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Effects of government regulations on Manufacturer's behaviors under carbon emission reduction

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Abstract

This paper shifts the discussion of low-carbon technology from science to the economy, especially the reactions of a manufacturer to government regulations. One major concern in this paper is uncertainty about the effects of government regulation on the manufacturing industry. On the trust side, will manufacturers trust the government's commitment to strictly supervise carbon emission reduction? Will a manufacturer that is involved in traditional industry consciously follow a low-carbon policy? On the profit side, does equilibrium between a manufacturer and a government exist on deciding which strategy to undertake to meet a profit maximization objective under carbon emission reduction? To identify the best solutions to these problems, this paper estimates the economic benefits of manufacturers associated with policy regulations in a low-carbon technology market. The problem of an interest conflict between the government and the manufacturer is formalized as a game theoretic model, and a mixed strategy Nash equilibrium is derived and analyzed. The experiment results indicate that when the punishment levied on the manufacturer or the loss to the government is sizable, the manufacturer will be prone to developing innovative technology and the government will be unlikely to supervise the manufacturer.

Keywords Carbon emission reduction · Pollution · Government regulations · Traditional technology · Innovative technology · Nash equilibrium

Introduction

With the rapid development of China's economy, environmental issues have drawn more attention from Chinese society. Over the past 14 years, facing increasing gas and wastewater emissions, the Chinese government has increased its financial support for environmental pollution mitigation, and the growth rate of investment in environmental pollution abatement increased quite rapidly over these years, as shown in Fig. 1. However, from 2003 to 2007, the growth rate of direct economic losses caused by environmental pollution was far higher than the growth rate of indemnity and fines following pollution incidents. After that period, the growth rates of direct economic losses and indemnity and fines were comparable, as shown in Fig. 2. While the Chinese government has been increasing its financial support for environmental pollution abatement, a series of cross-national contracts on environmental protection created incentives for the Chinese government to regulate gas and wastewater emissions; however, the effect of government regulation is not significant regarding the direct economic loss caused by environmental pollution. It is obvious that, although the punishment of manufacturers that are involved in environmental pollution has increased over the past years, it can hardly offset the direct economic losses and gas and wastewater emissions.

Since the put forward of "Porter hypothesis" in 1990s, it has been widely believed that government regulations is conductive to innovation, and technological progress of enterprises (Jaffe et al. 1995). However, some research finds that government regulations will increase the production cost of enterprises, and decrease production investment. Government regulations can influence the input capacity of independent

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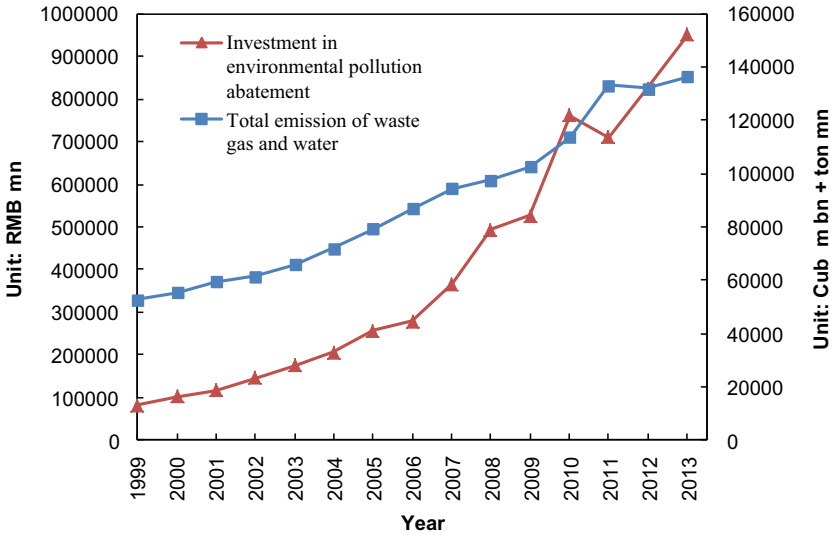

Fig. 1 Gas and waste water vs. investment in environmental pollution abatement (National Bureau of Statistics of the People's Republic of China 2013)

innovation, which will affect the growth of total factor productivity(Jorgenson and Wilcoxen 1990).There seems to be an U-shaped relationship between government regulations and technological progress in middle and east of China (Zhang et al. 2011). Government regulations reduced industrial pollution level in middle and east of China; however, it showed little effect in western region of China (Wang and Zhang 2011). With the increasing attention of green economy, a few scholars begin to focus on the research of environmental regulations on industrial total factor productivity. The intensity of environmental regulation of heavy polluting industries is relatively reasonable, which promotes the improvement of green total factor productivity, technological innovation, and efficiency improvement (Li and Tao 2012).

Take the implementation of《Classification scheme of acid rain control zone and SO_2 pollution control zone》as a natural experiment analysis object, after implementing the regulation of "two control zone," compared with non "two control zone" city, per capita GDP of "two control zone" city increased by 8.3%, per capita industrial GDP increased by 16.8%. This means that the implementation of appropriate and strict environmental regulation can promote the development of social economy and realize the win-win situation of environmental protection and economic growth. So, it is unclear whether indemnity and fines levied on companies should be related to the direct economic losses incurred by the government or whether the government regulations regarding environmental protection work. Moreover, we want to explore what kinds of environmental protection regulations are feasible for manufacturers and the extent to which the amount of punishment for environmental pollution behaviors is effective.

The main motivation behind the idea that government regulation is necessary to improve environment protection under economic development comes from a well-known hypothesis proposed by Kuznets (1955), who argued that income inequality in a nation would first rise and then fall with economic

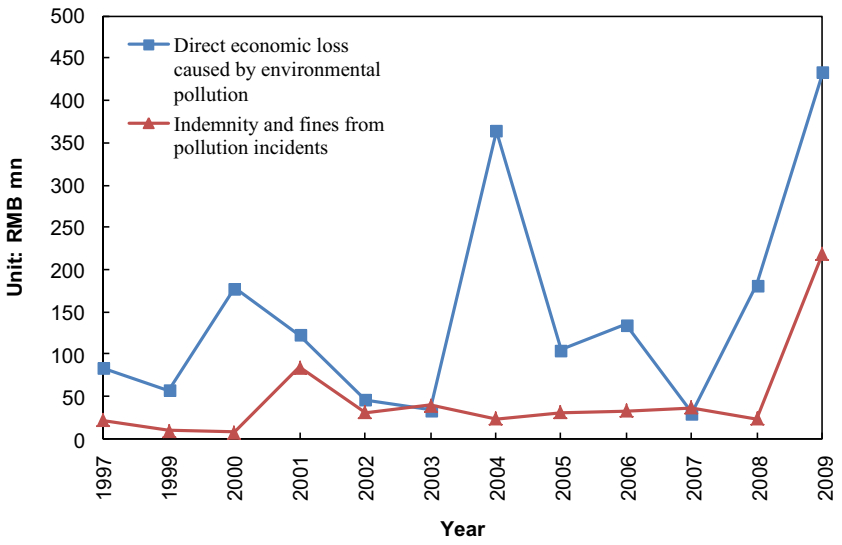

Fig. 2 Comparison of direct economic losses and indemnity and fines for pollution (National Bureau of Statistics of the People's Republic of China 2009)

development. The environment Kuznets curve (EKC) follows the proposed Kuznets curve that indicates that environmental degradation could not be avoided during early stages of economic development and that environmental pollution would be resolved as the economy became richer (Tan et al. 2014). Many studies followed the EKS, differing in terms of the country chosen, the period covered, the econometric techniques employed, the income and energy consumption levels, and the output and pollution levels (Akarca and Long 1980; Erol and Yu 1987; Hwang and Gum 1991; Masih and Masih 1997; Yang 2000; Jumbe 2004), but not much work has been conducted on the relationship between government regulation and environmental techniques. This paper seeks to contribute to the literature by exploring the relationship between government regulations and environmental techniques employed in a China-specific context.

Relationship between government regulations and manufacturer behaviors

The government's attitude towards environmental protection will affect the public's behaviors, and political polarization regarding the environment can extend to the public (McCright et al. 2014). Government efforts towards conducting environmental audits can affect environmental quality (Huang et al. 2014). Business activities, which are responsible for a major portion of pollution, are often the focus of environmental policy. Government regulations are important policy tools to incentivize businesses to engage in environmental protection. Jeffrey and Perkins (2014) found that overall business spending and business investment expenditures are positively related to government regulations. Under government regulations, businesses that are subject to environmental protection can make the desired changes. The findings from Tang et al. (2010) showed that local government support had some, but not decisive, influence on the effectiveness of environmental protection. Policy tools that are applied to environmental protection usually include financial mechanisms. Antoci et al. (2012) proposed a "satisfied or reimbursed" mechanism in which unsatisfied customers could ask for refunds of the money spent on a given good or service. From a dynamic view of regulation implementation, the government may set intermediate goals on the political level, testing what will help achieve a long-term goal. Freytag et al. (2014) studied the potentially positive effects of intermediate government goals on efficiency. While government regulations can monitor companies reducing pollution, the benefits are still vague compared to the economic losses caused by environmental pollution. Moreover, most environmental protection behaviors impede cost effectiveness, and companies that have incentives to follow government regulations have to make sizable investments in technological innovation. Economists have hypothesized that a major portion of environmental goals could be achieved at a lower cost through an incentive-based system that imposes appropriate taxes and charges (Elkins 1999). A key focus of recent governmental policy tools is the imposition of energy taxes to regulate environmental pollution (Aldy et al. 2008). For China, environmental and carbon taxes are just on the agenda, and the most relevant tax that is correlated with environmental protection is the resource tax. Pigou (1920) introduced the idea of taxing pollution and noted that natural resources were often considered societal assets, and the value of natural resources has not been factored into the costs of doing business. In this way, if the cost of environmental pollution could be internalized by companies and the government could develop regulations to motivate this outcome, then companies would pay to generate pollution and the behaviors of companies could be regulated. Government regulations can create competitive disadvantages for companies that use traditional technologies and compensate those that explore innovative, environmentally friendly technologies. The merits and drawbacks of various policy mechanisms have been subject to significant debate, and most discussions concentrate on the effectiveness of policy models (Hanlon and Heitzman 2010), the preconditions of implementing political tools for environmental protection (Aldy et al. 2008), and the benefits of government regulations for environmental protection (USCBO 2008).

Considering the current situation of environmental protection and industrial development in China, especially in the industrial field of environmental protection, where administration, market, and people all participate, environmental regulations were mainly the type of command-and-control before 1970s. During 1970s–1980s, incentive environmental regulations had become an important supplement to command-and-control environmental regulations. After 1990s, voluntary environmental regulation such as information disclosure, participation mechanism, environmental labeling have increasingly captured considerable attention (Zhang et al. 2015). Different government regulations have different effect on green growth, administrative and market type of government regulations contribute to the increase of industrial green growth, market type of government regulations are effective in highly greening area, and administrative type of government regulations are mainly implemented in poor environment, and people participated type of government regulations have limited effect on industrial green growth.

Previous studies of environmental protection focus on analyzing whether government regulations effectively benefit environmental protection, on policy tools and on policy mechanisms. Few studies consider the effects of environmental protection among both government and companies. Amouzegar and Moshirvaziri (2001) modeled an environmental problem between decision makers and followers as a

Stackelberg game. The difference between this study and the existing literatures is that this study combines government regulations with manufacturers' behaviors and explores the equilibrium to evaluate the performance of individual strategies under carbon emission reduction.

Problem description and model formulation

Many scholars have studied the problem of pollution abatement through game theory. By establishing game model of pollution abatement between the government and enterprises, obtained the balanced strategies and explained the strategic interaction of government and enterprises in pollution abatement. Through analyzing the pollution behaviors of enterprises in different equilibrium status to further explore how to effectively control pollution in the sustainable utilization of resources.

It is difficult for enterprises to consciously perform environmental protection behaviors out of self-interest. In most cases, environmental protection can usually be considered as a multi participant problem, and the linkage between enterprises and government should be taken into account, so as to achieve the goal of environmental protection. Mixed integer programming model has been used to study the design of green supply chain (Chaabane et al. 2011). Newsboy model has been used to analyze a Stackelberg game between carbon emission permit suppliers and manufacturers (Liu et al. 2012). Most of the existing literatures focus on the operation optimization or supply chain coordination of enterprises under the carbon emission permit, carbon tax, and carbon trading background. Few literatures focus on the interactive strategies taken by government and enterprises under environmental protection.

Consider a manufacturer who committed to carbon emission reduction under the supervision of a local government. The game with a manufacturer and a government proceeds as follows: the government proposes regulations to restrict carbon emissions by the manufacturer; if the manufacturer follows the government regulations, it has to adopt innovative technology. The problem is that the manufacturer has to decide whether to adopt innovative technology (i.e., low-carbon technologies) in manufacturing or whether to use traditional production technologies. The government chooses whether to inspect the manufacturer's innovative technology application behaviors. Assume that the application of low-carbon technologies is the only way to affect carbon emissions. The government prefers to control the manufacturer's behavior from the source of emissions rather than tracing its eventual carbon footprint, so implementing regulations is the government's action. Thus, the manufacturer needs to decide whether to use innovative technology.

Assume that the manufacturer would have a fixed income R regardless of whether it uses a traditional technology or an innovative technology. However, the manufacturer's variable costs are incurred when the government takes different actions. The government always has a fixed satisfaction level G whether supervising or not supervising the manufacturer's behaviors. However, the variable satisfaction level would emerge if the manufacturer cheats the government on carbon emissions.

If a manufacturer chooses to implement innovative technology H, it follows the government regulations on carbon emission reduction. The manufacturer's payoff of this strategy is R. From the government's viewpoint, whether it supervises the manufacturer's behavior or not, carbon emissions will always be reduced. However, it will cost the government i to supervise an obedient manufacturer.

If a manufacturer chooses to use traditional technology C, it cheats the government regulations. The manufacturer's revenue will be affected by the government's reactions. In this case, if a government supervises the manufacturer's behavior, which can be expressed as A, then it will save the government i units of satisfaction and cost the manufacturer l units due to cheating. However, if the government fails to supervise the manufacturer's cheating behavior, which can be expressed as N, then the government will be at risk and face k units of satisfaction loss, and the manufacturer will win i units of additional revenue.

Thus, manufacturer's total revenue is given byy_E:

$$y_E = R + hx_E x_G - lx_E(1 - x_G) \tag{1}$$

where x_E is an introduced variable, $x_E \sim N(0-1)$, and let

$$x_E = \begin{cases} 1, & S_E = C \\ 0, & S_E \end{cases} = H \tag{2}$$

where S_E is the manufacturer's strategy set $S_E(H,\ C)$, l is the manufacturer's extra loss when caught cheating by government in carbon emission reduction.

The government's satisfaction level is given byy_G:

$$y_G = G - kx_E x_G + i[(1 - x_G)x_E + (1 - x_E)x_G] \tag{3}$$

where x_G is an introduced variable $x_G \sim N(0-1)$, and let

$$x_G = \begin{cases} 1, & S_G = N \\ 0, & S_G = A \end{cases} \tag{4}$$

where S_G is the government's strategy set $S_G(A,\ N)$.

Given the foregoing assumptions, the payoffs of the manufacturer under different strategies can be deduced:

$$\begin{cases} y_E = R, & if\ S_E = H \\ y_E = R - l, & if\ S_E = C\ and\ S_G = A \\ y_E = R + h, & if\ S_E = C\ and\ S_G = N \end{cases} \tag{5}$$

The payoffs of the government under different strategies can be derived:

$$\begin{cases} y_G = G, \ \ if\ S_E = H\ and\ S_G = A \\ y_G = G + i, \ \ if\ S_E = H,\ S_G = N\ or\ S_E = C,\ S_G = A \\ y_G = G{-}k, \ \ if\ S_E = C\ and\ S_G = N \end{cases} \tag{6}$$

where

$$R, G, l, h, i, k > 0 \ \ , \ \ l > h, \ \ and \ \ k > i. \tag{7}$$

Equilibrium of government and manufacturer's strategies

If a manufacturer believes that the government is going to supervise its technology selection behavior, then the manufacturer's best response is to choose the innovative technology. On the contrary, if a manufacturer believes that the government will not supervise its technology selection behavior, then the manufacturer's best response is to keep using the traditional technology. However, if a government believes that the manufacturer will follow regulations and choose the innovative technology, then the government's best response is to not supervise. If a government does not believe that the manufacturer will follow regulations, then its best response is supervising the manufacturer's behavior. Thus, the best responses of the government and the manufacturer never coincide, so there is no pure strategy Nash equilibrium. However, a mixed strategy Nash equilibrium exists.

Assume that the government's mixed strategy is $(p, 1-p)$, and the manufacturer's mixed strategy is $(q, 1-q)$. Thus, p is the probability that the government supervises the manufacturer's behavior, and q is the probability that the manufacturer chooses the innovative technology.

First, to find the government's Nash equilibrium mixed strategy, the manufacturer's payoffs from adopting the innovative technology and maintaining the traditional technology must be equal. Since the manufacturer is mixing in selecting technologies to meet carbon emission reduction requirements, choosing the innovative technology and choosing the traditional technology must both be best responses. Then, the expected payoff to the manufacturer of choosing the innovative technology is $Rp + R(1-p)$, and that of choosing the traditional technology is $(R-l)p + (R+h)(1-p)$. Since both options are the government's best responses, they must yield the same payoff given by:

$$Rp + R(1{-}p) = (R{-}l)p + (R+h)(1{-}p) \tag{8}$$

On the side of the manufacturer, the Nash equilibrium mixed strategy should be based on the payoff of the government. The expected payoff to the government of supervising the manufacturer is $Gq + (G+i)(1-q)$ and that of not supervising manufacturer is $(G+i)q + (G-k)(1-q)$. Since both options are the manufacturer's best responses, they must yield the same payoff:

$$Gq + (G+i)(1{-}q) = (G+i)q + (G{-}k)(1{-}q) \tag{9}$$

Therefore, from Eqs. (8) and (9) we have

$$p = \frac{h}{h+l} \tag{10}$$

$$q = \frac{i+k}{2i+k} \tag{11}$$

So, if the government is mixing strategies, its best response is $\left(\frac{h}{h+l}, \frac{h}{h+l}\right)$, which means that government supervises the manufacturer's behavior with probability $\frac{h}{h+l}$ and overlooks the manufacturer's behavior with probability $\frac{l}{h+l}$. If the manufacturer is mixing strategies, its best response is $\left(\frac{i+k}{2i+k}, \frac{i+k}{2i+k}\right)$, which means that manufacturer adopts the innovative technology with probability $\frac{i+k}{2i+k}$ and adopts the traditional technology with probability $\frac{i}{2i+k}$. Thus, the mixed strategy Nash equilibrium of the government and the manufacturer is $\left[\left(\frac{h}{h+l}, \frac{h}{h+l}\right), \left(\frac{h}{h+l}, \frac{h}{h+l}\right)\right]$.

Proposition 1 A *mixed strategy Nash equilibrium exists when the mixture for the government between supervising and not supervising the manufacturer's behavior is* $\left(\frac{h}{h+l}, \frac{h}{h+l}\right)$, *and the mixture for the manufacturer between adopting the innovative technology and maintaining the traditional technology is* $\left(\frac{i+k}{2i+k}, \frac{i+k}{2i+k}\right)$.

Analytical behaviors of government and manufacturer under different conditions

Case 1 Government leans towards supervising the manufacturer Suppose that the manufacturer observes that government, instead of leaning towards supervising its behavior with probability $\frac{h}{h+l}$, leans towards supervising its behavior with a probability of more than $\frac{h}{h+l}$. The manufacturer's best response is adopting the innovative technology, where $R > R - l$, which can maximize the manufacturer's revenue. If the government leans towards supervising manufacturer's behavior more often, by more than probability $f\ \frac{h}{h+l}$, then the manufacturer's best

response is actually a pure strategy: always adopting the innovative technology.

Case 2 Government leans towards not supervising the manufacturer Suppose that the manufacturer observes that government does not lean towards supervising its behavior with probability of more than $\frac{l}{h+l}$. The manufacturer's best response should be maintaining the traditional technology, where $R+h>R$, which maximizes the manufacturer's revenue. If the government leans towards not supervising the manufacturer's behavior more often, with more than probability $\frac{l}{h+l}$, then the manufacturer's best response is actually a pure strategy: maintaining the traditional technology.

Case 3 Manufacturer leans towards the innovative technology Suppose that the government observes that the manufacturer leans towards adopting the innovative technology with a probability of more than $\frac{i+k}{2i+k}$. The government's best response is not supervising the manufacturer's behavior, where $G+i>G$, which maximizes the government's satisfaction level. If the manufacturer leans towards adopting the innovative technology more often, with a probability greater than $\frac{i+k}{2i+k}$, then the government's best response is actually a pure strategy: not supervising the manufacturer's behavior.

Case 4 Manufacturer leans towards the traditional technology Suppose that the government observes that the manufacturer leans towards adopting the traditional technology with probability of more than $\frac{i}{2i+k}$. The government's best response should be supervising the manufacturer's behavior, where $G+i>G-k$, which maximizes the government's satisfaction level. If the manufacturer leans towards adopting the traditional technology, with probability of more than $\frac{i}{2i+k}$, then the government's best response is actually a pure strategy: supervising the manufacturer's behavior.

Effects of a low-regulation scenario on manufacturer's behaviors

Now, consider a low-regulation scenario to account for how government regulation may affect the manufacturer's carbon emission reduction behaviors. In the low-regulation scenario, where regulation would increase the government's satisfaction level to $G+i^{'}(i^{'}>i)$ when the government detects that the manufacturer is using the traditional technology. The manufacturer's income will decrease to $R-l^{'}(l^{'}>l>h)$ if it is caught using the traditional technology by the government.

Compared with the prior analysis, the game has changed. Because the government has a higher satisfaction level when detecting that the manufacturer is using the traditional technology, the manufacturer will receive a harsher punishment when it is caught using the traditional technology. How are the strategies of government and manufacturer affected? Will the manufacturer be less likely to use the traditional technology?

There is no pure strategy Nash equilibrium. However, a mixed strategy Nash equilibrium exists. Due to the government's higher satisfaction level from detecting the manufacturer using traditional technology, the government should supervise the manufacturer's behavior more often than it did before. This phenomenon is defined as a direct effect. However, the manufacturer learns that the government's satisfaction level has improved, so the manufacturer will avoid using the traditional technology more often than it did before. This phenomenon is defined as an indirect effect. The problem is determining which effect will be dominant.

In light of models (10) and (11), it is relatively straightforward to find the new government and manufacturer equilibria. They are presented below:

$$p=\frac{h}{h+l^{'}} \tag{12}$$

$$q=\frac{i^{'}+k}{2i^{'}+k} \tag{13}$$

As is shown, the government's new equilibrium mix is $\left(\frac{h}{h+l^{'}},\frac{h}{h+l^{'}}\right)$, and the probability that the government supervises the manufacturer's behavior will decrease even though it can obtain a higher satisfaction level by supervising. The manufacturer's new equilibrium mix is $\left(\frac{i^{'}+k}{2i^{'}+k},\frac{i^{'}+k}{2i^{'}+k}\right)$, and the probability that the manufacturer maintains the traditional technology increases even though it will be punished more harshly if it is caught. Thus, it is evident that the indirect effect dominates, which is contrary to our intuition.

This phenomenon can be interpreted as follows: the government follows a low-regulation policy, which can bring it a higher satisfaction level and cause more losses to the manufacturer. If the probability that the government's strategy is supervising is higher, the manufacturer will only adopt the innovative technology. This cannot produce equilibrium. The government decreases the probability of supervising the manufacturer's behavior, which brings the manufacturer to equilibrium.

Proposition 2 *If the government implements a low-regulation policy that only increases the satisfaction level of the government and causes more losses for the manufacturer when the government catches it using the traditional technology for carbon emission reduction, then the government will not increase the probability of supervising the manufacturer's*

behavior, and the manufacturer will not decrease the probability of adopting the traditional technology.

Effects of high-regulation scenario on the manufacturer's behaviors

Consider a high-regulation scenario to account for how government regulation affects the manufacturer's carbon emission reduction behaviors. In the high-regulation scenario, both the government's satisfaction level and the manufacturer's income would decrease if the government fails to supervise a manufacturer using the traditional technology.

In view of the prior analysis, government's new equilibrium mix is $\left(\frac{h}{h+l'}, \frac{h}{h+l'}\right)$. It is obvious that the probability that the government supervises the manufacturer's behavior will decrease even though its satisfaction level will be lower if it fails to supervise the manufacturer using traditional technology. However, the manufacturer's new equilibrium mix is $\left(\frac{i+k'}{2i+k'}, \frac{i+k'}{2i+k'}\right)$, and the probability that the manufacturer maintains the traditional technology will decrease due to its acknowledgement of the government's punishment. Thus, in this scenario, the government can improve its payoff by supervising the manufacturer's behaviors, and the manufacturer will follow government regulations on carbon emission reduction.

Proposition 3 *If the government implements a high-regulation policy that decreases the government's satisfaction level considerably when the government fails to supervise the manufacturer using the traditional carbon emission reduction technology and causes a larger loss for the manufacturer when it is caught using the traditional technology, then the government will is not likely to supervise the manufacturer's behavior, and the manufacturer will lean towards adopting the innovative technology.*

Numerical experiments

In this section, the following numerical experiment is conducted to measure the probability that the government supervises the manufacturer's behavior p and the probability that the manufacturer chooses the innovative technology q. Previous models show that $p = \frac{h}{h+l}$, $q = \frac{i+k}{2i+k}$, and here, we use $1-q$ for simplicity. Since l, h, i, $k > 0$, $l > h$, and $k > i$, and the result is summarized in Fig. 3 by Maple. It shows that the smaller difference between l and h or k and i, the more equal the government and manufacturer strategies. Figure 3 indicates that when the punishment for the manufacturer is far larger than the additional revenue received by chance as $\frac{l}{h} \to +\infty$, the probability that the government supervises the manufacturer $p = \frac{h}{h+l} \to 0$ is considerably smaller. The government is less likely to supervise the manufacturer's behavior. When the government experiences a greater loss of satisfaction from failing to supervise a manufacturer using the traditional technology as $\frac{k}{i} \to +\infty$, the probability that the manufacturer adopts the innovative technology is $q = \frac{i+k}{2i+k} \to 1$, which will be larger. The manufacturer will definitely commit to developing an innovative technology. The results are consistent with Propositions 2 and 3. Under a situation with larger government and manufacturer losses, the government will not supervise the manufacturer, and the manufacturer's strategy is developing an innovative technology that is beneficial to environmental protection.

This phenomenon can be explained by Proposition 3, which implies that if the government introduces harsher punishments for manufacturers that exceed emissions limits and matches indemnity and fines to the direct economic losses, the manufacturer will increase its investments in environmental improvement facilities and develop innovative technologies for environmental protection. The direct economic losses can be considerably reduced.

Findings reveal the bilateral relationship between government regulation and manufacturer behavior, manufacturer's speculative behavior will affect government supervision, on the other hand, government regulations also affect manufacturer's choice of technology strategy, where has not been deeply involved in previous research. Specifically embodied in different strategic emerging industries, government rules and regulations on the binding force of manufacturer behavior are different.

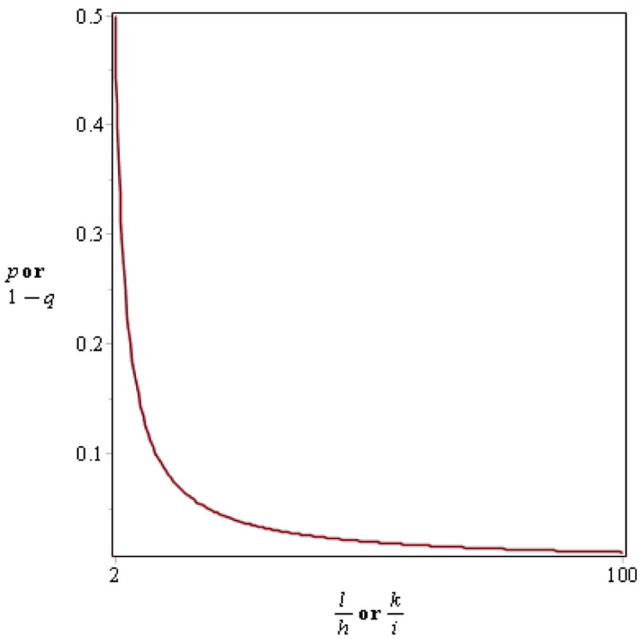

Fig. 3 Effects of rewards and penalties on the probabilities of government and manufacturer's behaviors

For China new energy industry, government regulation is mainly based on the past behavior of enterprises and previous innovation technology obtained and evaluated, identification of enterprise technology input can be highly recognized, the supervision cost of government in the regulation action is relatively low. It is easy to check out enterprises who do not comply with government subsidy, therefore government supervision and punishment is effective in the new energy industry.

For the new generation of information technology industry, the government's inspection cost is large, and even difficult to inspect the market, which restricts the implementation of government regulations to enterprise behavior. For example, Chinese government has subsidized enterprises for the implementation of energy-saving appliances since 2005, including air conditioning, TV, refrigerator, washing machine, and water heater. However, there exists cheating behavior among some well-known enterprises, like Hisense and Skyworth. They changed product efficiency information to meet the energy consumption standard without organizing technological innovation research activity. Compared with the great temptation of subsidy, the cost of illegal cheating is very low. According to the 《energy efficiency labeling management measures》, if enterprises virtually mark the energy efficiency, they will be punished "stopping the usage of energy efficiency label within a time limit by the local energy management department or the local quality inspection department; or will be fined ten thousand yuan by the local quality inspection department if the circumstances are serious.". Noticeably, the punishment is not implemented by the government departments who distribute subsidies, so they are not correlated with the amount of subsidies. It can be speculated that the department who distribute government subsidies do not have the ability of detecting energy-saving products, thus their inspection cost is very high regardless how much penalties will be fined, and government regulation can hardly play the role.

Conclusions and managerial implications

In this paper, we have studied the strategies of the government and the manufacturer in a low-carbon economy. We assume that the government prefers to supervise the manufacturer's behavior at the source of emissions rather than tracing the eventual carbon footprint, so implementing regulations is the government's action. In this way, the manufacturer needs to decide whether to use the innovative technology.

The Nash equilibrium shows the best strategies of the government and the manufacturer in carbon emission reduction. We show that a mixed strategy Nash equilibrium exists when the government supervises the manufacturer's behavior with probability $\frac{h}{h+l}$ and the manufacturer adopts the innovative technology with probability $\frac{i+k}{2i+k}$. We also show that under different kinds of government regulations, the manufacturer's technology decisions are varied.

Some enlightening managerial implications can be drawn from this paper as follows: government strategies should include rigorous low-carbon regulations in planning and closely engaged in the nation's development plan. Rules and regulations should be proposed with rewards and punishments, and preferential policies need to support enterprises in developing low-carbon technologies. Some recommended solutions include, but are not limited to, firstly, improve the efficiency of government regulations of enterprises and reduce government inspection cost. For strategic emerging industries, government subsidies should be set in relevant supervision organization, and the staff should be familiar with industrial policy guidance and business, in order to avoid high supervision cost due to circumvention behavior caused by enterprises. Meanwhile, government departments with product testing ability should be coordinated with third party qualification agencies to improve the professional efficiency of inspection. Secondly, government should increase penalties for enterprise that violates environmental protection rules, which will be a strong deterrent to enterprise that is hesitant in technology selection. It can promote more enterprises to invest more government subsidies into strategic emerging business. And reduce the density of government supervision, and improve work efficiency of the government. Strengthening the access threshold for the technical level and scale of production for new enterprises; closing down outdated production capacities by collecting progressive taxes according to the technical level and the scale of production of existing companies; procuring new energy-saving products; subsidizing prices; and restrict high energy consumption, high water consumption, and high resource consumption. Thirdly, accelerate cultivating strategic emerging industries. Most enterprises would not invest much in R&D and production in strategic emerging industries, because market demand of energy-saving products is insufficient, it is difficult for enterprise to attain minimum effective scale. Investing in energy-saving products and environmental protection areas, promoting the buying and selling of energy-efficient appliances and low-emission cars; making and popularizing energy-efficient housing policies.

Related to this topic, some require further research: due to the nature of government regulations, improvements in the environment may not emerge over the short term. Under an emissions trading system, emission reductions may not last

unless the government continues to regulate the cap. Therefore, further research can be conducted from a dynamic evolutionary viewpoint.

Nomenclature

- H Innovative technology
- C Traditional technology
- R Fixed income of the manufacturer
- G Fixed satisfaction level of the government
- R Manufacturer's payoff when choosing an innovative technology
- A Government supervises the manufacturer's behavior
- N Government fails to supervise the manufacturer's cheating behavior
- l Manufacturer's loss due to cheating when detected by the government
- i Government's extra cost when supervising an obedient manufacturer
- k Government's loss when failing to supervise a cheating manufacturer
- i Manufacturer's extra revenue when cheating is not detected
- y_E Manufacturer's total revenue
- y_G Government's satisfaction level
- S_E Manufacturer's strategy set $S_E(H, ?C)$
- S_G Government's strategy set $S_G(A, ?N)$
- p Probability of government supervising the manufacturer's behavior
- q Probability of manufacturer choosing an innovative technology
- l Manufacturer's loss due to cheating when detected by the government
- i Government's extra cost when supervising an obedient manufacturer
- k Government's loss when failing to supervise a cheating manufacturer
- i Manufacturer's extra revenue when cheating is not detected

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