacts of the CETS and the ECPTS. Our focus is on the changes in total benefits associated with potential output growth. Figure 1 illustrates the potential output growth increase in both the separate trading scenario and the joint trading scenario. Overall, we find that the market mechanism offering industries the choice between CETS and ECPTS (S2) has the greatest economic potential. However, compared to the inclusion of all industries in the CETS (S3), the total benefit of the output growth does not significantly increase in the joint market in Scenario 2. This indicates that establishing a free choice-based joint market does not provide a significant advantage from an economic benefit perspective.

According to the simulation, the highest average annual potential output growth ratio is 36.34% in Scenario 2, followed by 36.20% in Scenario 3, 29.43% in Scenario 1, and 18.06% in Scenario 4. Comparing Scenario 1 and Scenario 2, we can see that different industries are suitable for different environmental rights trading markets. By matching the industries with the most appropriate markets, we can significantly increase their economic potential. In Scenario 2, only 5 industries actively trade in the ECPTS, while 11 industries choose to trade in the CETS in 2019.

Allowing industries to choose their trading mechanisms freely helps to improve the potential output ratio, as evidenced by the comparison of Scenarios 1–4. However, the potential output ratios in Scenarios 2 and 3 converge in every year. This indicates that if a separate CETS is permitted, its overall economic potential will converge to the optimal case.
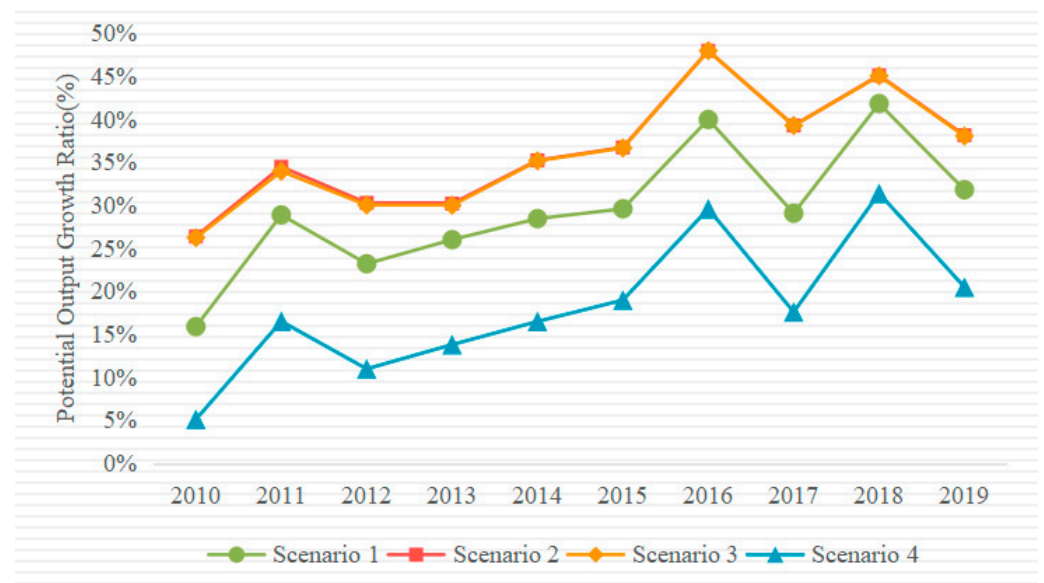
Figure 1. National potential output growth ratio on the industry level in 2010–2019 (%).

4.1.2. Comparisons of Energy Savings

To demonstrate the impact of energy conservation, we introduced the concept of the energy saving ratio, which represents the percentage of potential energy savings to the actual energy input. Table 4 displays the average energy saving ratios for various industries.

Table 4. National average economic potential and energy saving ratio on the industry level (%).

Year	S1		S2		S3		S4	
	Economic Potential	Energy Saving Ratio	Economic Potential	Energy Saving Ratio	Economic Potential	Energy Saving Ratio	Economic Potential	Energy Saving Ratio
2010	0.99	3.35	1.65	2.66	1.64	2.67	0.32	4.57
2011	1.80	2.85	2.15	2.02	2.12	2.53	1.03	3.36
2012	1.45	3.24	1.89	2.53	1.87	2.95	0.68	3.82
2013	1.62	3.26	1.88	2.80	1.87	2.86	0.86	4.55
2014	1.78	3.17	2.20	2.57	2.20	2.57	1.03	4.58
2015	1.85	3.11	2.29	2.60	2.29	2.60	1.18	4.44
2016	2.50	4.74	2.99	4.51	2.99	4.51	1.85	5.85
2017	1.81	3.38	2.45	3.11	2.45	3.11	1.10	4.50
2018	2.61	2.96	2.82	2.76	2.81	2.77	1.96	4.13
2019	1.99	2.97	2.38	2.60	2.38	2.59	1.28	4.17
Avg.	1.84	3.30	2.27	2.82	2.26	2.92	1.13	4.40

In a free-market system (S2), industries face minimal pressure to conserve energy in order to meet low-carbon goals. The separate CETS fares slightly better in this regard. Specifically, in Scenario 2, the average energy saving ratio is the lowest, at 2.82%. Meanwhile, the average energy saving ratio for the separate CETS (S3) is comparable, at 2.92%. Compared to the optimal scenario (S2), the average energy saving ratio is 0.48% higher under the expected scenario (S1) and 1.58% higher under the separate ECPTS (S4).

The level of energy conservation constraint varies for each trading entity and between different scenarios. The findings reveal that in both the expected scenario (S1) and the separate ECPTS scenario (S4), companies face the highest pressure to conserve energy, as they need to allocate more resources to achieve their environmental targets. In the separate carbon market (S3), the pressure to save energy is also relatively high, as companies are not yet at liberty to select the more cost-effective option. However, when companies have greater flexibility in choosing their course of action, they can balance output growth and energy savings based on their unique circumstances, thereby reducing the pressure

to conserve energy. As a result, the energy saving ratio is the lowest in the optimal scenario (S2).

Joint policies can certainly be employed to optimize the energy composition and promote emission reductions. However, a separate carbon market can simultaneously achieve multiple goals, such as economic growth, increased welfare, and improved environmental quality. Allowing industries to freely choose the CETS or ECPTS does not significantly improve the overall economic benefits compared to the inclusion of all industries in the CETS. Therefore, the government needs to consider the impacts of different policies on core players when formulating a policy combination. Analysis of both benefits and costs will help us to identify the optimal policy combination that achieves the maximum emission reduction at the minimum cost.

4.1.3. Robustness Test

To ensure the stability of our simulation results, we selected two pilot provinces, Shanghai and Fujian, to further validate our study findings. Shanghai was one of the first regions in China to launch a carbon market, and after 11 years of exploration, it has established a relatively transparent and effective carbon market. Meanwhile, Fujian Province launched its carbon market in 2016 and later explored the ECPTS in 2017. Using the same approach, we simulated the potential output changes of 16 typical industries in Shanghai and Fujian Province from 2010 to 2019 in different scenarios.

Based on the simulation results, we found that our conclusions were consistent. In the optimal scenario (S2), the joint market has the highest potential output ratio. However, when compared with the separate carbon market, the joint market does not have a significant advantage in terms of economic dividends. Specifically, the results for Shanghai in Figure 2 indicate that the potential output ratio is highest in the optimal scenario (S2), being 0.18% higher than that of the CETS (S3) and 6.95% higher than that of the ECPTS (S4). Similarly, the results for Fujian Province in Figure 3 show that the highest potential output ratio is obtained in the optimal scenario (S2), being 0.03% higher than that of the CETS (S3) and 17.40% higher than that of the ECPTS (S4). In conclusion, we believe that our findings are robust.
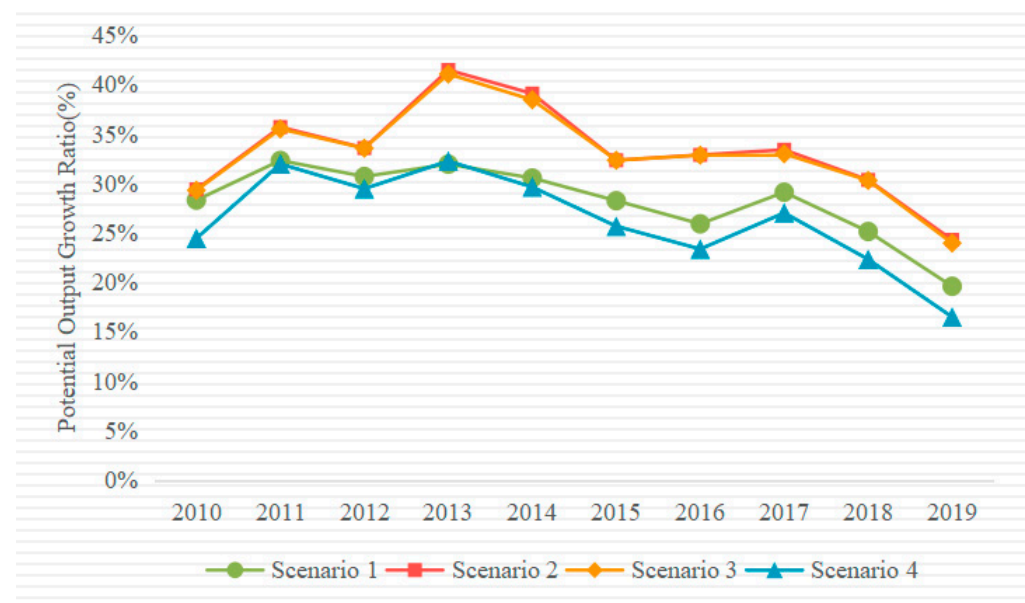
Figure 2. Potential output growth ratio on the industry level in Shanghai (%).
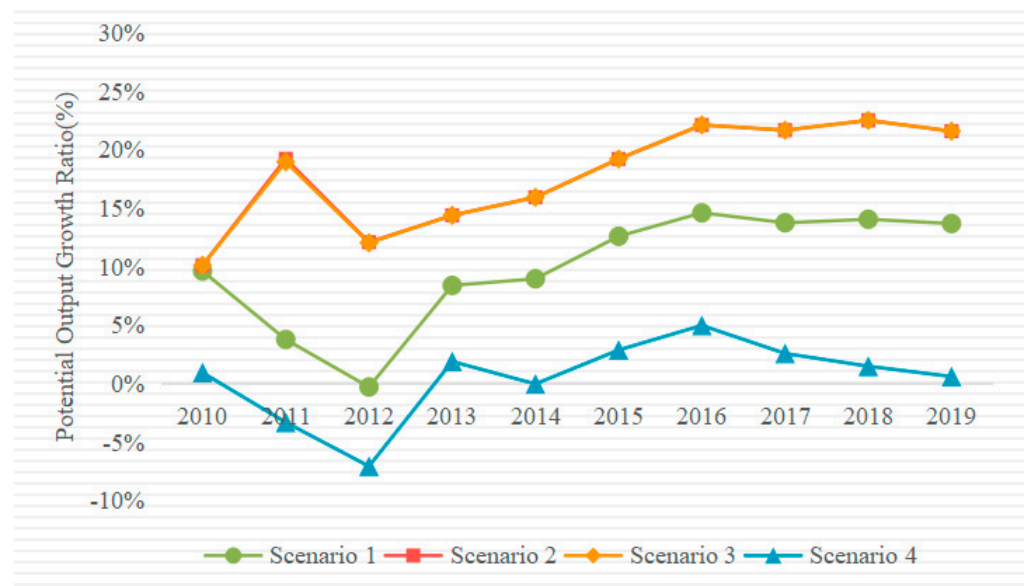
Figure 3. Potential output growth ratio on the industry level in Fujian (%).

4.2. The Cost Analysis

4.2.1. Business Operating Costs

Participation in the new environmental rights market can increase direct costs for companies. Here, to begin our analysis, we use the example of participants entering the carbon market, as the national carbon market's trading rules are more transparent and standardized. According to the disclosure information on China's carbon market, there are three additional costs for participants: human resource costs, transaction fees, and auditing costs.

Starting with the first point, enterprises need to hire and train professional staff in order to participate in the CETS. Compliance rules require enterprises to undertake tasks such as counting carbon emissions, cooperating with third-party organizations to verify data, and managing allowance accounts. Due to the complexity of this work, companies need to hire dedicated personnel to handle carbon trading-related tasks. Some companies also need to hire financial personnel responsible for developing optimal carbon trading strategies, managing carbon assets, and controlling management risks. Consequently, participants must pay additional human resource costs while spending a significant amount of time and money in order to fulfill their emission reduction obligations.

Next, buying and selling quotas incur necessary transaction costs, including account opening fees, membership fees, and commission charges. Transactions must be settled at the designated exchange in China, which adds to these costs. These exchanges have traditionally been managed through charges of annual or membership fees at favorable rates. However, with the development of the national carbon market, these annual or membership fees will become an essential part of the transaction costs for enterprises.

Lastly, auditing cost will become an important expense for participants. Carbon disclosure information needs to be authenticated by a third party. In the early days, local governments bore the auditing costs. However, as the national carbon market matures, enterprises are beginning to bear the costs themselves.

Apart from the direct expenses associated with entering a new market, firms that are given the option to choose between two markets by the government also face indirect costs such as information, learning, and decision making-related costs. Since the firms have the freedom to choose, the person in charge must gather and process a vast amount of data and information relevant to both markets before making any decisions. Additionally, the responsible individual must keep the core data and crucial information up to date in real time. Furthermore, the person in charge must possess a thorough understanding of

the trading rules of both markets and stay informed about any policy changes through attending training sessions and reading policy documents. Ultimately, to aid in decision making, the person responsible must evaluate the costs and benefits of both markets. They can then use this information to develop trading plans for the near future through the simulation of different models. When transactions are anticipated to be increasingly active or when price fluctuations are likely to be substantial, participants must make challenging decisions.

In light of this, enterprises will face increased direct and indirect costs when engaging in a joint environmental rights trading market. They will not only face energy conservation and emission reduction pressures but will also have to bear tremendous operation pressure. Therefore, prioritizing the establishment of a separate environmental rights market is the cost-optimal option to reduce the burden on enterprises.

4.2.2. Government Administration Expenses

In the case of two parallel markets, the institutional transaction costs are increased due to the multi-departmental management system. In China, the Ministry of Ecology and Environment is the governance subject for the CETS, while the National Development and Reform Commission governs the ECPTS. Thus, coordination between these two authorities is directly tied to the duplication of the two systems. Although the two authorities are independently managed, they have overlapping responsibilities, leading to a rapid increase in institutional transaction costs.

Furthermore, the incentive for local governments to implement the ECPTS may be higher due to the insufficient binding force of the relevant legislation. In Table 5, most of the policy and regulatory documents related to the ECPs are classified as local regulatory documents. On the other hand, policies related to the CEPs are generally based on administrative regulations. As the market rules of the ECPTS lack the compulsory power of laws, the government may need to spend more on regulatory costs to restrain enterprises from participating in trading.

Table 5. Energy consumption permit trading scheme in each pilot province in China.

Pilot Province	Regulations	Effectiveness Level
Zhejiang	Trading mechanism and pilot implementation plan regarding paid use of energy consumption permits in Zhejiang.	Local normative documents
	Trading mechanism and interim measures for transaction management regarding paid use of energy-consumption permits in Zhejiang.	
	Trading mechanism and interim measures for the management of third-party audit institutions regarding paid use of energy-consumption permits in Zhejiang.	
Sichuan	Trading mechanism and pilot implementation plan regarding paid use of energy-consumption permits in Sichuan.	Local normative documents
	Trading mechanism and interim measures for transaction management regarding paid use of energy-consumption permits in Sichuan.	
Henan	Trading mechanism and pilot implementation plan regarding paid use of energy-consumption permits in Henan.	Local normative documents
	Trading mechanism and interim measures for transaction management regarding paid use of energy-consumption permits in Henan; guidelines for auditing energy consumption reports of key energy-using units in Henan (for trial implementation).	

Table 5. *Cont.*

Pilot Province	Regulations	Effectiveness Level
Fujian	Interim measures for transaction management regarding paid use of energy-consumption permits in Fujian.	Local government regulations
	Trading mechanism and pilot implementation plan regarding paid use of energy-consumption permits in Fujian.	Local normative documents
	Implementation rules for credit evaluation in the energy consumption permit trading market in Fujian (for trial implementation); guidelines for auditing energy consumption in energy consumption permit trading scheme in Fujian (for trial implementation); implementation rules for regulating the energy-consumption permit trading scheme in Fujian (for trial implementation); management approach to energy consumption audit agency in Fujian (for trial implementation); management approach to energy consumption reporting in energy consumption permit trading scheme in Fujian(for trial implementation).	

The construction of two markets incurs a high system design cost. Additionally, when we consider the ECPTS, the total transaction volume is small, and the form of transaction is limited. For instance, in Zhejiang and Fujian Provinces in 2021, the total transaction volumes were 340 thousand tons and 1.2 million tons of standard coal, respectively. In Zhejiang, only 12 transactions occurred, involving 9 enterprises. This highlights the low liquidity of the ECPs. Moreover, all participants in Zhejiang directly purchased ECPs from local governments, a system equivalent to the "paid allocation" or "primary market" transactions in the carbon market. The lack of activity in the secondary market hinders the ECPTS's further development.

As a systemic project, the ECPTS incurs substantial costs that the government must bear. The scheme's effectiveness depends on the participation rate and the complexity of the trading system. Currently, China's energy consumption permit market remains a regional voluntary market. Moreover, the current mechanism is immature and cannot support the market in the efficient allocation of resources.

4.3. Discussion

According to the simulation results, in Scenario 2, the joint energy consumption permits and carbon emissions permits market has the highest average annual potential output growth ratio, which is 0.14% higher than that of the separate carbon market and 18.28% higher than that of the separate energy consumption permit trading market. This finding is consistent with the results of Wang et al. [6]. However, Wang et al. [6] did not distinguish between the construction costs of different markets. Based on a discussion of the costs, we argue that there is a significant difference in costs between the construction of a joint market and that of a separate market.

Additionally, when comparing the energy-saving effects, the energy-saving ratio of the separate carbon market (Scenario 3) is 0.1% higher than that of the joint market (Scenario 2). This suggests that the economic dividend of the joint market is not significantly greater than that of the separate carbon market, provided that the same energy-saving and low-carbon-related goals are achieved. Therefore, taking into consideration the economic–environmental benefits and costs, the construction of a separate carbon market is more favorable for the achievement of low-carbon-related goals at a minimal cost.

In contrast, Yu et al. [33] suggest that a separate energy consumption permits market can achieve higher cost savings. The inconsistency between their findings and ours is due to the different premises on which the studies are based. Yu et al. [33] first estimated the shadow prices of energy and CO_2 before calculating the cost savings. They did not take into account the changes in the shadow prices and the affordability of trading agents in the process of transitioning from local pilot carbon markets to national market. However, we studied the need for a joint energy use rights market while fully considering the costs and benefits of constructing a national carbon market over the past 10 years.

Various pilot regions have shown that energy consumption permits and carbon emissions permits have similar functions. The Chinese government aims to utilize energy consumption permits, a market-based instrument, to allocate resource factors effectively, promoting green, high-quality social development. Fujian Province is the only pilot region that participates in both the carbon and energy consumption permits markets. However, despite several years of piloting, the energy consumption permits market in Fujian remains small, with a trading volume of 1.24 million tons of standard coal, which is significantly lower than the carbon trading volume of 7.66 million tons of CO_2 in the same year.

After comparing the key energy consumption units and the list of emission controlling enterprises in the carbon market, we discovered that there is an overlap between trading subjects. High-energy-consuming enterprises engaged in thermal power generation, steelmaking, crude oil processing, and other industries are subject to both the carbon market and the energy consumption permits market. However, enterprises subject to double constraints may find it challenging to participate in energy consumption permit trading, since they can achieve energy saving and emission reduction through carbon trading [32]. This overlap between the energy consumption permits market and the carbon market poses a duplication problem. Therefore, the governing subject in each pilot region must consider this problem during mechanism design in order to avoid adding to the burden on enterprises and reducing their motivation to engage in green transformation.

5. Conclusions and Policy Recommendations

In 2016, the Chinese government proposed an innovative energy consumption permits trading policy. There is now a duplication of the ECPTS and CETS. The question arises as to whether we should establish a national market for energy consumption permits in addition to the national carbon emissions trading scheme. To address this question, we constructed a mixed-integer linear programming model to simulate the economic dividends and energy savings of China's energy-intensive and high-emission industries based on four scenarios from 2010 to 2019. Our main findings are as follows:

(1)   From an economic dividend perspective, although a joint carbon emissions permits and energy consumption permits market has the greatest economic benefits, a separate carbon market can also achieve economic benefits that converge to those of a joint market. The output growth ratio of the joint market in the optimal scenario surpasses that of the separate carbon market by 0.14%, and that of the separate energy consumption permits market by 18.28%. Nonetheless, in the joint market, most industries choose to participate in the carbon market on their own, indicating that the joint market lacks a distinct advantage, and most industries can meet low-carbon requirements at minimal cost by participating in the carbon market.

(2)   From an environmental perspective, the joint carbon emissions permits and energy consumption permits market has the smallest energy saving ratio. However, the difference with the energy savings of the separate carbon market is not significant. The energy savings in the joint market under the optimal scenario are 0.1% lower than those in the separate carbon market and 1.58% lower than those in the separate energy consumption permits market. Each industry will achieve different levels of energy savings through either a separate market or a joint market. A separate carbon market can generate higher energy savings than a joint market, and it is also more conducive to achieving the control target of total energy consumption faster for the region as a whole.

(3)   Compared with a separate environmental rights trading market, the joint carbon emissions permits and energy consumption permits market will significantly increase the operating costs of enterprises and the management costs of the government. Participating in the joint market requires enterprises to increase human resources, transaction, and verification costs, which increases their operating costs. Moreover, as the ECPTS is still in its infancy in China, the government's implementation and

system design costs are high. If an ECPTS is implemented alongside a carbon market, it may create problems such as overlapping management.

In summary, considering the economic and environmental benefits and the cost of market construction, we believe that cultivating and improving a separate carbon market has a higher input-output effect. The implementation of a separate carbon market can achieve low-carbon-related goals while also ensuring growth in terms of economic and social welfare. Additionally, we also simulate the changes in economic and environmental effects of the two local pilot markets, taking Shanghai and Fujian Province as examples, respectively. The calculated findings are consistent with the national macro-level results, indicating the robustness of the conclusions. Considering the cost input of enterprises and governments, the high operational and management costs can limit the effectiveness of the policy in a joint market. Therefore, we recommend improving a separate carbon market as it has a higher input-output effect. In light of this, we recommend the following policies.

Each pilot region in China should prioritize the development of the carbon market to provide a reference for the national carbon market. In the initial stage, reductions in core costs will help to increase the carbon market's size. The government should minimize the direct costs incurred by enterprises through participating in the carbon market to increase the incentive for participation. For example, the simplification of data submission and registration processes will help to achieve this. Additionally, we need to reduce the government's internal management costs. For instance, by accelerating the process of carbon trading legislation, standardizing the carbon emission data supervision system, and implementing a whole-chain management system from data collection and statistics to accounting, we could improve data management efficiency.

Considering the high costs required for building a joint market, we suggest avoiding the rapid expansion of the pilot scope of energy consumption permits. Departments should summarize their experiences of ECPTS, including the allocation method, trading scope, and reward and punishment principles. This will help to improve the top-level design of, and supporting policies for, energy consumption permit trading. Moreover, they should also summarize the problems encountered in the pilot work to reduce resource waste.

6. Limitations and Future Research

The primary data used in this paper, namely, carbon emissions and energy consumption data, were obtained from CEADs for the period of 2010–2019. However, there are limitations in terms of data timeliness. To address this limitation, we will collaborate with the CEADs research team to access and utilize the most current data available in our future research.

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