Carbon Neutrality

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Optimal city carbon emissions in China from a theoretical perspective

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Abstract

Cities are the main spaces to study a low-carbon economy. This paper introduces basic concepts covering "tolerance of planning carbon emissions," "inevitable carbon emissions" and "excessive carbon emissions," then discusses the problem with optimal city carbon emissions under the condition of tolerance. Theoretical analysis and scenario analysis were employed. First, according to optimal allocation theory of resources, we discuss how optimal society carbon emissions take place. Then, the deviation of optimal city carbon emissions was explored and analyzed, which was mostly caused by the missing price of carbon emissions allowance, excessive carbon emissions, and so on. Third, we analyzed optimal city carbon emissions under different conditions, in which different types of tolerance were included. Results show that theoretical investigations on optimal city carbon emissions provide relative ideas for determining control index and optimizing control countermeasures. Policy implications include improving the control index of city carbon emissions through environment enhancement, setting a reasonable control index of city carbon emissions under the consideration of the relationship between city economy and its environment, and establishing trading allowance and compensation mechanism of city carbon emissions, etc.

Keywords City carbon emissions, Inevitable carbon emissions, Excessive carbon emissions, Planning tolerance, Planning tolerance, China

1 Introduction

Climate change has become a strongly debated global issue for which carbon dioxide emissions is considered to be the main cause. Low carbon emissions in a city's economy promote the transformation of city development, and are one of the ways of employing the strategy of sustainable development, which is valued and practiced in many countries and areas.

China's annual carbon emissions have ranked first in the world since 2007, accounting for more than one-fifth of the world's total annual carbon emissions. Cities are responsible for a large proportion of these carbon emissions. China is currently in the middle stages of industrialization and has seen a high rate of urbanization, characterized by coal in energy consumption. China accounted for 27% of the world's total carbon emissions in 2019. In addition to affecting the global climate, a large number of carbon emissions also indicate that China's green economy is underdeveloped and its economic structure is in urgent need of transformation and upgrading [14]. Therefore, economic progress leads to high carbon emissions which results in pressure to reduce the emissions in China.

To solve the problem, the Chinese government initiated programs like "China's National Programme to Address Climate Change," "Work Notification on Low Carbon City and Province Pilot" [23–25], "Work Plan for Controlling Greenhouse Gas Emissions During the 12th Five-Year Period," and "China's National Plan on Climate Change (2014–2020)," including general requirements

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and work arrangements, to develop a low-carbon economy and to control carbon emissions in China. Substantial evaluations of China's low carbon development, including specific standards and requirements on "reducing CO_2 emissions of per unit of GDP," have been conducted in selected cities and provinces to achieve the goal of carbon emissions control.

The "greenhouse effect" has caused a series of serious problems such as climate change, which many countries have responded positively. In order to implement the new development concept and promote high-quality development, China has set a "two-carbon goal", namely carbon peak and carbon neutrality, referring to the sustainable development goal of win–win ecological protection and economic development by 2030. At the meeting, Xi Jinping mentioned that during the 14th Five-Year Plan period, China's ecological civilization construction has entered a critical period of taking carbon reduction as the key strategic direction, promoting pollution reduction and synergistic reduction, promoting the comprehensive green transformation of economic and social development, and realizing the improvement of ecological environment quality from quantitative to qualitative [5]. Based on the former two batches of low-carbon city pilots, the third batch of low-carbon city pilots has been required to meet the commitment to peak year of city carbon emissions [25].

Much of the research on optimal CO_2 emissions has been mainly on a global scale, based on economic models including maturity mode DICE [21, 22], modified mode DICE [28], SIAM [7], etc. Researchers think that greenhouse gases can be optimally discharged, and that it is reasonable to reduce CO_2 emissions in the economy of climate change [12], therefore a significant reduction of CO_2 emissions should be taken into account [28], which means the increase of temperature should be controlled below 3 °C in the 21st century [21]. In this case, the annual reduction of CO_2 emissions should be controlled at ± 3.2%. Different research studies have different results that are affected by disasters, cost evaluation, choice of discount rates and decision standards, morality (or ethics), and other factors [1, 28].

Based on the relationship between economic development and carbon emissions [41], as well as the optimal economic growth path or its circumstances, Chinese research studies have been conducted to determine, or predict, optimal carbon emissions or the index in various regions and domains of industry from the whole country [39], midland China [44], the provinces [8], and cities [42]. Qi and Xie summarize the principles, standards, and model methods in current space allocations of carbon emissions [27]. Yuan, with other scholars, analyzed the effects of allocation standards of carbon emissions allowances on coordinated development among regions using the CGE model [43]. Based on the perspective of energy structure optimization, the feasibility and the optimal path of realizing the dual control target of carbon emission reduction are proposed [37]. Xiang brings forward a distribution pattern of the carbon emissions index in industries [40]. Jiao believes that the administrative supervision system of carbon emission right trading should be improved by improving the regulatory laws and regulations system, unifying the regulatory rules and clarifying the legal responsibility system [9]. Some scholars aim to maximize the efficiency of regional carbon emissions or minimize net cost of carbon emissions to discuss optimal allocation of carbon emissions allowance [3, 6, 32]. In addition, some scholars analyze the relationship between optimal emissions and product price [18] as well as production [20] in companies based on profits or the maximum cost efficiency from the perspective of companies.

To summarize, it can be concluded that while the global research focuses on optimal carbon emissions, Chinese scholars focus on the allocation of carbon emissions or trading volume. Perspectives of the research are straight forward while studying optimal carbon emissions (allocation of total amount, trading volume, etc.) aiming either to maximize efficiency of carbon emissions or minimize net cost of carbon emissions in regions or companies (which is "top-down" market demand), or to achieve carbon reduction under optimal increase in a macro economy (which is the "bottom-up" task index).

Research in developed countries implies that the evolution of correlation in economic increase and carbon emissions follow the three rules of the inverted U-curve, which state: the "inverted U-curve of emissions intensity → inverted U-curve of per capita carbon emissions → inverted U-curve of total carbon emissions" [2, 17, 33]. Currently, four countries – UK, the Netherlands, Germany, and France – have experienced the accumulation of carbon emissions and the comparative reduction of carbon emissions, as well as having crossed the peak of carbon emissions and achieving an absolute reduction of carbon emissions. China's carbon emission stock has a large base effect, and the carbon emission pressure brought by urbanization and consumption upgrading, China has great pressure on carbon emission reduction [4], and is under the inflection point's value of the inverted U-curve of per capita carbon emissions (37,170 yuan per capita, and which maintained the same levels in 2000) [15].

Since China is in the midst of high-speed urbanization and industrialization currently, the Chinese government can not hinder the economic growth to reduce environmental pollution [11]. Carbon emissions

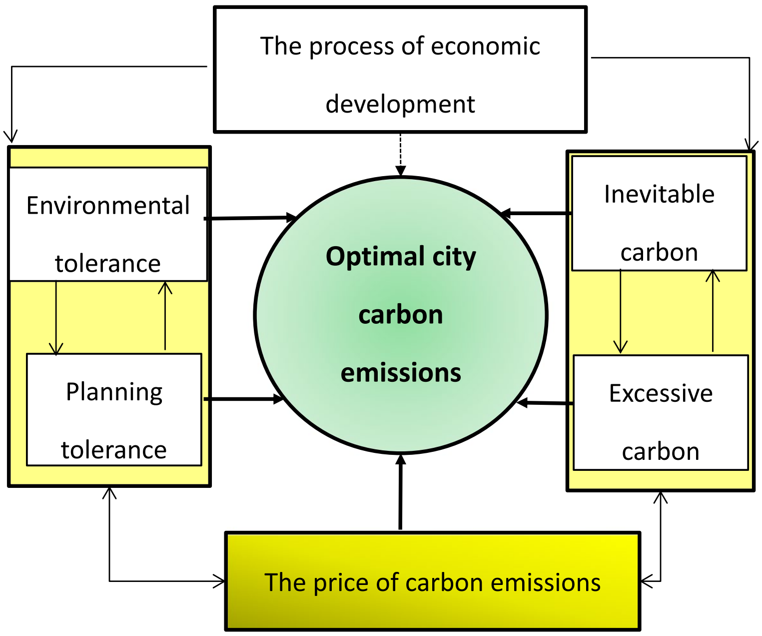

Fig. 1 Analysis framework

will increase inevitably, especially in cities, which will aggravate global climate change and result in environmental pollution. Therefore, it is necessary to control carbon emissions reasonably with the development of the economy. The question becomes, how can optimal carbon emissions in cities be determined under limited environmental capacity? With the increasing development of the trading market's pilots of carbon emissions allowance in China, and the role played in the market's "decisive effects" and government's "regulative effects," "top-down" and "bottom-up" theories on optimal carbon emissions in cities will provide new ideas for an ideal solution for economic growth and carbon reduction in cities.

2 Method and analysis framework

2.1 Method

It has been established that the way to study optimal carbon emissions is the quantitative model. Based on the assumption of optimal economic allocation of resources and environment, the basic concept of "inevitable carbon emissions" is introduced in this paper, and the analysis framework of optimal carbon emissions is established. Considering the reality in China, scenario analysis is used to explore the existence and influence of city carbon emissions in China.

First is the problem of excessive city carbon emissions. Considering China's rapid economic growth, carbon emission in cities is inevitable, the amount of which, in certain cities, should be ranged appropriately. This paper discusses the concepts of "inevitable carbon emissions" and "excessive carbon emissions," controlling for the constraints of carbon emissions. Just as natural environments can eliminate and contain the pollutants, urban pollutants caused by carbon emissions are also qualified with a specified tolerance. Since carbon emissions and pollutants come from the same sources, city carbon emissions have certain tolerance from the perspective of nature, which is termed "environmental tolerance" of city carbon emissions. From the perspective of management, urban carbon emissions should be controlled through administration such as city planning to achieve optimal carbon emissions. "Planning tolerance" is adopted to discuss urban carbon emissions.

2.2 Analysis framework

First, this paper is based on the optimal allocation theory and explores the problem of optimal society carbon emissions. Second, deviation of carbon emission framework is also discussed. Third, the trend of urban carbon emissions through scenario analysis is explored. The overall analysis framework used in this paper can be demonstrated through Fig. 1 as shown here.

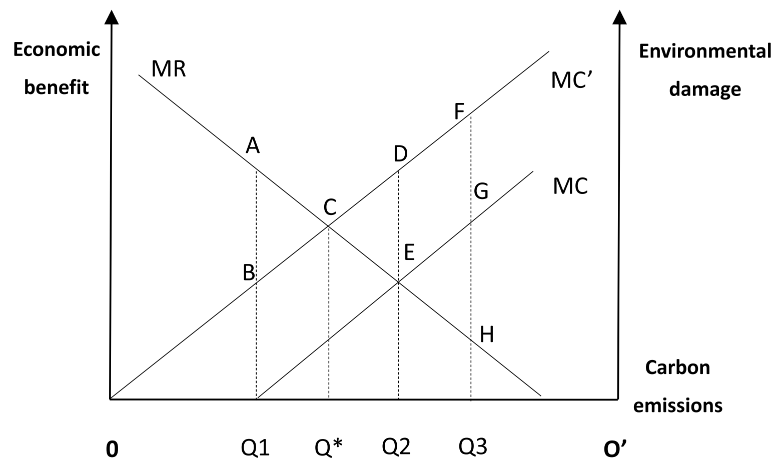

Fig. 2 Optimal city carbon emissions under the tolerance. (Note: 0O' refers to city carbon tolerance under the assumption that planning tolerance is consistent with environmental tolerance)

3 Optimal society carbon emissions

According to the optimal allocation theory of resources, equality of marginal cost and marginal revenue is the condition for optimal allocation of resources. Therefore, optimal carbon emission's analysis models in societies are established in this paper, as demonstrated by Fig. 2. In Fig. 2, MR refers to marginal revenue in economy[1] (which can be shown by GDP "exchanged" through the increase of carbon emission units); MC refers to marginal cost of carbon emissions, which is carbon emission units' economic value on local (separated by GDP on administrative regions) environmental damages (or called marginal revenue of carbon emissions); MC' refers to economic value at the cost of carbon emissions on the environment, including damaged economic value of the city and out of it.

Here, "Carbon emissions" are qualified as a special "resource," when its marginal revenue in economy equals the marginal cost of carbon emissions, and carbon emissions reach optimal carbon emissions in societies. Therefore, city carbon emissions should be put on the Q* point. Only, when carbon emissions are at Q* point, allowances of carbon emissions of city allocation will reach optimum levels in societies, and economic growth and low carbon development will achieve the ideal "win–win" solution, instead of the dilemma. Q*O' allocation reaches optimal turnover of carbon emissions in carbon emission trading market under the premise that the environmental tolerance is large enough and planning tolerance[2] equals environment tolerance.[3] However, the reality is complicated by several factors such as the price of carbon emission allowance, significant externality, government's inconsiderable intervention, and the "tournament" system, which may lead to inconsistency of the city's actual carbon emissions and optimal carbon emissions.

4 Deviation of optimal city carbon emissions

4.1 Influence of price on carbon emissions allowance

CO_2 emission space is provided with resources, and as a new resource [16], its considerable allocation is the basic "win–win" solution in promoting economic development and carbon emission reduction. Market mechanism is the key to solving the carbon emission problems and optimizing allocation. Recently, the Chinese government

[1] This implies an assumption that carbon emissions are positively relative to economic activities in the short term – as structures of industry and energy with technological development and institutional environment are fixed, and that with an increase of economic activities and consumption in land and energy, pollutant and carbon emissions will increase in turn.

[2] Considering the uncertainty of goals in steady climate changes, complexity of the relation between carbon emissions and pollutant emissions, extreme difficulty of calculating theocratic tolerance, and the high cost of calculation and management, it is hard to perform calculations of city carbon emissions in climate and environmental science. Under the pressure of international carbon emissions reduction and estimation of present economic development, carbon emission tolerance is determined by "top-down" index decomposition, reflecting a decrease of unit GDP carbon emissions (carbon emission intensity). This is called "planning tolerance" of carbon emissions, and reflects the requirements of "top-down" carbon emission control.

[3] From the perspective of the environment and meteorology, specific climate resources in a region that bear the number, intensity and scale of natural systems and economic activities in human societies, which is climate tolerance, is limited [26]. Pollutant emissions or carbon emissions have a certain tolerance range or threshold value. In the tolerance, an environment can purify and recover itself, and the index in carbon emission tolerance is called "environment tolerance" of carbon emissions, which reflects the maximum of carbon emissions of regional ecological environment.

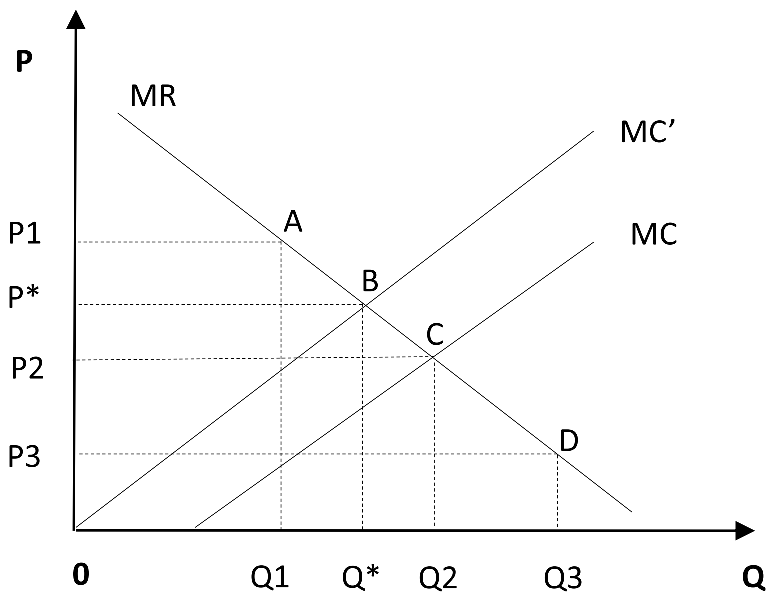

Fig. 3 The relationship between carbon emissions and carbon emissions prices

established the carbon emissions trading market in some provinces and cities by borrowing from foreign experience [29]. In 2021, Shanxi province will launch a pilot project of green electricity trading and actively promote the low-carbon energy transformation. With the green power certificate, enterprises convert a certain amount of carbon emission reduction, saving their own carbon emission right quota, which serves as an important basis for carbon emission reduction in carbon emission verification [19]. Price is the core of the market system, an essential way to evaluate cost and regulate supply and demand, and a necessary factor in studying optimization market behavior and derivative.

In Fig. 3, Prefers to the price of carbon allowance, and Qrefers to carbon emissions; MR refers to market revenue in economy, and MC refers to carbon emission units' economic value on local environmental damages (which correspond to marginal revenue of carbon emissions). Theoretically, there are three kinds of prices in carbon emissions allowance – first, P* refers to equilibrium price formed in both marginal cost of carbon emissions (MC', including internal and external environmental damages) and marginal revenue of the economy; second, P2 refers to equilibrium price formed in both the marginal cost of carbon emissions (MC, excluding environmental damages beyond regions) and marginal revenue of carbon emissions; third, P1 and P2 refer to equilibrium price affected by intervention factors in trading (including the central government's strong control and local government's weak control and execution). As demonstrated by the figure, when the price is at P* point, carbon emissions are at OQ* point; when the price is at P2 point, carbon emissions are at OQ2 point; when the price is at points P1 and P3, carbon emissions are at OQ1 and OQ3 respectively. Therefore, carbon emissions will lead to excessive emissions when its price is zero or too low.

At present, China's city carbon emissions control is given priority over strength index and administrative management, with a lack of a sound carbon emissions trading mechanism [43], which is incomplete in the carbon market, low in trading price, and narrow in the field of development of projects [38]. According to Chris P. Nielsen, the director of China's program in Harvard university, the "limit" in carbon emissions in China is non-specific in "carbon trading", because the "limit" in carbon emissions is dependent on energy-intensive industries and the GDP, which lead to non-specific "limit" of carbon emissions and a non-specific carbon price, and on that, cannot reflect effects related to emission reduction (Neilson qtd. by [34]).

4.2 Excessive city carbon emissions

Considering the present environmental management system and the GDP assessment system, as well as insufficiency in consideration of environmental damage values by local governments, P3, which is the specific allowance price of carbon emissions in China's rapid economic development presently, and which is weakly intervened or "indulged" by local governments, is more realistic compared with P1 which turns out to be excessive carbon emissions. Therefore, this paper combines optimal carbon emissions in societies with the present process of carbon emissions in Fig. 2 and divides city carbon emissions into (1) inevitable carbon emissions and (2) excessive carbon emissions.

(1) Inevitable carbon emissions: Inevitable carbon emissions signify that city development will inevitably lead to the consumption of various resources such as land, energy, and so on [35, 48], which causes necessary and reasonable carbon emissions regionally. It is also the necessary carbon emissions in a city's economic and social development in the market with its complete functions, which is the inevitable and reasonable cost of economic growth. The standard of "reasonable cost" is achieved after the internalization of carbon emission externality. The allocation of carbon emission allowance reaches the relative free market equilibrium, which is OQ^* in Fig. 3 as inevitable cost. Inevitable carbon emissions, to some extent, are survival emissions, the establishment of which index is essential to maintaining the survival and development rights of everyone on earth [46].

(2) Excessive carbon emissions: Carbon emissions is a general term or abbreviation for greenhouse gas emissions. Excessive carbon emissions refer to the part exceeding inevitable carbon emissions without internalization of externalization in carbon emissions, including excessive carbon emissions I and excessive carbon emissions II. Excessive carbon emissions I is Q^*Q2, referring to the excessive emissions underestimated by their effects on cross region that fails to incorporate non-market value, integrating environmental damages outside the regions by carbon emissions in regional economic growth into cost-effective decisions due to market failure. Excessive carbon emissions II is Q2Q3, referring to regional excessive carbon emissions due to the intervention or indulgence of the government, distorted or unreasonable prices of carbon emission allowance, and ignorance or exclusion of the market on allocation of carbon emissions. The behaviors of local governments and processes of carbon emissions are the process of "public choice".

In reality, local governments are not only the agents of the central government but also act on behalf of the local micro-entities on interests (enterprises, individuals and other organizations), and may tend to "bargain" with and "object to" the central government on sustainable development policy [10]. Due to the current system of fiscal decentralization and the institutional arrangements by local governments in China, excessive city carbon emissions are caused by ignorance or perfunctory carry-out, with the aim of controlling carbon emissions, and by pursuit of the maximum on GDP, fiscal revenue and political performance in local governments.

5 Optimal city carbon emissions under tolerance

A lack of carbon emissions markets and excessive carbon emissions fail to reach optimal carbon emissions at a city level. How to determine optimal carbon emissions in cities under environmental and planning tolerance will be discussed on different scenarios. In Fig. 4, C1 represents marginal social cost in carbon emissions management, and C2 represents marginal social cost in environmental damages caused by carbon emissions; $Q_{capacity}$ represents the environmental tolerance of city carbon emissions, and $Q_{capacity1}$ with $Q_{capacity2}$ represents two of the environmental tolerance cases; Q_G represents planning tolerance of city carbon emissions. To simplify the analysis process, this paper assumes marginal social cost of carbon emissions will move only on C_2.[4]

Scenario I: $Q_{capacity} = Q_{capacity\ 1}$, city carbon emissions stay within the environmental tolerance of city carbon emissions. In this case, optimal carbon emissions Q^* can be calculated when the marginal cost of carbon emissions management equals the marginal cost of carbon emissions damage. At this point, if the carbon emissions index (Q_G) is higher than Q^*, carbon emissions will be expanded to Q_G point by local governments, but the marginal cost of carbon emissions management will exceed the marginal cost of carbon emissions damages which is not optimal for the economy. If the carbon emissions index (QG) is lower than Q^*, governments will control carbon emissions to Q_G point, and the marginal cost of carbon emissions management will be less than the marginal cost of carbon emissions damages, which is not optimal for the economy of cities as well, because the incentive mechanism is incomplete for local governments to control carbon emissions without compensation.

Scenario II: $Q_{capacity} = Q_{capacity\ 2}$ city carbon emissions stay beyond the environmental tolerance of city carbon emissions. In this case, carbon emissions from economic activities will exceed city environmental tolerance.

[4] When regional carbon emissions exceed their environmental tolerance, marginal social cost of carbon emissions may be "leap-frogging" on those whose cost curve moves upward. In the short term of settled technological development, the relative curve of marginal cost of carbon emissions management may move upward to form a new balance point of carbon emissions. In terms of small regions of environmental tolerance (such as $\mathbf{Q_{capacity2}}$), new balance points will be only more than, or equivalent to, environmental tolerance (L2 and its right sides). Theoretically, optimal carbon emissions in economy will depend on the changing ranges between the marginal social cost of carbon emissions and the marginal cost of carbon emissions management. Relative problems remain to be further discussed in the future.

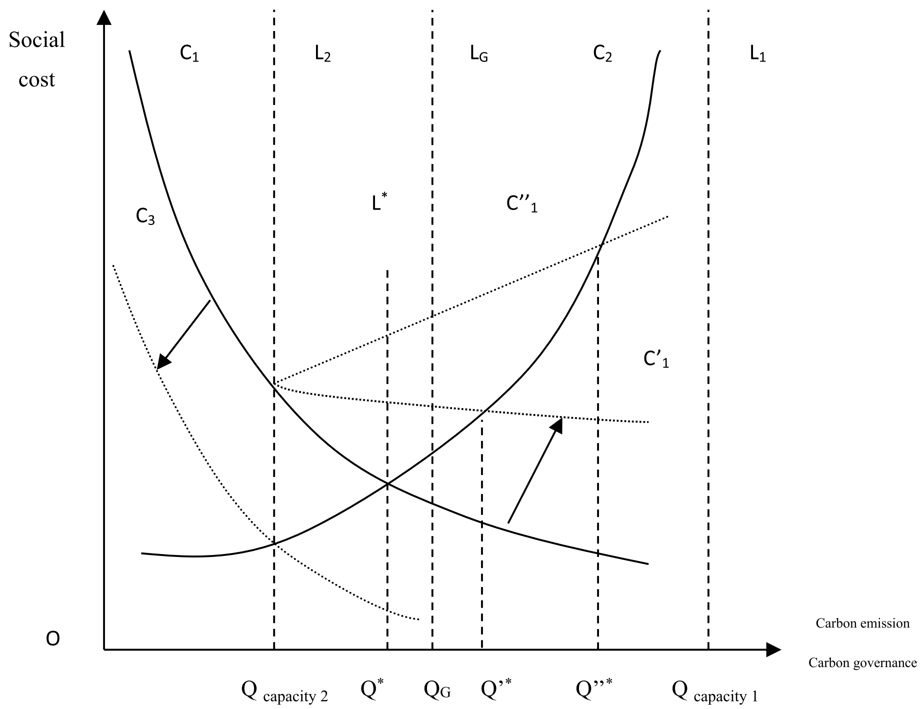

Fig. 4 Optimal economic orientation and city carbon emissions trends

Therefore, marginal cost of carbon emissions management will achieve the "leap-frog"[5] effect with its curve moving up when the technical level remains, which comes to C'_1 or C''_1 from C_1 (in extreme circumstances). Considering economic optimum principles only, optimal carbon emissions in the economy will reach Q'^* or Q''^*. In this case, city carbon emissions will tend to increase and be far-off from Q^*, the initial optimal carbon emissions in the economy; city carbon emissions will also be far-off from $Q_{capacity2}$ (the environmental tolerance of carbon emissions), and form a vicious cycle which is "the excessive growth of carbon emissions – non-green economic growth – the excessive growth of carbon emissions." At this point, however large or small the carbon emissions index (Q_G) is, it is difficult to curb the trend of excessive carbon emissions effectively in cities. Less-developed areas lack sufficient economic technologies and the gradient transfer of high-carbon industries; therefore, it is hard to keep the marginal cost of carbon management down from C1 to C3 even in the long period of time to realize optimal carbon emissions in the economy under environmental tolerance. This is why it is hard to control ecological deterioration in less-developed areas.[6]

6 Policy implications and discussion

6.1 Policy implications

The determination of the optimal carbon emissions and the trading of carbon emissions allowance in cities under tolerance can help avoid the "excessive" carbon emissions in cities, optimize the allocation of carbon emissions allowance, establish a "win–win" situation in city economic development and carbon reduction. How to achieve the optimal carbon emissions in Chinese cities, the government policy can be derived from the theoretical analysis of this paper:

(1) The relationship between the city economy and the environment should be given priority, and the control index of city carbon emissions should be determined reasonably. In reality, due to asymmetric information, there is a continuous and lagging two-

[5] When carbon emissions exceed environmental tolerance, damages to environment are more than the carbon emissions in tolerance ranges and relative management costs will grow larger as well, which is far beyond the marginal cost of the whole society. The phenomenon is called "leap-frog" in this paper. In this case, scale effect of carbon emissions management will be weakened or dismissed, therefore it is shown not only in the upward move of management cost curves, but may appear as an extreme rise of the cost curve.

[6] Studies have shown that carbon emissions intensity in most western provinces or pilot cities tends to be high [30]; with the backdrop of eastern industries transferring to the west, a high proportion of coal consumption in energy, rapid industrialization and urbanization, intensification of land use, and the backwardness of technological development, carbon emissions tasks in less-developed provinces increase sharply so that a few provinces fail to compete.

way action mechanism between economic development and the increase of environmental pollutant emission, and a lack of a carbon emissions trading market, especially in the economic or fiscal "tournament" system, local governments or enterprises tend to increase short-term economic (profit) and fiscal revenue with frequent occurrence of "governments entwining companies" [47], and carbon emissions will increase rapidly, which will lead to degradation of the city environment consequently. Studies have shown that a rise in the proportion of environmental losses and environmental management costs in GDP offset the economic growth.[7] In addition, accelerating the reduction of carbon emissions will affect the economy negatively when low-carbon facilities and technologies are incomplete and less widespread [45]. Therefore, with the comprehensive consideration of "economic optimum" and "environmental tolerance", optimal city carbon emissions can be determined and achieved to realize and coordinate sustainable development in cities.

(2) Balancing the principle of efficiency and equity and establishing and bettering trading of carbon emissions allowance, a carbon emissions transfer and compensation system will be put into use. Different cities should focus on different regulations and control of carbon emissions, especially in giving priority to less-developed cities with a fragile environment. Considering the technology of carbon emissions management, the natural environment, industrial structure, energy structure, development of urbanization and opening-up, and ownership structure that lead to a difference in intensity[8] and efficiency of carbon emissions in cities [13], integrating the achievement of total carbon emissions. Pilot areas including the current seven provinces and cities should be extended for trading carbon emissions, so that the national market will be established to reduce costs of carbon emissions and realize the maximum of allocation of carbon emissions allowance as a whole.[9] In addition, to maintain the high speed of economic development and realize the present goal of carbon reduction, a better command of space transfer in city carbon emissions and economic benefits should be taken into account, a reasonable transfer of carbon emissions in China's provinces should be effectively guided [31], and a complete system of coordinating carbon emissions should be established [13]. Meanwhile, based on equity development theories, active external compensation by carbon emissions control should be given to less-developed areas with fragile environments, and the support to cities in less-developed areas by developed areas should be strengthened in technology, foundation, intelligence and so on to shoulder the "responsibilities" of large amounts of carbon emissions.

(3) Moreover, policy implications also include improving the environment; raising environmental tolerance in city carbon emissions; establishing estimation over carbon emissions with their environmental damages and system of public information; determining prices of carbon emissions allowance considerably; building diversified entity coordinated and incentive mechanisms and system; improving the evaluation system of local government performance to strengthen environmental responsibilities; and develop low-carbon technology.

6.2 Discussion

(1) First of all, optimal carbon emissions in specific cities should be based on practical statistics, where critical index refers to marginal revenue of economic activities, and marginal cost of carbon emissions. Economic activities vary from carbon emissions; thus, it is necessary to refine industries to obtain marginal revenue. In terms of marginal revenue of carbon emissions, average marginal cost should be calculated based on city reality and specifically evaluated, the effects of which on carbon emissions inside cities may be different outside the cities.

[7] "China Green National Accounting Study Report 2004" shows that China's economic losses in 2004 are about 511.8 billion yuan caused by environmental pollution, accounting for 3.05% of the GDP in 2004. As "China Green National Accounting Study Report 2004 (Public Version)" shows, the costs of ecological environmental degradation reached 1.538,95 billion yuan, accounting for 3.5% of GDP in 2004. This means that China's environment is depreciating with the high speed of economic development. In addition, McKinsey pointed out that costs of carbon emissions reduction can only fall to 40 euro per ton, accounting for 0.6–1.4% of global GDP in carbon emissions reduction, even with technological development and efficient control by 2030.

[8] According to reports, Wang Jingnan thought that the intensity of carbon emissions is the control of its total; if intensity of carbon emissions is increased solely, it will be difficult to calculate and allocate in practice [36].

[9] Because the effects on global climate change by equivalent CO_2 emissions in different countries remain the same, there is no difference in its effects on emissions regions, and a carbon leak may fail to realize the aims of global CO_2 reduction. According to reports, Wang Jingnan thought that carbon trading is more suitable to trade in cross regions and any extra decrease cannot be achieved by market trading, which can cut down costs of carbon emissions reduction with the aim of slashing and controlling the total amount [36]. Regions are different in coping with carbon emissions changes; therefore, eco-fragile regions are easier to be affected directly and indirectly by carbon emissions.

(2) Second, there is an essential, potential assumption in the paper that economic structure and technological development are settled. However, the economic structure, technological development, and policy environment are changing constantly in the long term. Thus, continuous amendment is needed.
(3) Third, the effects of research boundaries on optimal carbon emissions are remarkably different in excessive carbon emissions. Based on different research purposes and requirements, optimal carbon emissions in different ranges can be evaluated including city agglomerations "coordinating" optimal carbon emissions, which will be a significant step to cooperate in cities, establish trading systems and regional optimal carbon emissions. Therefore, empirical studies on different levels should be conducted intensely, and enrich theoretical analysis.
(4) Finally, Under the background of China's system, this paper discussesed the optimal urban carbon emissions from a theoretical perspective, and its research ideas can be used for reference to the research on other countries' cities optimal carbon emissions. However, it needs to be pointed out that for cities in different countries or different cities in the same country, due to the differences in planning systems and governance systems and their different levels of development and stages of development, the actual optimal carbon emissions are also dynamic.

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Authors' contributions
JC contributes to Section 1 (Introduction), Section 4 (Deviation of optimal city carbon emissions). XM contributes to Section 2 (Method and analysis framework), Section 3 (Optimal society carbon emissions), FH contributes to Section 5 (Optimal city carbon emissions under tolerance). and Section 6 (Policy implications and discussion

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Competing interests
The authors declare that they have no competing interests.

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