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Research on carbon market price mechanism and influencing factors: a literature review

Chang-Jing Ji[1,2,3] · Yu-Jie Hu[1,2,3] · Bao-Jun Tang[1,2,3,4]

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Abstract Carbon emissions trading is being used by more and more countries or regions to solve the global warming problem. The establishment of China's carbon market mechanism is still under exploration and improvement. This paper focuses on the price determination mechanism in the carbon market. Based on the price theories, we analyze the theoretical basis of the carbon price formation and the carbon price transmission mechanism from the perspective of the agents that affect carbon price. From these angles including residents' demands, enterprises' actual emissions and indirect effects on residents' demands, the government's setting for carbon market institutions and indirect effects on residents and enterprises, as well as energy markets and financial markets, we analyze how these factors influence the carbon price. In turn, we discuss how carbon price affects the enterprise costs, energy-saving technologies and residents' welfare. Besides, we summarize the current price mechanism of domestic and overseas major carbon markets. Finally, based on the current research on carbon price theory and its influencing factors, we also present some further directions on carbon price mechanism and influencing factors including China's carbon market price mechanism design, the quantitative analysis of carbon price factors and improvement of carbon price theory.

Keywords Carbon market · Price mechanism · Influencing factors · Transmission

✉ Bao-Jun Tang
tbj@bit.edu.cn

[1] Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing 100081, China

[2] School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China

[3] Collaborative Innovation Center of Electric Vehicles in Beijing, Beijing, China

[4] Sustainable Development Research Institute for Economy and Society of Beijing, Beijing, China

1 Introduction

In recent years, global warming has drawn much attention. Extreme weather events that glaciers decrease and sea level rise causes extreme socioeconomic losses. Interagency Working Group's most recent central estimate was $50 in global damages per ton of carbon dioxide, based on year 2020 emissions, converted from 2007 to 2017 dollars, which was the best estimate of the social cost of greenhouse gases (Revesz et al. 2017). Unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100 and widening global income inequality, relative to scenarios without climate change (Burke et al. 2015).

Under the market-oriented economy, the phenomenon that emitters do not need to pay for the loss of socioeconomic losses resulting from their greenhouse emissions, and other individuals and companies will not be compensated for the welfare loss, results in external diseconomy, which makes private costs less than social costs. The most fundamental solution to deal with external diseconomy is to make the private cost equal to the social cost. Moreover, the emitters should pay for the external costs caused by their emissions, realizing "polluter-pays." This requires the government to formulate corresponding policies to internalize the external costs of emitting enterprises to achieve the Pareto optimality of the whole society, and the carbon pricing emerges, as the times require (Montgomery 1972; Ha-Duong and Grubb 1997; Hultman et al. 2011; Twomey 2012; Wesseh Jr et al. 2017).

There are two main types of carbon pricing policies: carbon tax and carbon emissions trading. This paper focuses on carbon emissions trading policy. Carbon emissions trading refers to that emitters achieve emissions target through emissions trading rights. The price of carbon emission rights determined by market demand and supply in the process of carbon emissions trading is carbon price, and the market is the carbon market. It originated from Coase theorem that as long as property rights are clear, the market can solve the externality without direct government intervention (Coase 1960).

Carbon emissions trading scheme (ETS) started as early as 2005 in the EU. There are 19 carbon markets in operation by the end of 2017, which covers more than 7 billion tons of greenhouse gas emissions, accounting for over 15% of global carbon emissions of the world. Since 2013, China has implemented seven carbon emissions trading pilots and two carbon markets in non-pilot areas and by 2017, has formulated its national carbon market. If the national carbon market further develops and covers more and more sectors, it will replace the EU-ETS to become the largest one in the world. Due to the different emission reduction targets and abatement costs in various countries or regions, the current carbon price is as low as US$ 1/ton, up to US$ 18/ton (World Bank 2017; ICAP 2017). Therefore, the current research on the carbon market price mechanism is more practical and instructive.

This paper focuses on the issue of the carbon market price mechanism and discusses the principles of carbon prices formation, influencing factors and transmission mechanisms (Fig. 1). Section 2 analyzes the formation of the price in the market-oriented economy and applies it to the formation of the carbon price in the carbon market, mainly based on the price determination theory. Section 3 discusses the transmission path of different agents which affect the carbon price, including the impact of carbon price by residents through demand, enterprises through actual emissions, government through policies on other agents. Section 4 summarizes the current mainstream carbon market price mechanism at home and abroad. Section 5 puts forward some further research directions regarding the carbon price. Section 6 gives the conclusions of this article.

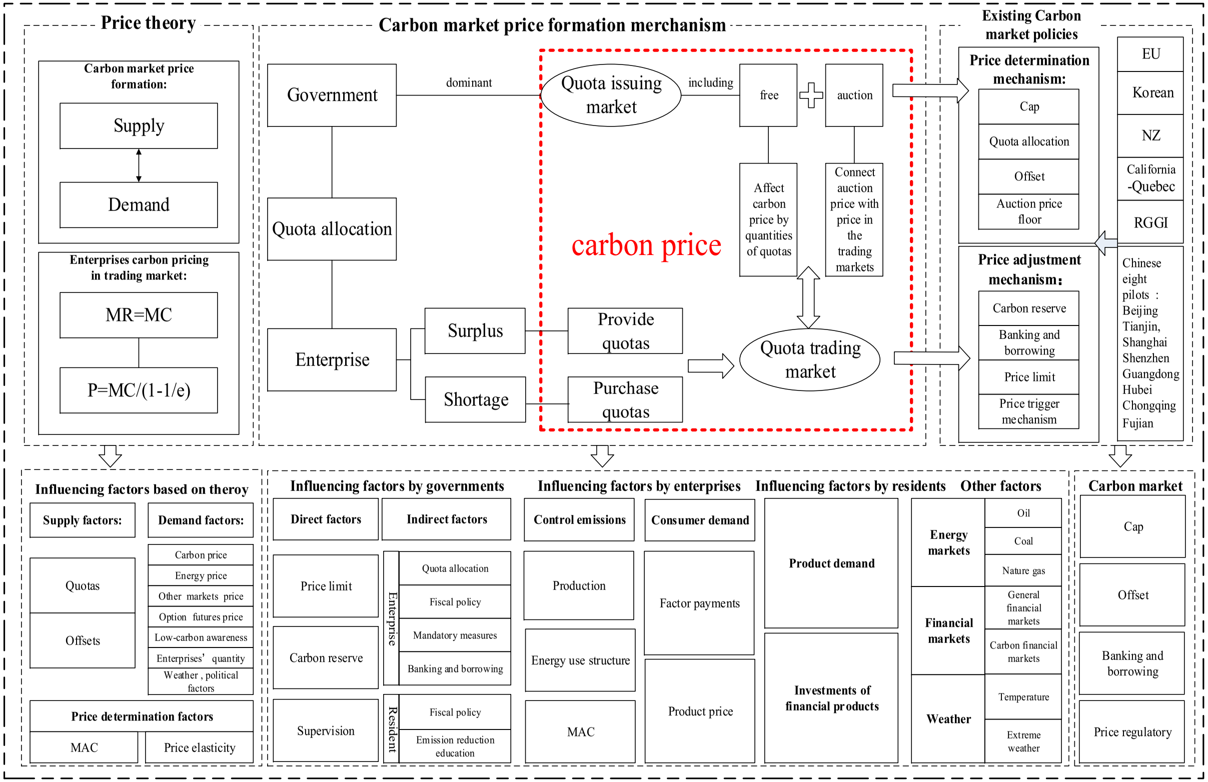

Fig. 1 Formation of carbon market price mechanism and influencing factors (*Note MC* marginal cost, *MR* marginal revenue, *MAC* marginal abatement cost, *e* the price elasticity of demand)

2 Theoretical bases of the formation of carbon market price mechanism

2.1 Price determination theory

Enterprises and governments are the agents of price determination. Under the market economy, the market price is set by the enterprise and then formed by the market. Under the planned economy, prices are set by the government and adjusted by the government. Since most countries implement a market economy system, we mainly discuss the enterprise's pricing.

According to the assumption of "rational choice," in the process of pricing, the enterprise will pursue the maximization of profit when the marginal cost (MC) of the enterprise is equal to the marginal revenue (MR), which is MC = MR.

$$\mathrm{MR} = \frac{\mathrm{d}(PQ)}{\mathrm{d}Q} = P + P \cdot \frac{\mathrm{d}P}{\mathrm{d}Q} \cdot \frac{Q}{P} = P\left(1 - \frac{1}{\left|\frac{\mathrm{d}Q}{\mathrm{d}p} \cdot \frac{P}{Q}\right|}\right) = P\left(1 - \frac{1}{|E_{\mathrm{d}}|}\right). \tag{1}$$

By Eq. (1), $P\left(1 - \frac{1}{|E_{\mathrm{d}}|}\right) = \mathrm{MC}$. As a result, when the enterprise obtains the maximum profits, the price is written as $P = \frac{\mathrm{MC}}{1-1/|E_{\mathrm{d}}|}$.

From this we can know that two factors affect the enterprise's pricing, which are enterprise's marginal cost and the price elasticity of demand on the market. The marginal cost has a positive effect on the price, while the price elasticity of demand has a negative effect. In a special case, if the market is perfectly competitive, the price elasticity of demand for commodities currently is infinite and then the enterprise's pricing $P = \mathrm{MC}$.

After the enterprise has formulated the price, it will be influenced by the balance between demand and supply during the formation of the price in the market. Several factors will affect the quantity of demand, such as the price of the commodity, consumer's income level, the prices of the relevant products (including alternatives and complements), consumer's preferences, consumer's expectations of the product, the number of consumers, the weather and other political factors (Fig. 2). The price of the commodity and the price of the complementary product have negative effects on the demand, while factors such as the consumer's income level, the price of the substitutes and the consumer's preference have positive effects on the demand of the product. If consumers expect future prices will rise, they will also increase the current demand. Different weather conditions will lead to different demands; for example, residents will buy more air conditions in summer. Main factors that will affect the quantity of supply are the price of the product, the cost of production, the product's technical level, the producer's expectations in the future, the price of the relevant product and the number of producers. Specifically, factors such as the price of the product, the production technology, the price of the complementary product and the number of producers have positive effects on the supply, while others such as the cost of production when the price is constant, the price of the substitutes and the expected future price of the product have negative effects.

2.2 Carbon price determination

Firstly, the enterprise will take its marginal abatement cost (MAC) and carbon emission permits' price elasticity of demand into consideration when it determines the carbon price

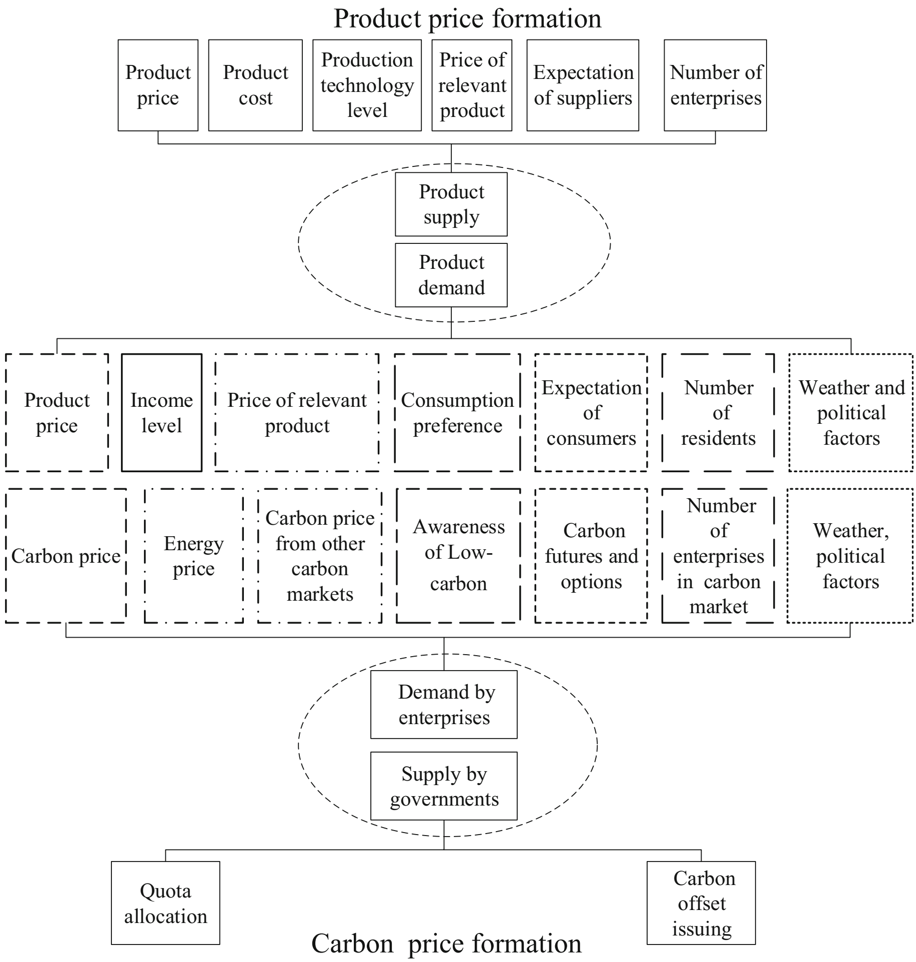

Fig. 2 Corresponding relationship of the price formation. The same line illustrates the corresponding relationship between product markets and carbon markets

in the trading market. The lower the MAC is, the lower the price will be, and the higher the elasticity is, the lower the price will be.

Secondly, carbon price will be influenced by the balance between supply and demand of carbon permits in the ETS (Springer 2003; Benz and Trück 2009; Cong 2010; Chang 2015; Fahimnia et al. 2013; Zhu et al. 2015). The supply of carbon emission permits in China's carbon emissions trading market comes from emissions cap set by the government, including the carbon quotas and China certified emission reductions (CCERs). Therefore, the tightness of the cap, different ways of quotas allocation and difficulty of issuing of CCERs will influence the supply of carbon permits. The demand comes from actual emissions of emitting enterprises and will be influenced by carbon price, traditional energy price, clean energy price, price from other carbon markets, awareness of energy conservation and emission reduction, the price of carbon option futures in the carbon finance market, the number of enterprises in the carbon market, weather and political factors

(Fig. 2). Specifically, factors such as clean energy price, carbon price from other carbon markets and the price of carbon option futures have positive effects on the demand, while others such as carbon price, traditional energy price and awareness of energy conservation have negative effects. Weather has impacts on the enterprise's production, so that affects carbon emissions.

3 Relationships between residents, enterprises, governments, other markets and carbon markets

In the current carbon market, the basic reason for the formation of carbon prices is driven by the balance between carbon permits supply from governments and demand from emissions reduction enterprise. The governments distribute quotas to the enterprises for free or by auction in the quota allocation market. The actual emissions of the enterprises will be excessive or short of the quota, which forms the supply and demand sides in the quota trading market. Both two sides will provide a price offer based on their own MAC and price elasticity of demand in the carbon market, then match the price through several consultations and finally form the transaction price, which is carbon price (shown in Fig. 1).

We integrate the factors mentioned in Sect. 2.2, which affect the balance between supply and demand in the carbon market, so that we can form the transmission diagram about the influencing factors of the carbon market price fluctuations. As shown in Fig. 3, it includes five agents, which are residents, enterprises, governments, other markets and carbon market, and a factor, weather. We also explain how these agents or factors transmit and finally influence the carbon price. Solid lines depict the direct effect on the carbon price, while dotted lines describe that different influencing factors of agents indirectly affect carbon price through other agents.

3.1 Residents' impacts on carbon price by changing demand for products

Residents affect carbon price, mainly through enterprises, which is an intermediary (Table 3). Usually, with the increase in the demand for some products, enterprise will increase their productions, which will increase emissions. As a result, enterprises need more carbon permits, resulting in a higher carbon price and conversely, the carbon price will decrease. But sometimes we can see residents will consume more low-carbon products with the improvement of their low-carbon awareness so that enterprises will prefer to produce more low-carbon products, and this is a special case that enterprises emit less with the increase in demand. Residents buy shares or other financial derivatives through enterprises or financial markets according to their own expectations of product prices, which affects prices both in product market and in financial market; thus, it affects enterprises' decisions and then carbon price. Particularly, residents' investments on carbon financial markets will directly influence the carbon spot price (Zhang et al. 2015). Wei (2010) pointed out that different expectations on carbon financial markets will affect the carbon price. Low expectations of return rate lead to low demands for financial markets so that change in carbon price is clearer compared to that under high expectations of return rate, which is more irregular and has higher risks.

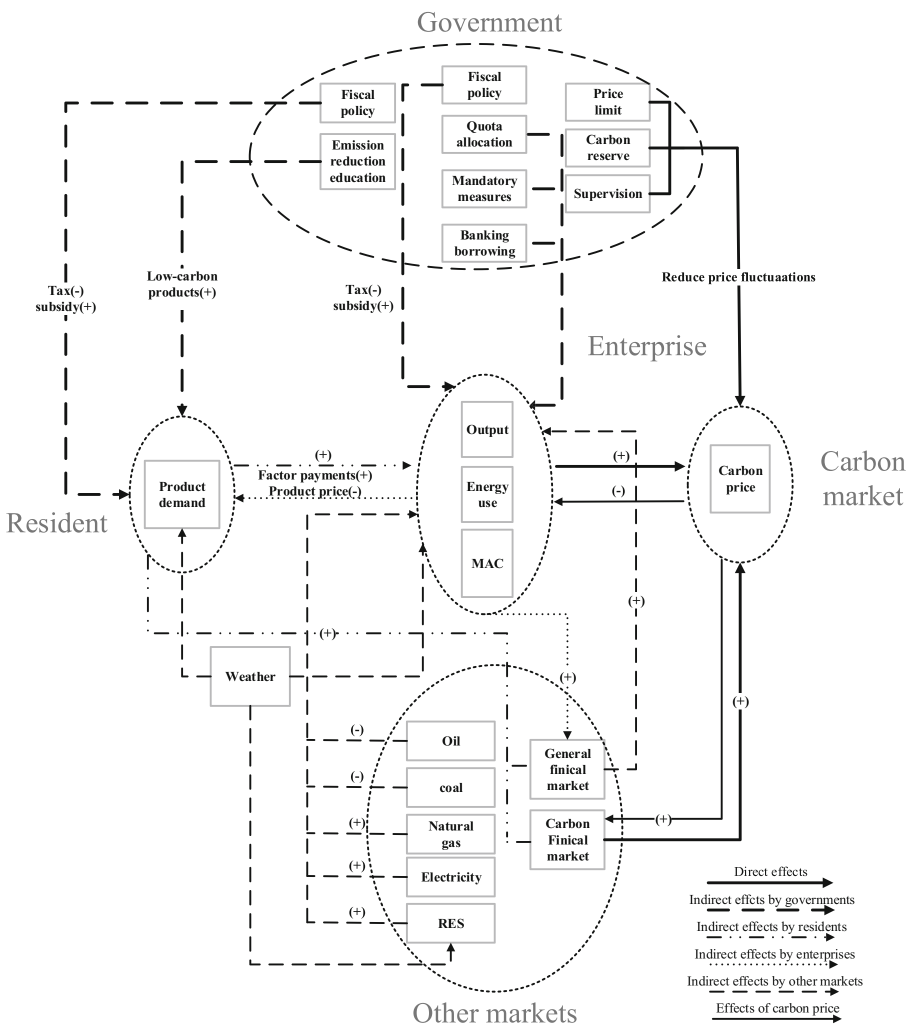

Fig. 3 Transmission diagram about the agents and influencing factors that result in carbon market price fluctuations

3.2 Enterprises' impacts on carbon price by controlling emissions and influencing consumer demands

There are two paths for enterprises to affect the carbon price (shown in Table 1). First, enterprises can control their own emissions to influence the demand for quotas. Second, enterprises can influence consumer demands to indirectly influence the demand for quotas. Besides, as investors, enterprises are also involved in financial markets, but the transmission mechanism of enterprises is similar to that of residents, we are not going to repeat.

Firstly, enterprises can directly affect carbon price by controlling their own emissions. Zhang and Wei (2011b) pointed out that two reasons can explain how economic activities of various enterprises in the EU-ETS can affect the carbon price. One is that industrial

Table 1 Transmission of carbon price by residents and enterprises

Agent	Transmission mechanism		Study
Resident	Change the demand for products to influence the production		Zhang et al. (2015)
	Affect carbon price by investing carbon financial products		Wei (2010)
Enterprise	Direct effects	Production	Chevallier (2015) Brink et al. (2016)
		Energy use structure	Wagner et al. (2015) Keen (2014) Bergh et al. (2013)
		MAC	Rubin (1996) Zhou et al. (2015)
	Indirect effects	Change residents' demand by factor payments and product price	Ma et al. (2014)

enterprises can influence the price of carbon market by selecting mitigation measures. The other is that industrial enterprises have been hedging their carbon allocations according to actual productions between 2005 and 2007. We summarize the factors that affect the actual emissions of enterprises as productions, energy use structure of enterprises and MAC. (1) The factors that influence the productions of enterprises are those that affect the products supply in the product markets. When the production of enterprises increases, enterprises are bound to emit more carbon dioxide; thus, it will increase the demand for carbon emission rights and raise the carbon price. In addition, interregional trade can affect productions and cause interregional carbon emission flows, thus influencing actual emissions. If trade-embodied emissions increase, carbon price will increase as the demand for quotas rises. Mi et al. (2017b) calculated emissions embodied in China's foreign exports that declined from 2007 to 2012, mainly due to production structure changes and efficiency gains. Chevallier (2015)confirmed that industrial production has a significant positive effect on carbon price in the EU-ETS by establishing TVAR model (threshold VAR model) and using Industrial Production Index of EU-27. Brink et al. (2016) evaluated that when GDP growth rate falls to 1.3% from 2.3% in EU, the carbon price falls from 11.1 to 6.7 euros, because production decrease will lead to fewer demand for quotas. (2) Energy use structure of enterprises is mainly influenced by adjustments and policy guidance to energy use structure in their countries, as well as their own awareness of energy emissions reduction. Once the enterprise improves energy use structure, it will reduce carbon emissions. Wagner et al. (2015) concluded that in 2014, while Germany exported more electricity than ever, the carbon emissions of German electricity industries were the second lowest over the years since 1990, because German electricity industries had been promoting renewable energy since 2000, including solar power and wind power, which made the non-fossil energy proportion increase significantly. The author further put forward a policy that promotes carbon price through promoting the development of renewable energy. Keen (2014) concluded that the development of renewable energy source (RES) has a significant negative effect on carbon price. Bergh et al. (2013) concluded that in the electricity sector the introduction of RES would result in the reduction of fossil energy share in power generation and the increase in share of RES would make the carbon price go down by 15 euro/ton in 2007, 46 euro/ton in 2008 and 100 euro/ton in 2010 at most. (3) MAC is a decisive factor of the carbon price, so carbon price will fluctuate with the change in MAC. If MAC is lower than carbon price, enterprises would rather reduce emissions rather than using carbon permits to reduce the demand for quotas. Rubin (1996) proposed MAC would affect the quota and the price, and provided three kinds of methods to reduce MAC, including emissions trading between enterprises with different MACs, internal conversions of different energies within enterprises and banking and borrowing of quotas. Zhou et al. (2015) evaluated MACs of different enterprises and found that the current carbon price in Shanghai carbon market was well below the estimated MACs, making the current Shanghai carbon market less effective in reducing carbon emission costs. In the future, carbon price needs to be raised by policy instruments.

Secondly, enterprises can affect residents' demand for products by changing factor payments of residents and prices of products (Ma et al. 2014) and then affect carbon price ultimately by the transmission of residents.

3.3 Government's impacts on carbon price by setting up carbon market mechanism and implementing policies to residents and enterprises

There are three paths for governments to conduct carbon price: direct transmission of carbon market mechanism and indirect transmission through residents and enterprises (Table 2).

Governments can formulate relevant policies to affect the carbon market directly. (1) Governments can design price ceilings and floors to avoid extreme fluctuations in carbon price. In Australian carbon market, when the price is lower than the floor, the government will levy extra tax. On the contrary, when the price is higher than the ceiling, the government will subsidize. Regional Greenhouse Gas Initiative (RGGI) has an auction floor price which has played a significant role in ensuring the price is not too low. (2)

Table 2 Transmission of carbon price by governments

Transmission mechanism	Measure	Study
Direct effect to carbon markets	Price limit	Tietenberg (2013)
	Carbon reserve	Word Bank (2017)
	Supervision	Twomey (2012)
Indirect effect to enterprises	Quota allocation	Alberola et al. (2008) Cong and Wei (2010) Hepburn et al. (2006)
	Tax and subsidy	Liang et al. (2016) Lin and Li (2011) Brink et al. (2016)
	Mandatory measures	Twomey (2012)
	Banking and borrowing	Alberola et al. (2008) Wei et al. (2010) Daskalakis and Markellos (2008) Chevallier (2011b)
Indirect effect to residents	Fiscal measures and emissions reduction educations	Tietenberg (2013)

Governments can implement the carbon permits reserve policy. When the carbon price is too high, the government will release enough permits to decrease the price, and when the carbon price is too low, the government will buy back permits to increase the price. China carbon emissions trading markets have already set up reserve system by setting a certain percentage of carbon reserves to buy or sell quotas to regulate supply and demand in the carbon market. (3) Governments' supervisions on carbon markets will affect the operational efficiency of the carbon market. Once the government relaxes the regulation on the carbon market, the market efficiency will be reduced and the emission reduction target will not be achieved. Twomey (2012) agreed that single-carbon-price policy will make the carbon market less efficient and result in market failure, because of the existence of information asymmetry, markets power, administration and other transaction costs. In this situation, governments should implement information provision or benchmarking, such as enterprises information disclosure mechanism.

Four paths can be used by governments to affect carbon price through the transmission of enterprises. They are quotas allocation and CER issuance, tax or subsidy policy, compulsive abatement policy and banking and borrowing of quotas, which can influence enterprises' demand for quotas to affect carbon price. (1) The quantity of quotas allocated to the enterprises will affect the enterprises' demand for quotas. Alberola et al. (2008) provided a rigorous econometric analysis to confirm that one of the major factors contributing to the volatility of carbon prices was the over-allocated or over-supplied mechanism design defect during the first phase of EU-ETS. Brink et al. (2016) evaluated that if governments set the linear reduction factor (LRF) from 1.74 to 2.52%, corresponding to an annual decrease in the cap of roughly 54 million quotas, the effective price in 2013 would increase from 6.7 to 11.1 euros with an 1.3% increase in GDP. Keen (2014) concluded that the quantity of CERs issued by government was significantly negatively correlated with the price of EUA, but he also pointed out that the use of CER was not the main factor affecting EUA carbon price. The ways of quotas allocation such as free and auction allocation together with the guidelines of quotas allocation will play an important role in enterprises' purchasing decisions of quotas. Cong and Wei (2010) pointed out emission-based allocation would lead to a higher carbon price than output-based allocation. The reason for that is when emission-based allocation is introduced, the proportion of economic producers (0.394) is larger than that when output-based allocation is introduced (0.328), under which situation enterprises pursue more economic interests rather than the environmental interests. They also argued that discriminatory price auctions and uniform price auctions act differently in determining the carbon price (2010). Hepburn et al. (2006) agreed that the 10% quotas auction issued in phase II would restrain price fluctuations during 2008–2012 and provide long-term price signals support in the following time. (2) By subsidizing or taxing enterprises that are greatly affected by carbon prices, governments can also make a difference in carbon price through the change in emissions of enterprises. If the governments implement subsidy or tax policies for enterprises, the actual payment of enterprises for marginal cost = carbon price − marginal subsidy (+ tax). When the enterprises' marginal benefits are constant, they will adjust their production decisions. The most common situation is that many OECD countries impose lower energy taxes on some industrial sectors or exempt energy taxes to ensure industrial competitiveness, while imposing higher energy taxes on electricity and heating sectors, thereby promoting their use of renewable energy. Liang et al. (2016) used the general equilibrium model to find that half of the sectors would export more than before if the government cut taxes after the carbon price policy. Lin and Li (2011) found that because of the tax exemption for carbon-intensive industries, the emissions of Nordic countries except Finland were not reduced under the carbon tax policy. Brink et al. (2016) evaluated the situation that governments impose energy taxes on EU energy sectors based on the carbon price. They found that the effective carbon price was higher than the BAU scenario at the beginning, but lower than the BAU scenario after 2021, which reflected that energy taxes could promote enterprises to reduce emissions so that they could reduce the demand for quotas. (3) The government can influence the carbon price through some mandatory standards or regulatory measures. Twomey (2012) summarized these regulatory instruments including renewable energy targets, renewable energy certificate scheme, electricity supply or pricing regulation, technology standard, fuel content mandate, energy efficiency regulation, mandatory assessment, audit or investment, synthetic greenhouse gas regulation, urban or transport planning regulation. For example, if governments force enterprises to replace high-energy technologies with more advanced technology by setting energy efficiency regulation, it will reduce enterprises' emissions, thus affecting the carbon price. (4) Whether governments allow banking and borrowing, that is to say, whether or not governments allow extra quotas in this phase to be used in next phase, or quotas from next phase to be used in this phase, has a significant impact on carbon price. Many scholars have confirmed that because EU-ETS did not allow banking and borrowing between phases one and two, carbon price fell to nearly zero at the end of 2007 (Alberola et al. 2008; Wei 2010; Daskalakis and Markellos 2008; Chevallier 2011b).

Governments affect carbon market through residents as transmission media, mainly by changing residents' income and consumption preference.

Governments influence residents' income and then alter residents' consumption decisions by transferring payments or changing residents' personal income tax rates. The Australian government transferred 50% of revenues from fixed carbon price during 2011–2015 to its residents; in the meantime, Sweden and Finland reduced residents' income tax rates, all of which were used to make sure that residents' disposable income would not be affected under the carbon price policy, or even their purchasing power would be increased (Tietenberg 2013). In addition, if governments strengthen the propaganda to residents of energy conservation and emissions reduction, for example, governments can provide residents with promotion and education of renewable energy, as well as some relevant provisions about showcasing renewable energy efficiency, consumers' preference toward clean products and their purchasing decisions will both be changed.

3.4 Other markets and weather impacts on carbon price

Other markets affect carbon price mainly through enterprises, which act as intermediaries. This paper selects the energy market, financial market and weather which affect the carbon price significantly (Table 3).

The volatility of energy prices in the energy market will influence energy use of enterprises, especially energy consumptions and carbon emissions of electricity sectors through their energy use. Fossil fuel burning is a main source of carbon dioxide, and the price of fossil fuels, including oil, coal and natural gas, has an important impact on the volatility of carbon price. For instance, enterprises will increase the use of natural gas or other relevant clean resources when their prices fall, so that they can improve energy efficiency and reduce emissions. On the contrary, enterprises will emit more carbon dioxide when the unclean resources like coal have a lower price. Wei (2010) used cointegration theory to find that there was a long-term and short-term interaction between energy prices and carbon price in EU-ETS and that changes in energy prices have an important impact on the fluctuation of carbon price at the second stage. Zhang and Wei

Table 3 Transmission of carbon price by other markets and factors

Agents	Transmission mechanism	Study
Energy market	Enterprises' choice of energy use	Wei (2010) Zhang and Wei(2011a) Keen (2014) Pradhan et al. (2017)
Financial market	Affecting enterprises on production	Keen (2014) Chevallier (2009)
	Carbon financial market directly affects carbon price	Liu (2012)
Weather	Consumer demand, enterprise production, energy price	Alberola et al. (2008) Wei (2010)

(2011a) pointed out that oil price was an important contributor to the change in carbon price, accounting for 37%, the next was natural gas, accounting for 37%, and the last was coal, accounting for 2%, which coincided with EU's energy consumption structure. Keen (2014) concluded that change in natural gas prices had a significantly positive influence on EUA price (at the 5% significance level) by regression, and he explained that a rise in natural gas prices would reduce the profits of gas-fired power plants, stimulate more carbon-intensive generation technologies to switch, and thus result in a rise in quota demands and EUA prices. Pradhan et al. (2017) analyzed data from China and India, based on the general equilibrium model, and concluded that carbon price can be affected by energy intensity and emissions coefficients as well as domestic and foreign energy prices. Foreign abatement costs and policies will affect domestic carbon prices through energy prices.

Price changes in financial markets can also be transmitted to carbon prices through its impact on enterprises. Financial markets are divided into general financial markets and carbon financial markets. Stock indexes or yield rates in general financial markets can reflect the development situation of current and future macroeconomy or industries. Once stock index falls, enterprises will cut down production. Conversely, when the economic situation shows an upward trend, enterprises will appropriately increase their production. Keen (2014) used regression analyses to find that the economic sentiment index (ESI) and stock index have great impacts on carbon price. A 1% change in ESI will cause a 1.2% change in carbon price, and a 1% change in stock index will result in a 0.7% change in carbon price. In the carbon financial market, carbon futures and carbon options have a price discovery function on the carbon spot markets. Chevallier (2009) showed that carbon futures prices have a significant impact on stock and bond yield rates through regression analysis. Liu (2012) used the price of CER futures to forecast the carbon spot price and found that using short-term historical data (about 1 month) to make a short-term forecast (in 1 week) has high accuracy. In addition, the financial markets will also bring investment returns to enterprises and residents, thus changing residents' consumption demands and enterprises' productions and then finally affecting carbon prices.

Weather has three main paths to affect carbon prices. Firstly, changes in temperature will affect residents in consumer demand for particular products. For instance, demand for heating will increase with the decrease in temperature, resulting in more emissions and a higher carbon price. Secondly, as an important external factor affecting the production of enterprises, the weather also has a significant impact on carbon prices. Extreme weather conditions will affect the production of enterprises, thus reducing emissions and lowering carbon prices. Thirdly, extreme weather can have a direct impact on wind and solar power generation, thus affecting energy prices and then carbon prices. Alberola et al. (2008) confirmed that extreme weather had a significant impact on carbon prices. Wei (2010) utilized EMD model to analyze carbon prices in EU-ETS and found that the carbon market was sensitive to temperature and seasons. Several big increases in carbon prices were related to temperature rising, and the increases were fast, while the declines were slow. In addition, carbon price rises in summer and falls later, which is mainly attributed to the greater peak of electricity use in summer.

3.5 Carbon price impacts on some agents of the carbon market

This article still discusses the effects of carbon price from the perspective of agents. Carbon price is mainly implemented to enterprises and sometimes to residents. As a result, carbon price will have great impacts on residents' consumptions and enterprises' production decisions (Grubb and Neuhoff 2006; Perry 2012; Li et al. 2014; Li et al. 2017). Baranzini et al. (2017) summarized the effects of carbon price, including emissions reduction, promotion of low-carbon development, decrease in abatement costs, promotion of technology innovation, reduction in energy rebound, mitigation of carbon leakage and guidance of consumers' low-carbon decision.

Firstly, carbon price will have effects on enterprises' production costs, outputs and prices. Carbon price weakens the competitiveness of carbon-intensive industries and causes carbon leakage. Liang et al. (2016) simulated how carbon price would affect the international competitiveness of Chinese tradable sectors using CGE model. And they found that the shares of all tradable sectors in domestic markets would decrease except the crude oil and natural gas sectors after introducing a carbon price with no alleviation policies. In both initial and terminal years, the sectors whose domestic market shares were most negatively shocked included petroleum processing, iron and steel, chemical, nonferrous metals and equipment manufacturing. For all sectors except crude oil, natural gas and electricity, the reductions in their domestic shares would become greater over time. Cong and Wei (2010) calculated that electricity price would increase by 12% after introducing a carbon price and the carbon price fluctuation would shift to the electricity market, which would increase the fluctuation of electricity price by 4%. Sugino et al. (2013) pointed out that the production cost of Japanese enterprises would increase by 5.351 trillion yen at the carbon price cost of 4000 yen/ton.

Secondly, the carbon price will have an impact on technological revolution and development of low-carbon technologies. Nicholson et al. (2011) researched the impact of carbon price on the competitiveness of five power generation technologies, which were coal (both pulverized fuel and integrated gasification combined cycle) with carbon capture and storage (CCS); combined cycle gas turbine with CCS; Generation III nuclear fission; solar thermal backed by heat storage and gas turbines. Among these five technologies, solar thermal was, by comparison, the least competitive, while nuclear was the most competitive with the increase in carbon price. Chen et al. (2017) pointed out that it is beneficial for the application of energy-saving technology in coal-fired power industry when the carbon price is rising. Liu et al. (2016) estimated how carbon price could affect the investment of low-carbon technology in Chinese cement industry. They found that levying a carbon price of 20 yuan/ton would generate a 2.6% increase in technology diffusion rate in the BAU scenario in 2015, levying a price of 60 yuan/ton would increase 6.3%, and 60 yuan/ton would increase 9.2% in the same year.

Carbon price will affect residents' social welfare as well. Introducing a carbon price will make product price, especially electricity price, increase, so that residents shall undertake part of the cost of carbon prices. Laing et al. (2014) concluded that the pass-through rate of carbon prices in electricity sectors in EU-ETS varied from countries to countries, with the lowest rate at 5% and the highest at 100%. Nelson et al. (2012) summarized the pass-through rate of carbon price in Australian carbon market, ranging from 17 to 393% due to the differences in models. Grottera et al. (2015) had an analysis based on Brazilian Social Accounting Matrix and concluded that carbon prices would cause unfairness in income distribution. They pointed out that increasing costs for energy consumption would make low-income groups obtain less disposable income. However, if the government used the revenues from the carbon price to compensate low-income groups, the income distribution would be improved. They also put forward that, on the other hand, the increase in product prices could guide residents for low-carbon consumptions and improve their low-carbon awareness.

Carbon price will also affect financial markets. Oberndorfer (2009) pointed out that there was a significantly positive correlation between the carbon price and stock markets. He found evidence for a particularly strong impact of EUA price fluctuations on electricity stock returns during the period of market shock in April and May 2006, when EUA prices fell from nearly 30 euros to approximately 10 euros in a few days only.

4 Mainstream carbon markets price mechanism

4.1 International mainstream carbon markets price mechanism

This article focuses on the current mainstream carbon markets, including EU-ETS, Korea ETS, New Zealand ETS (NZ ETS), California–Québec Cap-and-Trade System and Regional Greenhouse Gas Initiative (RGGI), as shown in Table 4. These carbon markets have been in operation for at least 3 years, whose market sizes are the top five in addition to the Chinese ETS and the newly established Ontario ETS.

At present, the balance between supply and demand forms the carbon price within the mainstream carbon markets. Consequently, the governments use market measures to regulate the carbon price from the perspective of supply and demand.

Firstly, governments set the carbon emissions cap and the quantities and qualities of carbon offsets. Moreover, they define the emission reduction enterprises, which forms the supply and demand of carbon quotas, thus forming the carbon price. Currently, the entire carbon markets set a tighter cap due to the over-supplied in the first phase and their commitments to emission reduction. In addition, they are stricter with the examination of carbon offset projects and reduce the proportion of the offsets in the cap or enterprises' compliance obligation.

Secondly, governments take advantage of the flexible instruments to adjust carbon price by affecting the supply and demand of the quotas. (1) Carbon reserve: Governments can distribute certain quotas when the carbon price is too high, while buying certain quotas when the carbon price is too low. All the carbon markets have established or have planned to establish relevant carbon reserve systems. (2) Banking and borrowing of the carbon quotas: Enterprises can reserve certain quotas unused in this phase and use them in next phase; enterprises can borrow certain quotas from the next phase when quotas are not enough to use in this phase and after governments have published the quota distribution

Table 4 Summary of the international mainstream carbon markets price mechanism

	Cap	Carbon offset	Banking and borrowing	Price regulatory
EU	Tighter by years; currently LRF is 1.74% and the next phase is 2.2%	Verification of offsets from foreign countries is stricter: unlimited in phase 2; allows offsets from LDC and others already signed an agreement with the EU in phase 3; not allows international offsets in phase 4	Banking is allowed; borrowing is not allowed	Price floor; establish a market stability reserve (MRS) in 2019
Korean	Tighter by years	Source and quantity limit: only allows domestic offsets in phases 1 and 2, up to 10% of entity's obligation; in phase 2021–2025, up to 10% of each entity's compliance obligation with a maximum of 5% coming from international offsets	Banking and borrowing are allowed, maximum of 20% of entity's obligation	Carbon reserve; adjusts offsets limit; adjusts borrowing limit; temporary setup of a price ceiling or price floor
NZ	Tighter by years	Not allows international offsets since 2015	Banking is allowed; borrowing is not allowed	Price ceiling
California–Quebec	Tighter by years	Source and quantity limit are stricter: currently up to 8% of each entity's compliance obligation, will decrease to 4% in phase 3 and more than 50% local offsets	Banking is allowed; borrowing is not allowed	Auction reserve floor price; allowance price containment reserve
RGGI	Tighter by years, LRF is 2.5%	Source and quantity limit: up to 3.3% of each entity's compliance obligation; only five offset types are allowed	Banking is allowed; borrowing is not allowed	Minimum auction price; cost containment reserve; trigger mechanism of offsets

plan of the next phase. All carbon markets except Korea only allow banking, while Korea allows both. (3) Trigger mechanism of carbon offsets: Governments can adjust the proportions of carbon offsets to affect the supply and demand of the carbon market, thus stabilizing the carbon price. The proportions of carbon offsets shall return to a normal level, after the carbon price has returned to a normal level. Both Korea and RGGI have set such trigger mechanisms. As a result, currently governments mainly stabilize the carbon price through carbon reserves and trigger mechanism of carbon offsets and then avoid the dramatic fall in carbon prices during the transition period of two phases by allowing banking.

Apart from adjusting supply and demand of the quotas to stabilize the carbon price, governments also set mandatory regulations, which function as price signals guiding the enterprises in order to reduce emissions, because the carbon markets are not mature enough and price formed by the balance between supply and demand cannot reflect the carbon price truly. For example, Korea and RGGI set an auction price floor to avoid the price to be too low to affect enterprises' enthusiasm for emission reduction.

4.2 China's carbon markets price mechanism

China has set up seven carbon emissions trading pilots until 2017; they are Beijing, Tianjin, Shanghai, Guangdong, Hubei, Chongqing and Shenzhen; and two carbon markets in non-pilot areas: Fujian and Sichuan.[1] Their price mechanisms are mainly orientated by international mainstream carbon markets. Hence, the balance between supply and demand of the quotas forms the carbon price. However, China's carbon markets are not mature enough so that governments have more direct controls over the carbon price (shown in Table 5).

In the China's carbon markets, the supply comes from quotas and CCERs, which are controlled by the governments. At the same time, these are the fundamental drivers of the carbon price formation. Under the influence of China's pledge of reducing emission and low carbon price, currently the cap of each carbon market is gradually decreasing. China's carbon offsets only come from the CCERs, and each carbon market makes different quantity limits to the use of offsets. Beijing, Guangdong, Hubei and Fujian even set a floor on the local source of offsets.

For the adjustments of carbon price based on the supply and demand, all carbon markets have reserved certain quotas to stabilize the carbon price, like most of the carbon markets. Furthermore, for the intertemporal use of quotas, only banking is permitted.

The distinct characteristic between China's carbon markets price mechanism and the international carbon markets is the direct price regulation policy. This policy aims to limit the price in a range of 10–30% in order to prevent large price fluctuations. Additionally, when quotas are distributed by auctions, governments will set up an auction price floor, such as Guangdong and Hubei that have a high proportion of auction. Nevertheless, the auction completion price of each carbon market is near the price floor.

5 Discussion

5.1 Designing price mechanism for China's carbon market

Future research will focus on the design of China's national carbon market price mechanism. The market mechanism of China's carbon emissions trading market is still being explored, and the carbon price between each carbon market is quite different. The average carbon price in 2016 is 31.88 yuan/ton in Beijing, which is the highest, and 5.07 yuan/ton in Shanghai, which is the lowest.[2] Firstly, in the carbon market price determination

[1] It should be noted that in this paper we discuss eight carbon markets in China except Sichuan, due to the lack of carbon emissions trading price in Sichuan.

[2] Source: Date are available at http://k.tanjiaoyi.com/.

Table 5 Summary of the China's carbon emissions trading scheme price mechanism

	Cap	Offset	Banking and borrowing	Price regulatory
Beijing	Tighter by years	Source and quantity limit: only allows CCER, limited to 5% of the annual allocation, at least 50% come from Beijing	Banking is allowed; borrowing is not allowed	Carbon reserve; price limit is 10% of the benchmark price
Chongqing	Tighter by years	Quantity limit: only allows CCER, up to 8% of compliance obligation	Banking is allowed; borrowing is not allowed	Price stabilization measures; price limit is 20%
Guangdong	Tighter by years	Source and quantity limit: only allows CCER, up to 10% of compliance obligation; at least 70% come from Guangdong	Banking is allowed; borrowing is not allowed	Carbon reserve; auction floor price; price limit is 10% of the opening price
Hubei	Tighter by years	Source and quantity limit: only allows CCER, limited to 10% of the annual allocation, must come from Hubei or from regions that have signed agreements with Hubei	Banking is allowed; borrowing is not allowed	Government reserve; price limit is 10%
Shanghai	Tighter by years	Tighten the quantity of offsets: only allows CCER, limited to 1% of the annual allocation from 5%	Banking is allowed; borrowing is not allowed	Price limit is 10%; carbon reserve; auction price floor
Shenzhen	Tighter by years	Quantity limit: only allows CCER, up to 10% of compliance obligation	Banking is allowed; borrowing is not allowed	Carbon reserve; price limit is 10% of the closing price the previous day
Tianjin	Tighter by years	Quantity limit: only allows CCER, up to 10% of compliance obligation	Banking is allowed; borrowing is not allowed	Carbon reserve; price limit is 10% of the weighted average price
Fujian	Tighter by years	Source and quantity limit: allows CCER and FCER, CCERs are up to 5% of compliance obligation, FCERs are up to 10%	Banking is allowed; borrowing is not allowed	Carbon reserve; price limit

mechanism, carbon price should be formed by the balance between supply and demand; as a result, on the supply side we need to consider the emissions cap, quotas distribution, offsets issuance as well as auction price. Though quotas are mainly distributed free in the current regional carbon markets, with the development of the carbon markets, more quotas shall be distributed by auction, so that we need to discuss how to set the auction price and how to connect the auction price with the quota trading markets. In addition, on the demand side, we also need to weigh the enterprises' demand for quotas. Secondly, in the price-adjusting mechanism of carbon market, the current price mechanism of China's carbon emissions trading markets mainly refers to the foreign price mechanism, but more use of non-market means to regulate the carbon price. In the future, national carbon markets should use market-based measures supplemented by non-market methods to adjust the carbon price, such as carbon reserve, banking and borrowing, trigger mechanism of price. Though carbon reserves are set up in all carbon emissions trading markets, they are rarely used in price adjustment, so that we need to consider how to better use the carbon reserve policy in the carbon price adjustment. In addition, in the carbon market, the price is affected by factors resulted from many agents such as resident's factors, namely, consumer demand, enterprise's factors, namely, productions, energy use structure and MAC, as well as factors payment and product price, government's factors, namely, carbon reserve policy, price limit, carbon market supervision as well as indirect fiscal policy, emission reduction education and other mandatory regulations. When we design the price mechanism, we should take the risk control measures into account to avoid the severe impact on carbon price made by these agents and factors.

As for newly established national carbon emissions trading market in the end of 2017, which only covers power sector temporarily, the following points should be noted particularly. (1) On the supply side, national carbon markets intend to introduce offsets and auctions gradually, and further study should consider when and how much offsets and auctions should be included. (2) On the demand side, China's electricity price is under the regulatory, so that power sector is unable to transfer cost through consumers, making no difference with carbon price through indirect transmission. When designing carbon price in the current national carbon market, only direct and indirect factors containing MAC, energy structure and government's policy that influence power sector production shall we take into consideration. In addition, as the government tends to lower the threshold to cover more sectors and enterprises, we are supposed to take more discussions on the choice of coverage sectors.

5.2 Quantitative analysis of influencing factors

Future research will focus on the use of top-down macroeconomic models such as computable general equilibrium (CGE) and integrated assessment models (IAMs) to make quantitative analysis of the factors that affect the carbon price. The current research on influencing factors of the carbon price is based on qualitative analysis, using econometric model (Alberola and Chevallier 2009; Chevallier 2011a, 2015; Keen 2014), and fewer research is based on quantitative analysis (Brink et al. 2016). Due to the lack of quantitative analysis, we cannot measure the specific influence of certain factors on the carbon price; therefore, it is impossible to make reasonable circumvention to some possible effects. As a result, we should use CGE or IAM to make quantitative analysis. For example, IAM can be used to assess the emissions and its social abatement cost under the scenario of economic growth, energy consumption and fuel fix, carbon emission peak, technological change and industrial structure change (Mi et al. 2017a, b). We can also introduce carbon emission trading and set more scenarios that will affect carbon price into IAM. In addition, we also can alter different variables in CGE that influence carbon price according to our research contents, such as constant elasticity of substitution of different input energies in the production block, tax and transfer payment in the income expenditure block and other carbon market mechanism designs in the newly established policy block. Finally, we can measure how much these different influencing factors will result in carbon price.

In addition, the carbon market should be regarded as an agent to comprehensively and quantitatively assess how all these key factors or related agents will affect the carbon price. Although there are articles measuring the importance of carbon price factors quantitatively, such as Zhang and Wei (2011a), Chevallier (2015), only the impact of energy price on carbon price has been studied, which has not been extended to all factors that affect the carbon market. Comprehensively measuring the importance of the key factors is of great importance to the detection of carbon price fluctuation. Future researches can utilize the transmission mechanism of carbon price based on the agents to make a specific assessment of agents or factors that affect carbon price.

5.3 Improving the carbon price theory

Future researchers can continue to improve the carbon price theory and do further study on the carbon markets' price elasticity of demand and its influencing factors of the supply and demand. The current carbon price theory comes from the equilibrium price theory and marginal utility theory, which regards that prices are determined by supply and demand. Nevertheless, according to the further deduction of marginal price equal to marginal revenue, we can get the pricing formula of enterprises in the non-perfect competition market, which is related to the price elasticity of the demand in the carbon market and MAC of the enterprises. At present, there is no study on the price elasticity of demand in the carbon market, so future studies can consider the estimate of the price elasticity of demand and then get a carbon price. In addition, currently, the influencing factors of carbon price are simply divided or listed (Aatola et al. 2013; Hintermann 2010; Chevallier 2011a, b, 2015) and have not formed a complete system, which makes the analysis of the influencing factors of carbon price not comprehensive.

6 Conclusions

This article focuses on the price mechanism and its influencing factors in the carbon markets. In terms of the price theory, we extend the price determination theory from general markets to the carbon markets. And then from perspective of the different agents, we analyze how they affect the carbon markets and how the effects transmit to the carbon price. Finally, we summarize the price mechanism in international mainstream carbon markets and China's carbon emissions trading schemes.

1. Carbon price is driven by MAC, price elasticity of demand and other factors that affect the supply and demand of the quotas. As the price theory shows, the price is set by the enterprise and then formed by the supply and demand. MAC and price elasticity of demand are the key factors when enterprises set the carbon price, and several factors affect supply and demand of the quotas resulting in the carbon price volatility.
2. This article analyzes the carbon market price transmission mechanism, from the upstream and downstream agents of the carbon price transmission. We divide the agents into residents, enterprises, governments and other markets including energy and financial markets and illustrate how different agents affect the carbon price. Residents mainly affect the carbon price by changing the demand for products in the product market and thus affecting the production decisions of enterprises. Enterprises affect the carbon price by changing their own demand for carbon quotas and influence consumer demand. There are three ways to change the demand for quotas: changing enterprises' production, adjusting energy structure and influencing the MAC. Governments affect carbon price by directly intervening in the carbon market and affecting consumer demand and enterprises' demand for carbon quotas. Among them, the direct intervention measures include setting a price limit, implementing the carbon reserve policy and strengthening the supervision of carbon market. Measures for affecting

consumer demand include changing residents' income and consumption preference. Measures for affecting enterprises' demand for carbon quotas include carbon quota distribution, fiscal policy, mandatory emission reduction measures and banking and borrowing. Energy market affects enterprises' emissions by changing energy prices. Changes in clean energy prices and changes in non-clean energy prices have the opposite effect on carbon prices. Financial markets affect the carbon market through price signaling. In addition, the influence of carbon price on partial agents is also analyzed. The main performance is the increase in production cost, the revolution of low-carbon technology and the increase in living cost.

3. Carbon price in the international mainstream carbon market is formed by supply and demand, and China's carbon emissions trading schemes mainly use non-market means to limit the price volatility. In the quota trading markets, carbon price is directly formed by the bid between enterprises or investors. In the quota allocation markets, the fundamental reason for the formation of carbon price is government's supply of quota and enterprises' demand for quota. In the foreign carbon market, the government mainly adjusts the carbon price by changing the quantity of carbon quotas and offsets, implementing the carbon reserve, price trigger mechanism and allowing banking and borrowing of the quotas. However, in our carbon market, government mainly uses the non-market means such as carbon price limit.

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