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A Dynamic and Continuous Allowances Allocation Methodology for the Prevention of Carbon Leakage: Emission Control Coefficients

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ABSTRACT: Carbon leakage has become the core issue of emission trading systems. Using data from Hubei Province, this paper identifies the drawbacks of the prevailing methods for preventing carbon leakage and proposes a new methodology to overcome them, namely, Emission Control Coefficients. In contrast to the common tiered structure method, we found that Emission Control Coefficients generate a dynamic and continuous emission control coefficient for each industry which will improve the effectiveness and fairness of allowance allocation, set aside sufficient time for the low carbon transformation of industries, and balance the needs to protect competitiveness and decarbonize and are particularly suitable for the emission trading systems of developing counties. This paper makes three main academic contributions: Firstly, this paper proposes a new indicator, the abatement potential. Secondly, this paper better distinguishes industrial differences. Thirdly, this paper can better respond to the problem of excess allowances due to technological advances and trade pattern changes.

Key words: emissions trading system; competitiveness; carbon leakage;

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allowance allocations; developing countries;

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1. Introduction

Emission Trading Systems (ETS) are used to minimize the cost of reducing CO_2 emissions. However, carbon leakages may occur if some countries and regions do not introduce comparable policies, and this will lead to imbalances in carbon constraints in different countries (IPCC, 2007). Given that CO_2 emissions in countries with carbon constraints will decrease, global CO_2 emissions will not necessarily fall since CO_2 emissions in countries without carbon constraints will increase, and make the ETS ineffective. Stakeholders, especially emission-intensive industries under ETS' and carbon tax schemes, have expressed concern about the implications of ETS' when they compete with firms located in jurisdictions without carbon constraints. Policy makers often use Border Tax Adjustments (BTA)[†] and Free Allowances (FA) to reduce the risk of carbon leakages when designing an ETS. BTAs theoretically perform best with respect to carbon leakage prevention and incentives for emissions reduction, but they face political and legal challenges. In reality, the most commonly applied method for preventing carbon leakages is the FA (Marcu et al., 2013).

FAs that have been in discontinuous use and have become outdated have caused partial failure of ETS'. Fox example, when determining which industries should be subjected to carbon leakage risk, the European Union's ETS uses a simple dichotomy classification and historical data which result in excess allowance supply, and

[†] Border Tax Adjustment (BTA), which would impose a carbon price on importers and refund the carbon price to exporters.

consequently a low carbon price: a reason that symbolizes the failure of the EU’s ETS (Clò, 2010; Crossland et al., 2013). Outdated data also ignore technological progress and changing trade patterns. Other major ETS’, such as in California, Australia, New Zealand and South Korea, have all introduced policies aimed at the prevention of carbon leakages (World Bank, 2015), which are basically the same as the EU’s ETS and thus suffer similar problems.

However, the policy makers and market participants will never be able to perfectly anticipate in advance the future developments which will determine the actual constraint. Thus, the prices can hardly be maintained at desirable levels (de Perthuis and Trotignon, 2014) and this constitutes another important lesson from the EU’s ETS. As a matter of fact, the difficulty in maintaining desirable prices in trading schemes is not peculiar to the EU’s ETS. In the Regional Greenhouse Gas Initiative of the US, emissions were lower than previously anticipated due to low natural gas prices prompting a conversion to the lower-emitting fuel.

When China launched its nationwide ETS on 19 December 2017, it was able to draw lessons from other ETS’ and thereby improve the allowance allocation method. The Chinese national ETS faces many challenges that have not been seen in other ETS. Firstly, China has been emphasizing carbon intensity targets, not absolute emission reduction targets in its Intended Nationally Determined Contributions (INDC) (NDRC, 2015). Consequently, China's cap needs to be converted and will have to be flexible. Secondly, with the ongoing structural reforms on the supply side, China's economic is undergoing rapid transformation. Therefore, China’s ETS must have a dynamic mechanism of allowance allocation which will provide great flexibility in dealing with the uncertainty from structural change(Sun et al., 2016). Thirdly, China’s national ETS also needs to introduce an innovative method to manage two conflicts of interest: On the one hand, if China wants its ETS to stimulate investment in low-carbon technologies, it will have to maintain relatively high carbon prices. On the other hand, China needs to protect its carbon-intensive industries which still have important roles in the national economy.

Rather than simply adopting the policies of developed countries, China must design its own allowances allocation methodology. Otherwise, it will not only face the dilemma of the collapse of carbon prices, as happened with the EU ETS, but also not cope with China's particular problems. Beyond the typical concerns of most developed countries, China's carbon leakage prevention policy must consider abatement potential in order to remove outdated firms and industries, a priority of the current government(State Council, 2013). The Chinese situation is similar to that in other developing countries. Hence China's carbon leakage prevention policy is of high reference significance for developing countries.

This paper innovatively proposes Emissions Control Coefficients (ECCs) under China's national ETS for the prevention of carbon leakages. It aims to calculate ECCs for each industry to determine its free allowance proportion. It would seem that ECCs have real policy relevance for China and other developing countries as an alternative carbon leakage prevention policy.

The remainder of this paper is organized as follows: Section 2 reviews the existing literature and policies on carbon leakage, Section 3 analyses major problems with the current FA methods, and Section 4 discusses the proposed methodology and explains the construction of the three indicators and how the three indicators are integrated to set up the ECCs. Using Hubei Province data, Section 5 demonstrates how to apply the ECCs and explains their relative advantages compared to the existing FA methodology. Section 6 concludes the paper with policy implications.

2. Literature Review

Preventing carbon leakages is a core issue in any ETS design. Asymmetric carbon constraints between countries can alter the competitiveness of industries and lead to carbon leakages, which can greatly reduce the environmental contribution of an ETS and damage ETS countries' welfare. In the case of the EU's ETS, the carbon leakages and negative effects on competitiveness have been quite serious (Antimiani et al., 2016). The metal and chemical industries present the highest leakage rates. In California, the carbon market there is leaking 33.5-58.9 million tons of CO_2 through 2020 (Cullenward, 2014). In recent years the problem of carbon leakages from industries has been widely addressed in the literature (Bednar-Friedl et al., 2012; Fischer et al., 2017). The competitiveness channel is the main source of carbon leakage, while the demand channel is smallest ones(Tan et al., 2018).

Broadly, there are two main instruments to avoid carbon leakages. One instrument is to set up a system of BTAs, which impose the carbon cost on importers and refund the carbon cost to exporters. Therefore, they are often perceived to be more effective at reducing leakage (Caron, 2012). Firm-targeted carbon tariffs deliver larger leakage reduction and global welfare gains (Böhringer et al., 2017). The policy of combining a consumption tax and an output-based rebate can be equivalent to a border carbon adjustment and is a robust policy to mitigate carbon leakage. However, BTAs may impede domestic industrial decarbonisation (Schinko et al., 2014). For example, with a BTA on clinker, companies directly import cement from no ETS area in the EU ETS (Allevi et al., 2017). The effectiveness of carbon tariffs in reducing carbon leakage is limited(Antimiani et al., 2013), and BTAs are not optimal policy tools to address carbon leakage concerns (Sakai and Barrett, 2016).There are some problems that make the BTAs relatively less practicable as they create the potential for conflict with the WTO and other free trade rules(Rocchi et al., 2018). The policy makers should evaluate the effectiveness of border adjustments from both perspectives of forward and backward industrial linkages and especially focus on the sectors with a greater level of global production fragmentation (Zhang and Zhu, 2017).

The other instrument is providing a FA for controlling emissions companies. This has emerged as the preferred and practical method for preventing the risk of carbon leakages. The most salient example of the use of FAs is within the EU's ETS where the method of preventing carbon leakages is to list risk industries according to their cost intensity and trade intensity (Monjon and Quirion, 2011). On the risk list, in principle, industries are eligible to receive 100% of the FAs. For industries not on the risk list, the proportion of FAs is to be gradually reduced. In 2013, the proportion was 80% and it is to be reduced by 30% every year to 2020. The FA instrument in general many have a limited effect and thus proper design is needed. If the allocation of FAs is phased out too rapidly, firms in regulated industries may enjoy the benefits of an initially generous policy, but do not invest enough in abatement equipment to render the option to stay in their home-country (Martin et al., 2014; Schmidt and Heitzig, 2014). Research on the US carbon market shows that freely allocating fewer than 15% of the emission allowances generally suffices to prevent profit losses in the most vulnerable American industries. Freely allocating all of the allowances substantially overcompensates these industries(Goulder et al., 2010).

There are also many questions and criticisms about the free allocation of allowances. Increasing the share of free allocations for emission allowances, as opposed to auctions, has no effect on environmental quality but reallocates resources among firms toward the most productive ones which has an impact on firms' entry and exit decisions, the mass of firms, and the composition of the market (Anouliès, 2017). In the EU ETS, grandfathering of EUAs can turn a penalization for carbon intensive industries into an incentive (Falbo et al., 2013). This might call for a sectorial- and country-differentiated anti-leakage risk policy. A sensitivity analysis suggests stronger leakage protection measures for coastal areas than in landlocked areas because they are well protected by transport costs(Meunier et al., 2014). The competitiveness of the steel sector seems to be better protected against the impact of the EU's ETS. For the oil refining sector, it seems that, again, freely allocated allowances as proposed by the EU policy would not be justified, and that different countries and industries, with different industry structures and costs, will be subject to different degrees and types of leakage risks (Santamaría et al., 2014). Free allocation not only foregoes the opportunity to raise revenue, but can also introduce a number of efficiency and fairness concerns (Burtraw and McCormack, 2017).

There is a growing number of studies on ETS designs for China, from either the subnational (sectorial or regional) level or the national level. Xiong et.al, (Xiong et al., 2017) examined China's allowances mechanism from two aspects: allowance allocation and allowance distribution, through comparing China's carbon trading pilots with the EU's ETS and California's Cap and Trade Program. Following the launch of China's pilot ETS projects in 2011, some scholars have focused on the design of the regional ETS' in specific provinces or cities (Li and Lu, 2015; Qi et al., 2014). The initial allowance allocation under a certain abatement target would hardly affect sectoral production but remarkably affect trade behaviors in the carbon trading markets in China (Yu et al., 2018).The best choice of ETS allowance allocation scheme in the electricity sector would be the scheme that is based on historical emission intensity(Lirong et al., 2018).

Few studies have been carried out which examine sector competitiveness in China. Wang et al. (Wang et al., 2017) analyzed potential carbon leakage risk within and outside an ETS and found that six four-digit industries will be exposed to carbon leakages under a regulated electricity pricing mechanism, and the leakage could be serious if the percentage of auctioning increases or if the electricity market is liberalized in the future (Long et al., 2018; Wang et al., 2018). Zhu et.al. (Zhu et al., 2017) demonstrated that the allocation of FAs can cause a competitiveness distortion among normal and outdated capacities. Given the government's intentions to remove outdated capacity and to upgrade production technology, an output-based allocation approach is suggested for China's iron and steel sector. Lin et.al. (Lin et al., 2015) suggested that the electricity industry should be given FAs and at the same time the price of electricity should be kept constant in order to maintain a balance between CO_2 emission reduction and industry upgrading. The research on the evaluation of carbon leakage channels shows that the competitiveness channel is the main source of leakage and that the energy channel is modest due to limited energy price fall (Xiujie et al., 2018).

Through reviewing the literature, we find that the existing research mainly includes: the measurement of the carbon leakage degree in developed countries, and the design of carbon leakage prevention policy and its implementation effect evaluation, the design of China's ETS and its economic impact and the impact of China's ETS on industry competitiveness and other aspects. Therefore, there are still some gaps that need to be made up: (1) There is no relevant research on solving the industrial inequities brought about by the dichotomy of the carbon leakage policy. (2) There is no relevant research for solving the problem of excessive allowances and price collapse caused by the non-dynamic adjustment of the carbon leakage policy.

(3) Most of the existing research does not aim to formulate a carbon leakage policy for applicability to the ETS' of developing countries.

Based on China's actual situation, this paper proposes a carbon leakage prevention policy. This paper makes three main academic contributions: Firstly, different from the FA in the EU and other prevailing ETS' that include two indicators, this paper proposes a third indicator, the abatement potential, which gives industries with higher emission intensities a higher pressure to reduce emissions and encourage these industries to catch up with the reference group. Secondly, this paper breaks the widely used "dichotomy" categories applied by industries to determine the percentage for FAs, and forms a continuous value. It is thus better able to distinguish industrial differences and avoid inequality between industries in and out of the risk groups. Thirdly, ECCs can better respond to technological advances and trade pattern changes and thus balance the need to protect industrial competitiveness with the incentive to decarbonize, which is more applicable to the ETS' of developing countries.

3. Problems with Current Carbon Leakage Prevention Policies

The most common carbon leakage prevention policies in the world have a tiered structure, such as the EU's ETS, in which there are only minor differences in the selection of the indicator, calculation formula, and number of tiers. Policy makers must make a judgment as to how to determine the relevant eligibility and assistance thresholds. Two main indicators: carbon intensity and trade intensity have been generally used, either in isolation or combination. There are no significant differences between ETSs with respect to how activities or industries that are at risk of carbon leakage are identified. The European, Californian, Australian and Korean ETS' all use criteria based on trade intensity and energy or carbon intensity to identify industries at risk. However, a wide variety of thresholds and definitions are used. Carbon intensity captures the impact that carbon pricing has on a particular firm or sector, and it is measured as the volume of emissions per unit of output, revenue, value added, profit, or other similar economic metric (the term emissions intensity can be used interchangeably). Trade intensity can be thought of as a proxy for the ability of a firm or sector to pass on costs without significant loss of market share. In Table 1, we summarize the main policies currently used in various ETS' under the FA allocation.

In the existing policy, industries are often classified into either two or three categories in terms of significance of carbon leakage that is measured by two indicators among cost intensity, trade intensity and carbon (energy) intensity. The third phase of the EU's ETS used two indicators, namely cost intensity and trade intensity from 2009 to 2011, to divide the industries into two categories: risk and no risk. The risk industries are to receive 100% FAs until 2020 and more than 83% of the Phase 3 FAs will be granted to installations deemed to be at a significant risk of carbon leakage. In its Proposal for Phase 4, the EU's ETS will employ better targeted carbon leakage rules and split industries into three categories: "very high", "high" and "medium". Once an industry classification is confirmed it will remain unchanged for five years. This combination of trade exposure and emissions intensity can also be found in California's ETS, which then leads to a classification in three categories: high, medium and low leakage risk [29]. The Australian ETS divided industries into two categories, namely, emissions intensity and trade exposure. However, its industry must be qualified as trade-exposed before an emissions-intensity criterion is applied for further classification. On the basis of these two criteria, industries are then categorized as either highly or moderately emissions-intensive activities in Australia's ETS. Differing from the EU's ETS, the level of emissions intensity in Australia's ETS is not based on production costs, but is instead calculated as either tons of emissions over revenue or tons of emissions over value added. New Zealand's ETS also uses a measure of revenue to define emissions intensity. If an emission-intensive industry is not trade-exposed, it will need to purchase allowances. In the case of a trade-exposed and emission-intensive industry, it will receive FAs. The Korean ETS divides industries into two categories: energy-intensive and trade-exposed (EITE), and not EITE. Each classification leads to a specific level of FAs and the levels are diversified among countries (Table 1).

As the world's first carbon market, the EU's ETS has accumulated extensive experience in the design and operation of carbon leakage prevention policies, but there are also many problems, so it has been widely criticized. However, the criticism suggests that the methodology of the ETS Directive 2009/29/EC, which amended the first ETS Directive 2003/87 2009/29/EC was politically driven with highly arbitrariness and inefficient criteria to assess which industries are exempted from auctioning, thus causing unfairness (Clò, 2010). The first problem is about the reference price and reference periods. When the Commission calculated the appropriate level of protection against carbon leakages, it used a reference carbon price of EUR 30/tCO2. In the third phase up to 2017, carbon prices were consistently below EUR 7/tCO2. The reference periods were 2005-2007 for the carbon leakage list applied during 2013-2014, and 2009-2011 for the carbon leakage list applied from 2015 to 2019. The fixed reference period did not reflect the changes that have taken place in technologies and the global patterns of trade during the actual times. The second most criticized aspect has been using tiered criteria for the classification of industries because it results in significant inequities. For example, according to the EU's ETS policy, if industry A has a trade intensity of 30% and industry B has a trade intensity of 29%, then industry A will receive 100% FAs in 2020 and industry B will receive only 30%, leading to serious inequality in the competitiveness between the two industries(Clò, 2010).

Table1 Policies Responses for the Prevention of Carbon Leakages

Scheme Name	Indicators	Data	Adjustment Period	Tiered Structure	Free Allowance Percentage
EU ETS III	CI and TI	2009-2011 Price: EUR 30/tCO_2	5 year	risk list not risk list	**on risk list**:100%; **not on risk list**: 80% in 2013, reach 30% in 2020.
California (2015-2017)	EI and TE	2013–2017	2 year	high risk medium risk low risk	**high risk:**100%; **moderately risk:** 75%; **low risk:** 50%
Australia	EI and TE	2006–2008	undisclosed	highly exposed moderately exposed	**highly exposed:**94.5%; **moderately exposed:**66%
New Zealand	EI and TE	2006–2008	3 year	highly EIA moderately EIA (Emissions-Intensive Activities)	**highly EIA:** 90%; **moderately EIA:**60%
South Korea	EI and TE	2011–2013	undisclosed	EITE not EITE (Energy-Intensive and Trade-Exposed)	**EITE:**100%; **Not EITE:**97% in Phase II (2018-2020), and 90% in Phase III(2021-2026)

Notes：CI: cost intensity, TI: trade intensity, EI: emissions intensity, TE: trade exposure.

The main program with the tiered criteria to classify industry is illustrated in Figure 1. In Figure 1, the industries are classified according to two categories: cost intensity (CI_1) and trade intensity (TI_1). In the EU's ETS, industries where the CI or TI fall into the A (A_1+A_2), B (B_1+B_2) and C (C_1+C_2+C_3+C_4) areas are included in the carbon leakage risk list. If $\mathrm{CI}_0 \leq \mathrm{CI} < \mathrm{CI}_1$ and $\mathrm{TI}_0 \leq \mathrm{TI} < \mathrm{TI}_1$, industries where the CI or TI fall into the D area will also be included in the carbon leakage risk list. In contrast, industries which fall into the E（E_1+E_2+E_3）area are not identified as carbon leakage risk. Obviously, this discontinuous classification method will bring unfairness among industries E and others.

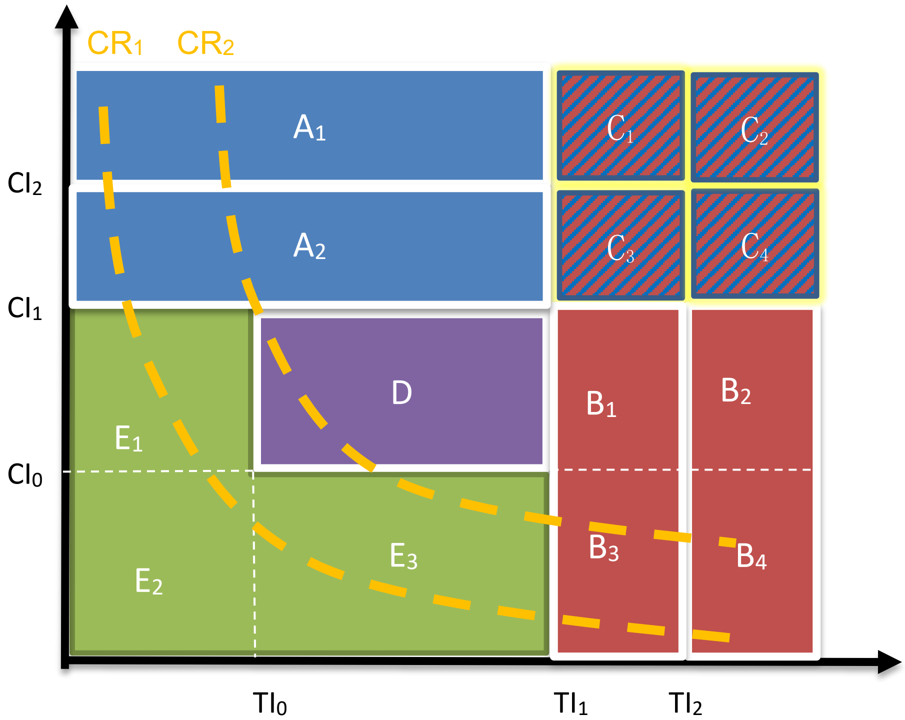


Figure1 Tiered structure and criteria

The EU's ETS in phase IV (2020-2030) will split leakage risk into three tiers: "very high", "high" and "medium" and use a single indicator calculated by multiplying emissions intensity with trade intensity, which is called a Classification Reference (CR). As shown in Figure 1, the industry will be categorized into three categories with CR_1 and CR_2, those for the low risk industries below the CR_1 curve, those for medium risk industries between CR_1 and CR_2, and those which are higher than CR_2 for high risk industries. Although this reform reduces the unfairness in allowance allocation among industries, it still cannot fundamentally solve the inequality issues for industries that are on different sides but close to the boundary.

Since all the major ETS' adopt the tiered structure, they face the same problems. For example, California's ETS classifies leakage risk into three categories through combining the metrics of emissions intensity and trade exposure. It uses a more complex classification method: on the one hand, unlike the EU's ETS, which divides

CI and TI into only two segments with CI_1 and TI_1 , California's ETS divides CI and TI into three segments with CI_1, CI_2, TI_1, and TI_2 (Figure 1). On the other hand, California's ETS gives a higher priority logic for emission intensity. The emission intensity can directly determine which industry type is included, but trade intensity needs to be combined with emission intensity to make judgments, which involve minor logic. In order to demonstrate more fully the classification method of the California ETS, we further divide the B and C area of Figure 1 into four parts. According to the classification method of California's ETS, A_1, C_1 and C_2 are directly identified as high-risk industries due to their position above CI_2. However, despite falling to the right of TI_2, only C_4 will be identified as high-risk industries, while B_2 and B_4 will not be considered as high-risk industries. They will instead be considered as medium and low risk industries, respectively.

Furthermore, at the industry level, the impacts of economic fluctuations, technological advances and trade pattern changes are significant, resulting in significant changes in the cost constraints of ETS' on industries over time, and thus further undermining the fixed reference base analysis. In addition, the data used in the classification of industries are old and there is a lack of a dynamic adjustment mechanism. This exposes failure risks to carbon leakage policies due to their excessive cost constraints on some industries and loose cost constraints on others, further creating a new industrial competitiveness distortion.

4. An Alternative Method: Emission Control Coefficients (ECCs)

The fundamental function of an ETS is to encourage enterprises to carry out R&D and investment in low-carbon technologies through market-oriented means, in order to achieve emission mitigation targets at the lowest cost. However, there are differences in many aspects including trade intensity, cost intensity and abatement potential between industries, resulting in the presence of imbalanced and uneven impacts in all industries imposed by the ETS. These, in turn, could cause unfairness among industries as in the EU's ETS. A carbon intensive but economically important industry could be disadvantaged and even destroyed by carbon prices. Therefore, different industries should be given different treatments in determining the proportion of free allowances in order to reflect the industries' differences more accurately.

To overcome the problems in the current and prevailing carbon leakage policies, we propose an alternative method for the Chinese national ETS, that is, ECCs. EECs have three indicators. The first two, cost intensity and trade intensity, are commonly used in other ETS' in developed countries. The third is the abatement potential (AP) indicator to dynamically reflect the gap between the technological level of an industry in developing countries and the reference case, such as the world advanced level. The AP indicator is a specific indicator for developing countries. Unlike developed countries, the technologies used by intensive carbon industries in developing countries are still at the middle and lower levels and thus need time to transfer into low-carbon modes. However, just like trade protectionism, an ETS cannot provide indefinite protection to the industries. Thus, the carbon market needs to gradually increase the strictness of cost constraints to push these industries towards low carbon modes.

4.1 The advantages of ECCs

The proposed ECCs have three advantages: 1) the classification of industries is based on a continuous value; 2) the allocation method can be dynamically adjusted; and 3) the cost constraint tightens incrementally. A more detailed discussion of each of the goals is given below.

First, the continuous ECCs can effectively overcome the drawbacks of the tiered structure by giving each industry a unique emission control coefficient based on its characteristics. This method can accurately distinguish differences between industries and thus avoid a greater impact on the competitiveness of an industry. Continuous ECCs can also improve the fairness of allowance allocations, reduce the quantity of invalid FAs and increase the effectiveness of carbon price signals, so as to better encourage enterprises to invest in low carbon technologies.

Second, ECCs dynamically adjust by updating the indicator values instead of using a fixed value for a certain year to reflect changes in the characteristics of the industries in a timely manner, further improve the effectiveness of allowance allocations to avoid carbon price collapse as in the EU's ETS, and raise the effectiveness of carbon price signals.

Thirdly, ECCs introduce a gradual tightening process instead of a quick and hurried one. The AP indictor will give consideration to the different abatement potentials of different industries and ensure there will be no big bang for any industry. They can also be consistent with governments which may prefer to keep some energy intensive industries for economic reasons at a particular stage of economic development. In this methodology, the advanced industries will be given smaller abatement pressures; and conversely outdated industries will be given more pressure to reduce emissions. This is to reflect the technology gap between assessed industries and their global frontiers. For those industries that have a carbon intensity that is close to the advanced world's level, the limited abatement potential will be recognized by allocating more FAs compared to those further away from the frontier. Moreover, with respect to the AP indicator, while leaving time for the industry, it also clearly signals the gradual tightening of cost constraints to stimulate industries to effectively reduce emissions. In the Chinese context, the AP indicator functions like industrial policies and coincides with the supply-side structural reforms carried out by the state such as done in the coal industry (Shi et al., 2018).

4.2 Calculation of the three indicators

Due to the dynamic characteristic of ECCs, the indictor will be industry specific and time varied. Thus, each indictor is indexed by industry, i , and year, t .

4.2.1 Trade Intensity (TI)

TI mainly reflects the competition pressures that an industry faces in international trade. The larger the value, the greater the international competition it faces and the lower its ability to pass through carbon costs, and thus the greater the risk of carbon leakages. Therefore, an industry of this sort should receive a larger proportion of free allowances. Conversely, the smaller the value is, the lower the percentage of FA should be given. For example, the power and cement sectors' TIs are very low. Thus, they should be granted a smaller proportion of FA. Otherwise, just as in the first phase of the EU's ETS, the power and cement sectors will gain an enormous amount of windfall profits (Darby, 2016; Sijm et al., 2006). In the proposed methodology, we adopt the EU's ETS trade intensity calculation method, as follows:

$$TI_{it} = \frac{\text{exports}_{it} + \text{imports}_{it}}{\text{total industrial output}_{it} + \text{imports}_{it}} \quad (1)$$

The trade intensity is calculated at the industrial level. Each index in this formula refers to one industry's index, e.g. exports refer to one specific industry's exports.

4.2.2 Cost intensity (CI)

CI reflects the cost pressure imposed by an ETS on industries. Unlike most other ETS' that use emission intensity instead of CI, we argue that only the combination of emission and price can reflect the real cost constraints that firms face. Therefore, we again adopt the EU's ETS formula which considers both emissions and carbon prices. However, instead of using a fixed carbon price of 30 euros, we suggest using the average annual carbon prices in the previous year which can better reflect the reality of the industries' cost constraints. The industry specific CI is calculated as follows:

$$CI_{it} = \frac{\text{industry's carbon emissions}_{it} \times \text{annual average Carbon price}_{t}}{\text{indusry's value added}_{it}} \quad (2)$$

The larger the value of CI, the greater the impact of the ETS on the industry and the greater the risk of carbon leakages. Therefore, this industry should receive more free allowances.

4.2.3 Abatement Potential (AP)

AP measures the abatement potential of an industry, which is represented by the ratio of carbon intensity between the assessed industry's value and the reference value. The reference value can take different values according to the actual situation. For example, a regional ETS can take the nation's average or advanced level of this industry; and a national ETS can take the international advanced level in this industry. With the greater AP and lower marginal abatement costs, an industry should receive fewer FAs in order to increase its cost constraints and push it to upgrade its technologies. The industry specific formula for the AP in industry i and year t is as follows:

$$AP_{it} = \frac{\text{carbon intensity}_{it}}{\text{reference value}_{it}} \qquad (3)$$

If the AP is less than 1, the industry's abatement technology is more advanced than the reference value, indicating it has a low AP and thus a high marginal abatement cost. This industry should receive a high proportion of FAs in order to reduce its cost constraints. On the country, if the AP is greater than 1, the industry's abatement technology is outdated.

4.3 Construction of ECCs

This section of the paper introduces ECCs for each industry in the initial allowances allocation scheme through integrating the three indicators. This is done so as to fully reflect the impacts imposed by an ETS, improve the effectiveness and fairness of the allowance allocation, maximize the incentive effects, and avoid carbon leakages. An ECC is a continuous coefficient between 0 and 1. The larger the ECC, the more FAs an industry should receive; the smaller the ECC is, the fewer FAs it should receive. According to the average GDP growth rate and the carbon intensity target, and taking into consideration different industries' trade intensities, cost intensities and abatement potentials, the ECC for industry i at year t is calculated using the following steps:

Step 1: Standardization of TI, CI and AP. In order to permit the normalized indicators to have the same direction trade intensity and cost intensity so as to adopt reverse standardization, and permit abatement potentials to adopt positive standardization, the following calculations must be performed:

$$STI_{it} = (TI_{max} - TI_{it}) / (TI_{max} - TI_{min}) \qquad (4)$$

$$SCI_{it} = (CI_{max} - CI_{it}) / (CI_{max} - CI_{min}) \qquad (5)$$

AP_{it}= $(AP_{it}-AP_{min})/(AP_{max}-AP_{min})$ (6)

Where max is the maximum value of the sample data and min is the minimum value of the sample data. STI_{it}, SCI_{it} and SAP_{it} represent standardized TI_{it}, CI_{it} and AP_{it}. After standardization, the values of the three indicators are all between 0-1 so that they can be compared with each other: the standardization still preserves relative performance gaps between industries after standardization (Zhou et al., 2017).

Step 2: Determine the Average Emissions Decreasing Rates (AEDRs). According to the forecasting growth rate of GDP and the INDC target, governments will determine an annual national target for carbon intensity reduction rate, namely the $AEDR_{jt}$. This is a factor useful for developing countries where the INDC is a relative intensity target rather than an absolute emissions reduction. As a result, the caps will be different every year, and may increase or decrease, depending on the total carbon emissions and economic growth rate.

Step 3: According to the $AEDR_{jt}$, the calculated decline coefficients for STI_{it}, SCI_{it} and SAP_{it} and respectively get $TIDC_{ijt}$, $CIDC_{ijt}$, and $APDC_{ijt}$, which represent the rate of carbon emissions reduction that needs to be achieved in the i-th industry under the j-th AEDR scenario in period t. It is calculated as follows:

$$TIDC_{ijt}=n \times AEDR_{jt} \times \frac{STI_{it}}{\sum_{i=1}^{n} STI_{it}} \quad (7)$$

$$CIDC_{ijt}=n \times AEDR_{jt} \times \frac{SCI_{it}}{\sum_{i=1}^{n} SCI_{it}} \quad (8)$$

$$APDC_{ijt}=n \times AEDR_{jt} \times \frac{SAP_{it}}{\sum_{i=1}^{n} SAP_{it}} \quad (9)$$

Among them, n is the total number of industries covered by ETS, i values 1, 2, ..., n, representing the industry, j values 1,2, ..., m, representing different $AEDR_t$.

Step 4: Assign the weights to three coefficients, and compute the comprehensive decline coefficient for each industry (CDC_{ijt}):

$$CDC_{ijt} = \alpha \times TIDC_{ijt} + \beta \times CIDC_{ijt} + \gamma \times APDC_{ijt} \qquad (10)$$

α, β and γ represent the weighting factors, respectively, and their values need to be determined by the decision makers according to their policy preferences.

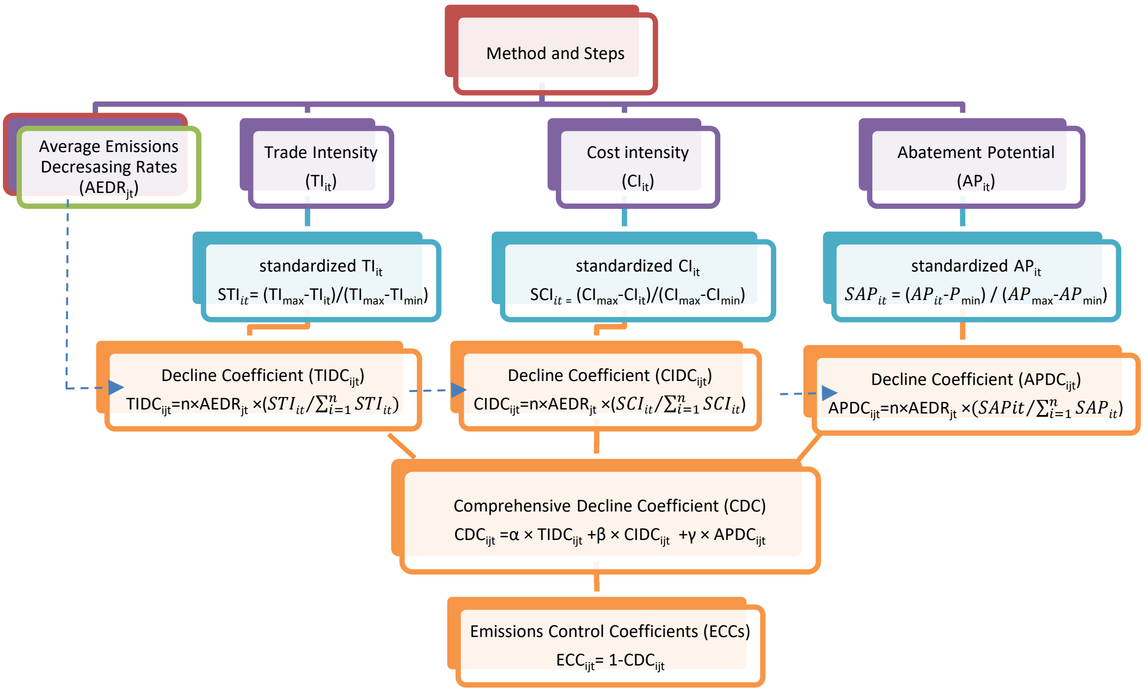
- *If more emphasis is given to the international competitive pressures, decision makers can give greater weight to TIDC.*
- *If more emphasis is given to cost constraints, decision makers can give greater weight to CIDC.*
- *If more emphasis is given to the abatement potential, decision makers can give greater weight to APDC.*

In fact, as shown in Table 1 and Figure 1, when considering indicators, decision makers must consider the priority logic or weight. For example, the EU's ETS gives CI and TI the same weight, but California's ETS gives CI absolute logical priority. In the ECC method, this is also an unavoidable problem. According to the actual situation, decision makers need to determine an appropriate weight value for TIDC, ACDC, and APDC.

Step 5: Convert CDC to Emissions Control Coefficient (ECC_{ijt}) for each industry. The CDC represents the proportion of emissions that each industry needs to reduce. But to enable ECCs to be used directly for allowance allocation systems, we also need to do some conversion:

$$ECC_{ijt} = 1 - CDC_{ijt} \qquad (11)$$

In Figure 2, we summarize the complete computational process of ECCs in a logical order. See Figure 2 for details.



Notes: The definitions of trade intensity, cost intensity and abatement potential are detailed in Section 4.2. This figure demonstrates how to use these three independent variables to form a weighted average value, that is, the ECC.

Figure 2. The Calculation Steps for Emissions Control Coefficients

5. A case study of Hubei Province

Based on the above formula, we use data for Hubei Province and China to calculate the ECC for each of the 16 industries covered by Hubei's ETS, and test the applicability of the ECC. Hubei Province, located in central China, was designated as one of seven locations for ETS pilots in China. Hubei Province is in the late stages of industrialization. Similar to many developing countries, its heavy industries have played a very important role in its economy.

5.1 Data

In the calculation of CI, the CO_2 emissions of each industry are equal to the quantity of an industry's energy consumption multiplied by the emission factors. Since the *Hubei Statistical Yearbook* reports only four kinds of energy consumption– raw coal, gasoline, diesel, electricity– this paper considers only four kinds of energy consumption. Among them, raw coal, gasoline and diesel emit direct emissions from industries, while electricity emits indirect emissions. The emission factors of raw coal, gasoline, and diesel are sourced from the IPCC (IPCC, 2006). The emission factor of electricity is taken from the *Central China Power Grid* published by the Climate Department of the National Development and Reform Commission. Following the launch of Hubei's ETS on 2 April 2014, 30 June has been designated Hubei's ETS Performance Date. The 2015 carbon price was set as the average price from 2 April 2014 to 30 June 2015, at 20.41 yuan/ton. The 2016 carbon price was set as the average price from 1 July 2015 to 30 June 2016, at 24.30 yuan/ton. The industry added value data is from the *Hubei Provincial Input-Output Table* and *Hubei Statistical Yearbook* compiled by the Hubei Provincial Bureau of Statistics and Hubei Provincial Input-Output Office. Likewise, for the calculation of TI, the import, export and total output data of various industries were obtained from these publications. The market competition pressure of an industry in Hubei Province is not only from the same industry globally, but also from the same industry in other regions of China. However, due to limited data availability, in the Hubei case study we did not take the trade between Hubei and other provinces of China into account. Furthermore, to keep the methodology applicable at the national level, which is the most likely application scenario, we only measured competition from international trade.

In the calculation of the AP, for Hubei Province's industry i, we chose average carbon intensity of national industry i as the reference value to estimate the AP. In order to be comparable with the data of Hubei Province, only four kinds of energy consumption －raw coal, gasoline, diesel, electricity －were measured in the calculation of CO_2 emissions from national industries using the emission factors of the IPCC (IPCC, 2006). The emission factor of electricity was also taken from *State Grid* published by the Climate Department of the National Development and Reform Commission. The energy consumption data comes from the *China Energy Statistical Yearbooks* and the output value of each industry comes from the *China Industrial Statistical Yearbooks*.

5.2 The three indicators

In this subsection, we briefly introduce the calculation results for the three indicators. From Table 2, we see that Hubei's ETS did not put a lot of cost pressures on the industries: the highest cost intensity was less than 5% and only five industries had a cost intensity of more than 1%. However, there are still obvious inter-industry differences. For example, the highest cost intensity of 'Production and Supply of Electric Power and Heat Power' was 24 times that of the lowest cost intensity of 'Processing of Food from Agricultural Products'.

Among the 16 industries covered by Hubei's ETS, the industry with the highest trade intensity was 'Oil and Natural Gas industries', and the lowest trade intensity industry was 'Production and Supply of Electric Power and Heat Power'; the former was 26 times that of the latter. Although there was a big difference in trade intensity between different industries, the overall trade intensity among the industries in Hubei Province was relatively low. Only five industries' trade intensity was more than 30% and six industries had a trade intensity of less than 20%.

The carbon intensity of nine industries in Hubei Province was higher than the national average, and the carbon intensity of seven industries was lower than the national average. The carbon intensity of 'Extraction of Petroleum and Natural Gas', 'Manufacture of Medicines', etc. was much higher than the national average, but the carbon intensity of 'Production and Supply of Electric Power and Heat Power', 'Smelting and Processing of Ferrous Metals' and other intensive carbon industries was much lower than the national average. The highest, 'Extraction of Petroleum and Natural Gas', was 8.9 times that of the lowest, 'Smelting and Processing of Ferrous Metals'. Calculation results show that many industries in Hubei Province still have a great AP, compared with the national average carbon intensity.

Table 2 Results of CI, TI and AP for industries in Hubei Province (2016)

Industries	CI（%）	TI（%）	AP
Extraction of Petroleum and Natural Gas	0.53	53.37	2.93
Manufacture of Automobiles	0.19	23.28	1.41
Manufacture of Chemical Fibers	1.45	35.19	1.8
Manufacture of Foods	0.56	24.54	1.92
Manufacture of General-Purpose Machinery	0.22	45.04	0.7
Manufacture of Medicines	0.33	16.71	2.27
Manufacture of Metal Products	0.43	20.5	0.82
Manufacture of Non-metal Mineral Products	2.24	14.25	1.04
Manufacture of Paper and Paper Products	0.65	15.98	0.68
Manufacture of Chemical Raw Materials and Chemical Products	2.62	29.12	1.56
Manufacture of Wine, Beverages and Tea	0.2	16.72	1.13
Processing of Food from Agricultural Products	0.19	6.86	1.07
Processing of Petroleum, Coking and Nuclear Fuel	0.32	36.51	0.8
Production and Supply of Electric Power and Heat Power	4.63	2.04	0.57
Smelting and Processing of Ferrous Metals	2.24	25.5	0.33
Smelting and Processing of Non-ferrous Metals	0.96	35.18	0.66

5.3 Standardization/normalization

Applying Equations 4, 5 and 6, the cardinally meaningful and ordinally meaningful standardized index is presented in Table A1 in the appendix.

5.4 Emissions Control Coefficients (ECCs) and their application

Based on the above formula, this part calculates an ECC for each industry and the calculation results are shown in Table A2 in the appendix. Given the need to set weights, this paper calculates ECCs under five scenarios, that is, AEDRs are 1.5%, 2.5%, 3.9%, 4.5% and 5.5%. While 1.5% and 2.5% are low-target scenarios, 3.9% are planned target scenarios, and 4.5% and 5.5% are high target scenarios given that the 3.9% scenario was determined on the basis of the CO_2 reduction target per unit of GDP. According to the "13th Five-Year Plan for Controlling Greenhouse Gas Emissions" issued by the State Council, the target for CO_2 reduction per unit of GDP during the "Thirteenth Five-Year Plan" period in Hubei Province is 19.5%. Therefore, it needs to decrease by 3.9% each year on average.[‡]

From Table A2 in the appendix, the ECC for each industry not only reflects the industrial differences, but also are highly correlated with the AEDRs. The ECCs can been applied directly to the allocation of allowances without any additional effort. Fox example, if using the benchmark method, then enterprises' free allowances will be: $FA_{kijt} = Activity\ \ Level_{kt} \times Benchmark_{kt} \times ECC_{ijt}$. While we highlight the time dimension, it does not mean that the ECCs need to be adjusted yearly. The policy makers can decide how frequently they should be adjusted.

5.5 Comparison of ECCs with other FA policies

In this subsection, we compare the ECCs with other carbon leakage prevention policies.

[‡] State Council, 2016. The "13th Five-Year Plan" Notification of Work Plan for Controlling Greenhouse Gas Emissions. The State Council of PRC, Beijing.

5.5.1 The Issue of fixed base year

Firstly, we demonstrate the dynamic advantage by comparing the ECCs between 2015 and 2016, which would not be the same using the traditional method. For the sake of simplicity, we calculated only the ECC of each industry in the 5% AEDR scenario using 2015 and 2016 data. As shown in Figure 3, eight of the 16 sectors would have decreased the ECCs in 2016, compared with 2015, while the other eight sectors would have increased the ECCs. The largest reduction among the ECCs was 0.89% in the 'Manufacture of Chemical Fibers' sector. By contrast, the largest increase among the EECs was 0.44% in the 'Processing of Petroleum, Coking and Nuclear Fuel' sector. The adjustment, although minor in one year, could be significant over a longer period. The dynamics will change the relative FAs across the industries.

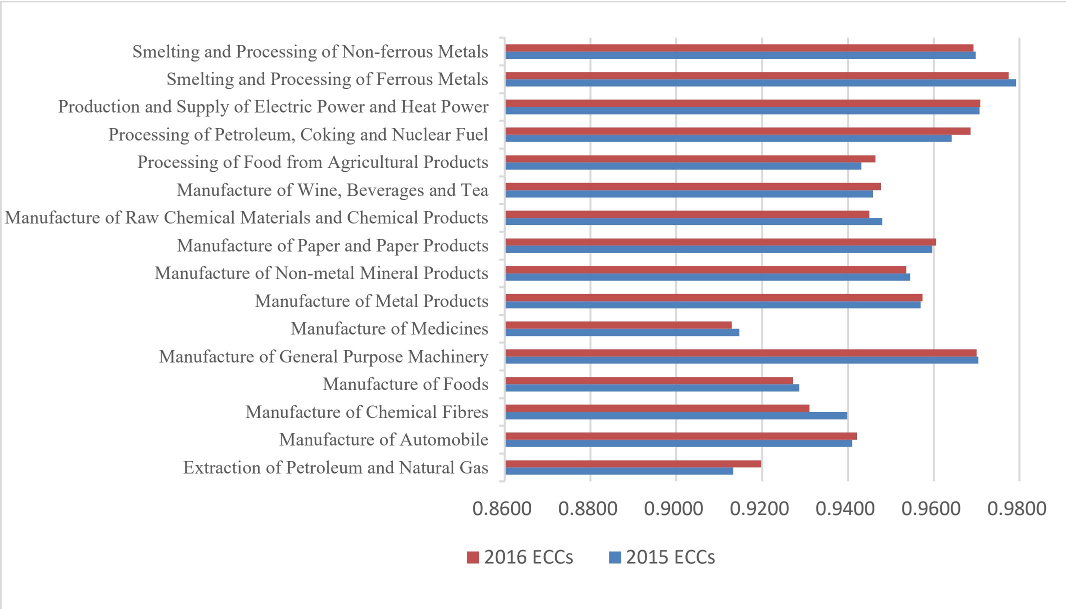


Figure 3. Comparison between 2016 and 2015 of ECC

5.5.2 Comparing with the EU Methodology without consideration of abatement potential

Secondly, we illustrated the difference between the ECCs and the EU's ETS dichotomy classification using Hubei's data for the 2016 allowance allocation. For the sake of demonstration, we used only the TI indicator and used the same 30% threshold to classify the 16 industries into two groups: risk industries and no-risk ones as in Table 5. According to the ETS Directive (Article 10a)(de Perthuis and Trotignon, 2014), the risk group (R) would receive 100% FAs while the non-risk (NR) group would receive 55% FAs as in the third phase of the EU's ETS.[§] The difference in the FA percentage is at least 20%. However, in our method, the FA range is between 91% and 98%. The difference between the two methodologies ranges from -0.09 to 0.43.

Table 5 Comparison of ECCs with dichotomy classification

industries	TI	Type	EU ETS	ECCs	Difference
Extraction of Petroleum and Natural Gas	53.37	R	1	0.91	-0.09
Manufacture of General-Purpose Machinery	45.04	R	1	0.97	-0.03
Processing of Petroleum, Coking and Nuclear Fuel	36.51	R	1	0.96	-0.04
Manufacture of Chemical Fibers	35.19	R	1	0.94	-0.06
Smelting and Processing of Non-ferrous Metals	35.18	R	1	0.97	-0.03
Manufacture of Raw Chemical Materials and Chemical Products	29.12	NR	0.55	0.95	0.4
Smelting and Processing of Ferrous Metals	25.50	NR	0.55	0.98	0.43
Manufacture of Foods	24.54	NR	0.55	0.93	0.38
Manufacture of Automobiles	23.28	NR	0.55	0.94	0.39
Manufacture of Metal Products	20.50	NR	0.55	0.96	0.41
Manufacture of Wine, Beverages and Tea	16.72	NR	0.55	0.95	0.4
Manufacture of Medicines	16.71	NR	0.55	0.91	0.36
Manufacture of Paper and Paper Products	15.98	NR	0.55	0.96	0.41
Manufacture of Non-metal Mineral Products	14.25	NR	0.55	0.95	0.4
Processing of Food from Agricultural Products	6.86	NR	0.55	0.94	0.39
Production and Supply of Electric Power and Heat Power	2.04	NR	0.55	0.97	0.42

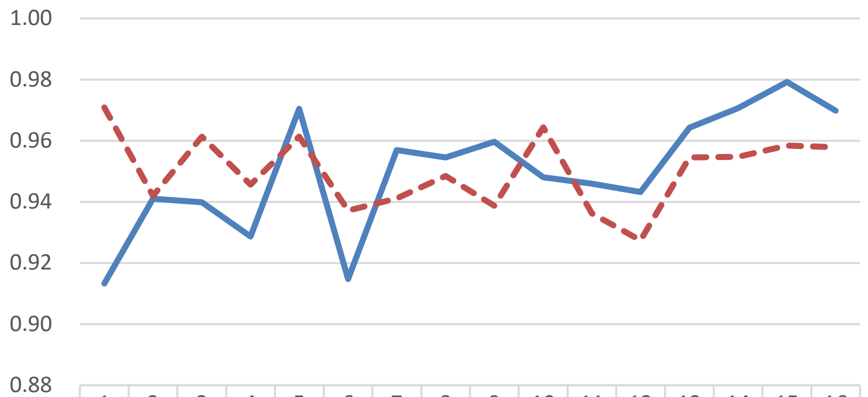
Notes: R: risk group; NR: non-risk group.

[§]According to the ETS Directive (Article 10a), the FAs are gradually reduced across phase 3 (80% in 2013, and reduced every year to reach 30% in 2020); thus, the proportion would be 55% in 2016.

5.5.3 With or without consideration of abatement potential

Thirdly, whether or not to consider the AP will also make a significant difference. The largest difference is seen in the sector ‘Extraction of Petroleum and Natural Gas’. When the AP is not considered, this sector would receive a 97% FA. However, when its energy intensity relative to the national average was considered, the FA would be reduced to 91% due to its high carbon intensity relative to the national average, and thus it has large abatement potential. This industry can reduce emissions by applying average-level technologies and thus its abatement cost will be low. On the contrary, some other industries are given higher percentage FAs due to their low abatement potential and thus high marginal abatement costs. These industries would be restricted in a carbon market without consideration of the AP, and thus the EECs with APs reward such advanced industry.

Figure 4 The ECCs of Hubei in 2016, with or without considering AP



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
ECCs with AP	0.91	0.94	0.94	0.93	0.97	0.91	0.96	0.95	0.96	0.95	0.95	0.94	0.96	0.97	0.98	0.97
ECCs without AP	0.97	0.94	0.96	0.95	0.96	0.94	0.94	0.95	0.94	0.96	0.94	0.93	0.95	0.95	0.96	0.96

6. Conclusion

The prevention of carbon leakages has been the core issue in the design of emission trading systems, and has attracted the attention of academicians, policy makers and industry practitioners. Most emissions trading systems adopt a tiered structure approach to divide industries into risk, no-risk, high risk, medium risk, and low risk, and adopt different free allowance allocation policies for different types. The tiered structure and arbitrarily set benchmark also cause unfairness among industries and inefficiencies in the emissions trading system. The dichotomy classification of industries has resulted in up to 83% of industries included in the list of carbon leakage risk, a poor measurement of the differences among industries. The carbon leakage policy has been one of the key causes of the carbon price collapse and carbon price signal failure in the EU ETS.

In order to overcome the problems in the existing emissions trading system and to cater to developing countries' context, this paper proposes a dynamic and continuous method, namely Emission Control Coefficients, and uses the data from Hubei Province to illustrate its application and advantages. In addition to the two indicators which are universally applied– cost intensity and trade intensity– we also suggest abatement potential as the third indicator. The abatement potential indicator is conducive to developing countries' industry catching up with developed countries, and the establishment of a tighter cost constraint mechanism. Emission Control Coefficients are better able to maintain a balance between competitiveness protection and mitigation intensives. For the common two indicators, we follow the practice of the EU ETS, but we propose use of a yearly average price instead of fixed carbon prices to allow for dynamic adjustment. To avoid inequality, this method also replaces the dichotomy classification of industries with a continuous method.

Dynamic Emission Control Coefficients are better able to cope with economic fluctuations, technological advances and trade pattern changes, keeping the carbon cost constraint in each industry at an accurate level. Continuous Emission Control Coefficients can accurately reflect the differences between industries and reduce the distortions in competitiveness among industries within and out of the risk. Emission Control Coefficients improve the effectiveness and fairness of allowance allocations, and provide incentives for enterprises to invest in low-carbon technologies. By comparing the free allowances allocation methods between Emission Control Coefficients and the EU ETS, we found that Emission Control Coefficients can largely overcome the shortcomings of the EU ETS, and they are also suitable for developing countries without absolute CO_2 emission reduction targets.

Emission Control Coefficients were tested in Hubei's ETS for four years (2015-2018), and proved that they were feasible and effective. Our study generates the following policy implications:

Firstly, while it is necessary to grant free allowances to prevent carbon leakages, the allowance allocation method needs to be improved to avoid carbon prices which are too low. The long-term slump in carbon prices will reduce the confidence to invest in low-carbon technologies resulting in market ineffectiveness. In the design of China's national ETS, it is necessary to introduce a carbon leakage prevention policy that reflects industry differences.

Secondly, dynamic free allowances adjustment mechanisms need to be established based on the changes in the industry's trade intensity, cost intensity and abatement potential, which improve the fairness and efficiency of the ETS. Therefore, for some industries, they should not be overly protected or pressured, and should establish a dynamic free allowances adjustment mechanism.

Thirdly, it is necessary to establish a clear and definite carbon cost constraint signal for industries rather than protecting them indefinitely. By considering the abatement potential of each industry, it is necessary to force the backward industries to gradually catch up to the world's advanced level and gradually complete the transition to low-carbon operations.

However, this paper relies solely on data from Hubei Province to verify the applicability of ECCs and does not consider the loss of competitiveness brought about by domestic trade. These two limitations are the direction of future research.

Acknowledgements

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Appendix

Table A1 Results of Standardization for industries in Hubei province (2016)

Industry	SCI	STI	SAP
Extraction of Petroleum and Natural Gas	0.92	0.00	1.00
Manufacture of Automobiles	1.00	0.59	0.42
Manufacture of Chemical Fibers	0.72	0.35	0.57
Manufacture of Foods	0.92	0.56	0.61
Manufacture of General-Purpose Machinery	0.99	0.16	0.14
Manufacture of Medicines	0.97	0.71	0.75
Manufacture of Metal Products	0.95	0.64	0.19
Manufacture of Non-metal Mineral Products	0.54	0.76	0.27
Manufacture of Paper and Paper Products	0.90	0.73	0.13
Manufacture of Raw Chemical Materials and Chemical Products	0.45	0.47	0.47
Manufacture of Wine, Beverages and Tea	1.00	0.71	0.31
Processing of Food from Agricultural Products	1.00	0.91	0.28
Processing of Petroleum, Coking and Nuclear Fuel	0.97	0.33	0.18
Production and Supply of Electric Power and Heat Power	0.00	1.00	0.09
Smelting and Processing of Ferrous Metals	0.54	0.54	0.00
Smelting and Processing of Non-ferrous Metals	0.83	0.35	0.13

Table A2 ECCs for Hubei's industries under different AEDRs (2016)

Industries	Low Target Scenarios		Planned Target Scenarios	High Target Scenarios	
	1.5%	2.5%	3.9%	4.5%	5.5%
Extraction of Petroleum and Natural Gas	0.9759	0.9599	0.9374	0.9278	0.9118
Manufacture of Automobiles	0.9826	0.9711	0.9548	0.9479	0.9363
Manufacture of Chemical Fibers	0.9793	0.9655	0.9462	0.9379	0.9241
Manufacture of Foods	0.9781	0.9636	0.9432	0.9344	0.9199
Manufacture of General-Purpose Machinery	0.9910	0.9850	0.9766	0.9730	0.9670
Manufacture of Medicines	0.9739	0.9564	0.9321	0.9216	0.9042
Manufacture of Metal Products	0.9872	0.9787	0.9668	0.9617	0.9532
Manufacture of Non-metal Mineral Products	0.9861	0.9768	0.9638	0.9582	0.9489
Manufacture of Paper and Paper Products	0.9882	0.9803	0.9692	0.9645	0.9566

Manufacture of Raw Chemical Materials and Chemical Products	0.9835	0.9725	0.9571	0.9505	0.9395
Manufacture of Wine, Beverages and Tea	0.9843	0.9739	0.9592	0.9529	0.9425
Processing of Food from Agricultural Products	0.9839	0.9732	0.9582	0.9518	0.9411
Processing of Petroleum, Coking and Nuclear Fuel	0.9906	0.9843	0.9755	0.9718	0.9655
Production and Supply of Electric Power and Heat Power	0.9913	0.9854	0.9773	0.9738	0.9679
Smelting and Processing of Ferrous Metals	0.9932	0.9887	0.9824	0.9797	0.9752
Smelting and Processing of Non-ferrous Metals	0.9908	0.9846	0.9761	0.9724	0.9662