A general equilibrium analysis of floor prices for China’s national carbon emissions trading system

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ABSTRACT
China announced the official start of its national emissions trading system (ETS) construction programme in December 2017, making ETS the primary policy to achieve China’s domestic decarbonization targets and global climate change pledges. Unlike ETS designs in other regions, China’s ETS features a flexible cap that is linked to both reduced carbon intensity and activity levels. Therefore, total CO2 emissions are allowed to increase if economic growth is strong – an important design feature for developing countries that demand an increase in CO2 emissions at least in the near term. Therefore, to guarantee that the carbon price signal emerging from the ETS is strong enough to support the achievement of China’s climate change targets given uncertainties in economic growth, technology improvement and renewable energy development, China’s ETS needs a carbon price floor. In this study, we simulate carbon price paths in different scenarios representing different uncertainty realizations using the China-in-Global Energy Model (C-GEM) and find that a price path of $4 before 2020, $8 between 2021 and 2025 and $12 between 2026 and 2030 (2011 constant price) is able to support the achievement of China’s climate pledges with a 90% chance. Therefore, this price path could be adopted as a feasible carbon price floor for China’s ETS.

Key policy insights
- A carbon price floor in China’s ETS is needed to achieve China’s climate pledges under uncertainty.
- Multiple dimensions of uncertainties need to be considered when estimating the carbon price floor.
- Under our representative estimation, the carbon floor price path needs to be set at $4 per ton before 2020, $8 per ton between 2021 and 2025, and $12 per ton between 2026 and 2030.

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1. Introduction
China’s Nationally Determined Contribution (NDC) submitted under the 2015 Paris Agreement includes three major targets to be reached by 2030: peaking CO2 emissions; reducing CO2 emissions per unit of gross domestic product (GDP) or CO2 intensity by 60% to 65% from the 2005 level; and increasing the share of non-fossil fuels in primary energy consumption to 20% (United Nations Framework Convention on Climate Change, 2015).

Emissions trading systems (ETTs) have been considered as the most promising policy to support the achievement of these targets. Since 2013, China has launched seven regional pilot ETSs in five cities and
two provinces. In December 2017, China announced the official start of its national ETS, indicating that the ETS has been officially adopted nationwide. As a market-based approach, carbon pricing emerging from the ETS is expected to provide incentives to reduce carbon emissions and achieve China’s climate targets while keeping the total abatement cost low. Unlike ETS designs in other regions, China’s ETS features a flexible cap that is linked to both reduced carbon intensity and activity levels. This means that total CO₂ emissions are allowed to increase if economic growth is strong—an important design feature for developing countries that demand an increase in CO₂ emissions at least in the near term. Therefore, to guarantee that the carbon price signal emerging from the ETS is strong enough to support achievement of the targets given uncertainties in economic growth, technology improvement and renewable energy development, China’s ETS needs a carbon price floor.

In this study, we simulate carbon price paths in 27 different scenarios representing different uncertainty realizations using the China-in-Global Energy Model (C-GEM), a global computable general equilibrium (CGE) model with detailed representation of China. We consider three major sources of uncertainty—future GDP growth rate, autonomous energy efficiency improvement (AEEI) rates and renewable development policies. We find the required carbon price path in each scenario to achieve China’s three major climate targets by 2030 and pick the 90th percentile carbon price from the 27 scenarios sorted by the simulated carbon prices from low to high. By setting this price path as the carbon price floor, China’s ETS will be able to support the achievement of China’s climate targets with a chance of 90%.

The rest of this study is organized as follows. Section 2 reviews the literature of carbon pricing mechanisms with a focus on carbon price floors. Section 3 describes scenario designs in this study. Section 4 introduces the model and data. Section 5 presents the main results and Section 6 concludes the article.

2. Policy background and literature review

2.1. Policy background

Carbon pricing, namely putting a price on carbon, is a market-based policy instrument to achieve carbon reduction targets at the lowest cost by using market operations to internalize the external costs of fossil fuels as well as other sources of GHG emissions. Ideally, carbon pricing should reflect the social cost of carbon (SCC), which represents the economic cost caused by an additional ton of CO₂ emissions or its equivalent (Nordhaus, 2017). In reality, however, carbon pricing is usually adopted to achieve certain climate targets, as it is widely considered one of the most cost-effective policy tools for realizing carbon reduction targets (Environmental Defense Fund & International Emissions Trading Association, 2016; International Carbon Action Partnership, 2017). Many of the NDCs submitted under the Paris Agreement include carbon pricing proposals, treating carbon pricing as a key measure for realizing commitment targets.

China has initiated the use of carbon pricing to promote energy conservation, emissions reduction and climate change, launching seven ETS pilots at the city and provincial level in 2011, including Shenzhen, Shanghai, Beijing, Guangdong, Tianjin, Hubei and Chongqing (Zhang, Karplus, Cassisa, & Zhang, 2014). ETS pilots have laid a solid foundation for the establishment of a national unified carbon trading framework. The National Development and Reform Commission (NDRC) released the official document Guidelines of national carbon emissions trading system construction approved by the State Council in December 2017 (NDRC, 2017). The construction of China’s national ETS will involve three phases. The first phase (‘infrastructure construction’) will require approximately one year and will focus on the construction of a national monitoring, reporting and verification (MRV) system, a national registry to track allowances, and a national platform for emission trading. The second phase (‘system test’) will require another year and involve a trial run with only one sector, power generation, to test the design of the national ETS without the full regulatory burden in place. The third phase ‘development and improvement’ will start a formal run with the power sector and gradually extend to other sectors. The scheme will cover enterprises whose annual energy consumption exceeds 10,000 tons of coal equivalent (tce) in eight key industries, including petrochemicals, chemicals, building materials, iron and steel, non-ferrous metals, paper, power generation and aviation (State Council, 2016).
2.2. Literature review

Carbon prices in the ETS are affected by many uncertainties. Therefore, researchers have discussed several forms of carbon price management, including a price floor, a price cap or both (also known as price collar) (Burtraw, Palmer, & Kahn, 2010; McKibbin & Wilcoxen, 2002; Wood & Jotzo, 2011). In this article, we focus on the discussion of the price floor because we are interested in the price path that is able to support the achievement of China’s climate targets with a high degree of certainty.

The price floor mechanism implies setting a minimum price on carbon, so that the carbon price will be always higher than the price floor. When the price hits the floor, the ETS becomes equivalent to a carbon tax. Some researchers advocate introducing a carbon price floor because it can reduce the volatility of the carbon price and provide a long-term stable price signal, which is important for investment in low-carbon technology (Brauneis, Mestel, & Palan, 2013; Weber & Neuhoff, 2010). Wood and Jotzo (2011) summarize three forms of carbon price floor: (1) Buying back emission permits at the floor price, which is equivalent to reducing the amount of permits in the market and paying a subsidy to firms (Hepburn, 2006; Roberts & Spence, 1976); (2) Setting an auction reserve price and limiting the amount of permits available (Grubb & Neuhoff, 2006; Hepburn, Grubb, Neuhoff, Matthes, & Tse, 2006). This approach is adopted in the US Regional Greenhouse Gas Initiative (RGGI) and California Cap-and-trade Program; (3) Paying an extra fee on top of the permit price in order to meet the floor price, when the permit price falls below it (Brauneis et al., 2013; Brink, Vollebergh, & Werf, 2016; Egli & Lecuyer, 2017; Wood & Jotzo, 2011). This approach is adopted in the UK.

The case of the UK provides a useful example of the operationalization of a carbon price floor. The UK carbon price floor was introduced on 1 April 2013 to increase the carbon price to a level that could drive more low-carbon investment (particularly in the power sector), because the carbon price under the EU-ETS was not high enough to do so (HM Treasury, 2011). The UK carbon price floor consists of two parts: (1) the EU-ETS price and (2) a carbon price support (CPS) on top of the EU-ETS carbon price. When the EU-ETS price is lower than the pre-determined carbon price floor, the utility companies need to pay the CPS, that is, the difference between the EU-ETS price and the carbon price floor. With the introduction of the carbon price floor, the output of coal power dropped significantly and several coal power plants were closed. Relative to 2013, coal consumption dropped by 70% in 2016 (World Bank, 2017). Initially, the UK government set the carbon price floor starting from £15.70 (US$24.5) in 2013 and increasing about £2 (US$3.1) per year to £30 (US$46.2) in 2020, and then increasing by £4 (US$6.2) per year until it reaches £70 (US$108.2) by 2030 (Sandbag, 2013). However, more and more opponents (Confederation of British Industry, 2014; HM Treasury, 2014) against the carbon price floor have argued that it will harm the energy intensive industry in the UK, with a growing gap between the EU-ETS price and the price floor. In 2014, the carbon price floor was reset to a fixed level of £18 (US$24.3) from 2016 to 2020 and was extended to 2021 in 2016 (HM Revenue & Customs, 2014). By 2017, one billion pounds had been collected by the UK Treasury due to the implementation of the carbon price floor.

The possibility of implementing a carbon price floor has been also discussed for the entire EU-ETS (European Commission, 2012, 2013). Some policy makers hold the view that interference with the carbon price should be minimized, and an arbitrary carbon price floor may harm the efficiency of carbon pricing given that total emissions have been already capped (Hirst, 2018). Some researchers proposed the market stability reserve as another option to address low permit prices in the EU-ETS (Perino & Willner, 2017). Compared to the EU-ETS, China’s ETS does not place an explicit cap on total emissions because the cap is adjusted according to the level of economic activity. This feature of not capping total emissions provides further rationale for a carbon price floor in China as it can help to increase the likelihood of achieving China’s climate targets under uncertainty.

3. Scenario design

We consider three dimensions of uncertainty: future GDP growth rate, AEEI rates and renewable development policies. These uncertainties affect China’s future CO₂ emissions path as well as non-fossil energy development, hence the extent to which China’s climate targets will be achieved.

We first discuss the uncertainty in China’s future GDP growth. Figure 1 represents estimates from different studies, such as the International Energy Agency (IEA), the World Bank (WB), the Organization for Economic
Cooperation and Development (OECD), the United Nations (UN), the International Monetary Fund (IMF), the EU and other institutions (Asian Development Bank, 2015; Economist Intelligence Unit, 2015; Energy Information Administration, 2014; EU, 2015; IEA, 2016; IMF, 2015; OECD, 2014, 2015, 2016a, 2016b; UN, 2015; WB, 2015). Three GDP growth scenarios are selected based on these forecasts. The low GDP growth scenario (lgdp) is the lower envelope line of all the forecasts, and the high GDP growth scenario (hgdp) is the higher one. The medium GDP growth scenario (mgdp) adopts the average numbers of the lgdp and hgdp scenarios.

The second uncertainty comes from the assumption of the AEEI rate. AEEI represents the invariant part of energy efficiency improvement in both baseline and policy scenarios without any policy intervention. It represents technological progress and the narrowing energy efficiency gap. We adopt 1% after 2015 as our medium AEEI scenario (maeei) following Weyant (2000). Low (laeei) and high (haeei) AEEI scenarios are set at 0.5% and 1.5%, respectively.

The third uncertainty covers the deployment of renewable energy. Our medium renewable scenario (mre) assumes that subsidies are provided to solar energy after 2020 and before 2030 and the rates are set at 25% (Huo, 2012; Zhou, 2017). Low (lre) and high (hre) scenarios are set at 12.5% and 50%, respectively.

In summary, we have assembled 27 (3×3×3) scenarios. To calculate the minimum carbon price path that would satisfy China’s three climate targets is computationally expensive, therefore, we assume that the carbon price covers all economic activity and apply an additional constraint for the carbon price path. The carbon price is set to achieve a fixed annual carbon intensity reduction rate, which is reasonable as China’s carbon intensity reduction rate in the past ten years has been relatively stable (4–6%). We apply 4%, 5% and 6% annual carbon intensity reduction rate in the above 27 scenarios and examine whether three climate targets (peaking carbon emissions, decreasing carbon intensity by 60–65%, and increasing the share of non-fossil energy in primary energy consumption to 20% by 2030) are met. The lowest price path for each scenario is selected and then the 27 price paths are sorted from low to high. We choose the 90% percentile of these price paths as the carbon price floor, meaning that the chance of meeting the targets is 90% when the above three sources of uncertainties are considered with a certain range.

4. Methodology and data

We apply the C-GEM to calculate the CO₂ price path under different assumptions and evaluate the CO₂ price floor needed to achieve China’s climate targets. The C-GEM has been applied in multiple studies on China’s
energy and climate polices. For instance, Qi, Winchester, Karplus, and Zhang (2014) use the C-GEM to analyse the impact of economic restructuring in the Chinese economy on trade-embodied CO₂ emissions; Zhang, Karplus, Qi, Zhang, and He (2016) use the C-GEM to simulate two climate policy scenarios (a continued effort scenario and an accelerated effort scenario) and assess how new policy directives affect China’s energy and emissions trend; Qi and Weng (2016) use the C-GEM to evaluate the impact of a linked ETS on the achievement of NDCs by 2030.

Several distinct features of the C-GEM make it appropriate to study the carbon floor price for the design of China’s ETS. Many other CGE models, e.g. CEEP Multiregional Energy-Environment-Economy Modeling System (CE3MS) (Wu, Fan, & Xia, 2016), the dynamic CGE model used by Dai, Xie, Liu, and Masui (2018) and the Emissions Prediction and Policy Analysis (EPPA) model (Paltsev, Reilly, & Jacoby, 2005) may have several of the features but not all of them. First, the C-GEM is a global CGE model that explicitly captures bilateral international trade flows. The trade responses to carbon pricing are important for a large open economy like China. Furthermore, by including other major regions in the modelling framework, we are also able to represent other regions’ climate policies and commitments, which affect China’s domestic carbon prices (see the sensitivity analysis in Section 5.2). Second, the C-GEM builds on the most recent economic and energy data for both China and global regions. The input-output and bilateral trade data are constructed based on the ninth release of the Global Trade Analysis Project data set (GTAP9), which is the newest available version (Angel, Narayanan, & McDougall, 2016) with the base year of 2011. China’s energy data are adjusted using the 2011 China Energy Balancing Table (National Bureau of Statistics of China, 2016). Using the most recent data for China is important given China’s fast and dynamic growth. We are not aware of any other global CGE models with a special representation of China that is built on the most recent data. Third, the C-GEM is a dynamic model that has incorporated the structural change that has occurred in China’s economy and is therefore able to reflect the economic rebalancing of recent years (Zhang et al., 2016). The model starts from 2011, iterates to the second period in 2015, and continues the iteration every five years until 2035. This dynamic structure allows us to explore whether carbon pricing could help to achieve China’s major climate targets.

The C-GEM is a multi-regional, multi-sector, recursive-dynamic, CGE model of the global energy and economic system, which is described in detail in Qi, Winchester, Zhang, Zhang, and Karplus (2014). It distinguishes the world into 19 geographic regions in which China is a single region. The major developed economies (the United States, EU, Japan, Canada and Australia) and major developing countries (China, India, Russia, Brazil and South Africa) are explicitly represented. For each region, the C-GEM comprises 21 production sectors (five energy sectors, four energy-intensive sectors, three service sectors and nine other sectors).

The basic structure of the C-GEM derives from the Walrasian general equilibrium theory formalized by Arrow and Debreu (Arrow & Debreu, 1954). As a CGE model, it is able to capture policy effects across the interlinked sectors of the economy, including interactions with goods, factor markets and bilateral trade between regions. Since modelling details have been fully described in Qi, Winchester, Zhang et al. (2014), here we confine ourselves to briefly introducing the main structure. The core static module consists of four sections: production and consumption, international trade, emissions and closure mechanism. The dynamics of the C-GEM is mainly driven by labour supply growth, capital accumulation, fossil fuel resource depletion and the AEEI.

The core of each production sector in C-GEM is the nested constant elasticity of substitution (CES) function, with different nesting structures and values of elasticities across sectors to reflect the characteristics of each industry (see an example for the primary fossil energy sector in Figure 2). When some climate policies or emissions constraints are introduced, these elasticities allow producers to respond by substituting towards less-carbon intensive fuels and using less energy by switching to capital and labour.

In the C-GEM, all goods except crude oil are treated as Armington goods (1969). This assumption means that consumers regard domestic production and aggregate imports as different kinds of goods, and in the model they are represented as imperfect substitutes for each other using a CES function, as shown in Figure 3. CO₂ emissions are computed by applying constant emission factors to the fossil fuel energy flows of coal, refined oil and natural gas based on the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). Energy-related CO₂ emissions enter into a Leontief structure with fuel, implying that the reduction of emissions in production sectors can only be achieved by reductions in fuel use. Finally, the C-GEM adopts the neoclassical closure. Government expenditure is assumed to be part of final
consumption and is fully funded by households. Tax is collected from production and consumption. Investment in the C-GEM is endogenous and equals savings in each period.

Moving to the dynamic module, as introduced in previous C-GEM studies, labour supply in the C-GEM is driven by changes in the population and labour productivity in each region over time (Equation (1)). The evolution of capital over time in the C-GEM includes both old capital carried over from the previous period and new capital from investment (Equation (2)). As for fossil fuel resource depletion, it complies with the Hotelling assumption (Hotelling, 1931) meaning that unit production costs rise as resources deplete. Similar to other energy-economic modelling work, AEEI factors are also assumed in this study to represent the trend of energy efficiency improvement.

\[ L_{r,t} = L_{r,t-1} \times (1 + n_{r,t})^n \times (1 + g_{r,t})^n, \]  

where \( L_{r,t} \) represents the supply of labour of region \( r \) in year \( t \), \( L_{r,t-1} \) is the labour supply in year \( t - 1 \), \( n_{r,t} \) is the population growth rate and \( g_{r,t} \) is the labour productivity growth rate.

\[ K_{r,t} = (1 - \delta_{r,t})^i \times K_{r,t-1} + I_{r,t-1}, \]  

where \( K_{r,t} \) represents the supply of capital of region \( r \) in year \( t \), \( K_{r,t-1} \) is the capital value in year \( t - 1 \), \( \delta_{r,t} \) represents the depreciation rate of region \( r \) in year \( t \), \( ti \) is the time interval (5 years in the C-GEM), \( I_{r,t-1} \) is the new investment capital, which is equal to savings and is determined by total national income and the saving rate.

The modelling framework has several limitations. First, the recursive dynamic structure assumes myopia, so the investment in each period does not reflect the level that optimizes across periods. This may lead to an

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**Figure 2.** The nesting structure of primary fossil energy sector in the C-GEM.

**Figure 3.** The Armington structure for imported goods in the C-GEM.
overestimation of the carbon price floor. Second, the model does not include vintaged capital, therefore, lock-in effects are ruled out, which might not be realistic. This assumption may lead to an underestimation. Third, we assume firms within a sector are homogenous, so we could only model the full coverage of the ETS. This may lead to an underestimation as well. Therefore, future modelling practices could consider these limitations and improve the estimation accordingly.

5. Results

5.1. Main results

Here we present simulation results for all the 27 scenarios, including CO\textsubscript{2} emissions and carbon prices.

Figure 4 displays the emissions path of each scenario with the carbon price that is able to achieve all the climate targets. Only six scenarios are explicitly shown in Figure 4 as other scenarios generate very similar paths to these six scenarios. It is obvious that uncertainties in rates of GDP growth and AEEI dictate the CO\textsubscript{2} emissions paths, while uncertainty in renewable subsidy plays a minor role.

Figure 5 shows the distribution of carbon prices over time. Each box plot shows the carbon price distribution of the 27 scenarios for one specific model period, and the dashed line for each box plot represents the 90\% percentile value of the carbon price. Translating these values to the carbon price floor, we obtain a price path of $4 before 2020, $8 between 2021 and 2025, and $12 between 2026 and 2030 (2011 constant price), which will be able to support the achievement of China’s climate pledges under the Paris Agreement with a 90\% chance. This price path is well in the range of other studies on the carbon price needed to achieve China’s climate targets, as shown in Table 1.

5.2. Sensitivity analysis

We run three more scenarios to test the model’s sensitivity to other regions’ climate policies, ETS sectoral coverage and elasticity of substitution between energy and capital/labour bundles.

In all the scenarios discussed above, we have included climate targets made under the 2009 Copenhagen Accord for 2020, and the NDCs under the Paris Agreement for 2030, from the United States, EU-28, Japan, South Korea, Canada, Australia, Mexico, India, Brazil, Russia and South Africa (UNFCCC, 2015). Except for India, the commitments for other countries include absolute emissions reduction targets. We use historical total
GHG emissions and CO₂ emissions data from the EDGAR data base (European Union Joint Research Centre, 2017) and reduction targets to calculate allowed CO₂ emissions in 2020 and 2030, deriving allowed emissions in other years using linear interpolation and extrapolation. For India, we use the carbon intensity reduction achieved from 2005 to 2015 and derive the required carbon intensity reduction for other years. To demonstrate the effects of other regions’ climate polices on China’s carbon pricing, we remove other regions’ polices and examine China’s carbon price. We find that the required carbon floor price is reduced by roughly 10% when other regions do not have climate policy, perhaps because substituting domestic production by imports is easier as the import prices are lower.

We are also interested to explore the effects of sectoral coverage on China’s carbon price. In this sensitivity test, we only include petrochemical, chemical, building materials, iron and steel, non-ferrous metals, paper, power generation and aviation sectors, which are sectors recognized to be covered in China’s ETS in the near term. We find that the carbon price floor increases by 15% to 25%.

Table 1. Forecasted carbon prices simulated by other studies.

| Source                          | 2020       | 2025       | 2030       |
|--------------------------------|------------|------------|------------|
| Li and Lu (2015)                | 30–50 RMB/ton | –          | –          |
| Tang, Shi, and Bao (2016)       | 39.61 RMB/ton | –          | –          |
| Li and Jia (2016)               | 28.00 RMB/ton | 40.00 RMB/ton | 48.14 RMB/ton |
| Cao, Ho, and Timilsina (2016)   | –          | 60% target: 18 RMB/ton | 60% target: 26 RMB/ton |
| China Carbon Forum (2017)       | 74 RMB/ton | 108 RMB/ton | –          |
| Qi, Winchester, Karplus, Zhang, and Zhang (2016) | 14.1 USD/ton | 19.0 USD/ton | 25.7 USD/ton |

Table 2. Sensitivity to other regions’ NDC, ETS sectoral coverage and elasticity of substitution between energy and capital/labor bundles.

|                                | CO₂ price (2011 US$/ton) | Change compared to floor price |
|--------------------------------|--------------------------|--------------------------------|
|                                | 2020  | 2025  | 2030  | 2035  | 2020  | 2025  | 2030  | 2035  |
| No NDC targets for other countries | 3.6   | 6.9   | 10.8  | 16.6  | –10%  | –9%   | –8%  | –7%  |
| ETS for eight industries        | 4.6   | 9.0   | 14.2  | 22.5  | 15%   | 19%   | 21%  | 26%  |
| Doubled elasticities of substitution between energy and capital-labour | 3.2   | 6.0   | 9.4   | 14.2  | –21%  | –21%  | –20% | –20% |
| Halved elasticities of substitution between energy and capital-labour      | 4.8   | 9.0   | 13.4  | 20.4  | 20%   | 19%   | 14%  | 14%  |
In addition, we test the sensitivity of one main parameter – the elasticity of substitution between energy and capital-labour bundle. We run two scenarios with the elasticity of substitution doubled and halved. We find that the carbon price floor will change by a range of 20%.

We provide a summary of results from the above sensitivity analyses in Table 2. Our base carbon price floor is relatively robust to other regions’ climate policies, ETS sectoral coverage and elasticity of substitution between energy and capital/labour bundles.

6. Conclusions

China’s national ETS, once fully implemented, will become the world’s largest ETS. As China’s primary climate policy, the ETS is expected to support the achievement of China’s main climate targets – emissions peaking, emissions intensity reduction, and rising non-fossil energy share in primary energy consumption. This study has conducted a comprehensive analysis on carbon price paths required to support the target achievement under multiple uncertainty scenarios. A carbon price path ($4 per ton during 2016–2020, $8 per ton during 2021–2025, and $12 per ton during 2026–2030) is proposed as the carbon price floor, which will be able to support the target achievement with a 90% chance. With different chances of expected achievement, and different modelling assumptions, this carbon price floor can be adjusted accordingly using the same methodology that we have proposed in this study. By introducing a reasonable level of carbon price floor, China’s national ETS can readily support the climate targets and improve the efficiency of emissions abatement under uncertainty.

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