Qingsong Wang, Xueliang Yuan, Jian Zuo, Ruimin Mu, Lixin Zhou, and Mingxia Sun

Dynamics of sewage charge policies, environmental protection industry and polluting enterprises - a case study in China

Sustainability, 2014; 6(8):4858-4876

Sustainability **2014**, *6*, 4858-4876; doi:10.3390/su6084858

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Dynamics of Sewage Charge Policies, Environmental Protection Industry and Polluting Enterprises—A Case Study in China

Qingsong Wang [1], Xueliang Yuan [1,*], Jian Zuo [2], Ruimin Mu [3], Lixin Zhou [4] and Mingxia Sun [5]

1. School of Energy and Power Engineering, Shandong University, 17923 Jingshi Road, Jinan 250061, China; E-Mail: wqs@sdu.edu.cn
2. School of Natural and Built Environments, University of South Australia, Adelaide 5000, Australia; E-Mail: jian.zuo@sdu.edu.cn
3. School of Municipal and Environmental Engineering, Shandong Jianzhu University, Fengming Road, Lingang Development Zone, Jinan 250100, China; E-Mail: ruiminmu@163.com
4. School of Economic and Management, Northwest University, Xi'an 710069, China; E-Mail: lixinzhou@163.com
5. Shandong Academy of Macroeconomic Research, Jinan 250014, China; E-Mail: sun.ming.xia2002@163.com

* Author to whom correspondence should be addressed; E-Mail: yuanxl@sdu.edu.cn; Tel.: +86-531-8839-9372; Fax: +86-531-8839-5877.

Received: 20 February 2014; in revised form: 18 July 2014 / Accepted: 24 July 2014 / Published: 31 July 2014

Abstract: The game model of sewage charges, based on incremental mode, was developed. Four modes of high/low sewage charge standards were utilized to analyze the relationship between control strategy on sewage discharge and the development of environmental protection industry. Results showed that the selection of control strategy was heavily dependent on the level of sewage charges. An empirical study was carried out to investigate the environmental protection industry in 31 regions in China in 2010. It was revealed that the sewage charge standards, formulated by the local governments and the development of environmental protection industry, varied significantly in different regions. The optimal level of environmental quality and social welfare, as a whole, was not achieved in China. It is proposed that different regions should adopt different sewage charges standards based on their economic development level and the current environmental quality. Similarly, the scientific and technological innovation of environmental protection industry should be further strengthened.

Keywords: game model; environmental policy; environmental protection industry, polluting enterprise; sustainable development

1. Introduction

China has achieved a rapid economic growth during the last few decades. However, the environmental issues associated with urbanization and industrialization have become even more crucial due to the coal-dominated energy mix and low energy efficiency in China [1–4]. It presents a significant challenge for the Chinese government to maintain sustained economic growth without the cost of the environment, which is reflected in Five-Year Strategic Plans released by the Chinese Government [5]. As a result, the environmental protection industry has developed rapidly. The official definition of the environmental protection industry is the production and business activities for the purpose of preventing environmental pollution and improving environmental quality. It consists of three aspects: the production of environmental protection equipment or products, the comprehensive utilization of resources, and environmental services [6]. Therefore, it is imperative to explore the dynamics of environmental protection policies, the environmental protection industry, and polluting enterprises to achieve an optimal balance. Sewage charge policy is one of the most effective environmental policies in China. The sewage charge cost will affect the attitude of the polluting enterprises in regards to environmental treatment, thereby affecting the production strategy for environmental protection industries. Therefore, sewage charges show a certain level of impact on the development of the environmental protection industry by affecting the behavior of polluting enterprises. The interaction among environmental policies, the environmental protection industry, and polluting enterprises has attracted substantial attention, both in China and overseas [7–9]. It is well recognized that sewage charge is one of most widely adopted environmental policies to deal with environmental issues [10–14]. Pollutant emission from companies has been controlled effectively by the sewage charges policy, especially in Europe and America [12,15,16]. Bressers argued that high sewage charges system played an important role in fostering pollutant-reduction behavior [17]. Bergman analyzed the sewage charges design theory and methods in Canada, and concluded that sewage charges were important for pollution control [18].

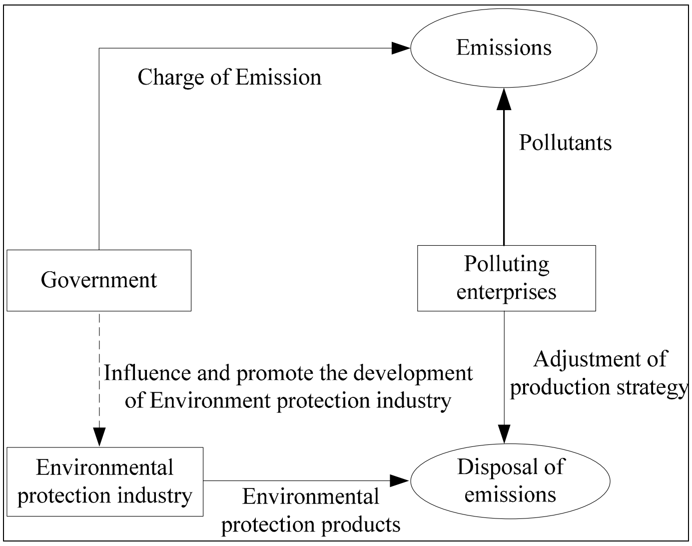
The environmental protection industry has its own development pattern, which is heavily guided by the government's policies [19]. Therefore, the influence of government on the environmental protection industry has become an important field of study [20]. As an effective method for policy analysis, game theory has been widely employed in the fields of economic and environmental sciences [21–24]. Scott introduced game theory into the system for vicissitude analysis for the first time. Thereafter, the evolutionary game of economy came into being [25,26]. Jones used a game theoretic framework to model regulatory decision-making and firm response to pollution prevention policies [27]. The system was a balance of potential social game [28]. John *et al.* found that combined payoffs are larger with decentralized control if payoffs are sufficiently heterogeneous and initial pollution stocks were sufficiently small with a dynamic game model [29]. This is due to a shadow price applied by the central authority to pollution, whereas local authorities use different shadow prices, and, therefore, different standards in a second-best world. Segerson and Wu developed a simple game-theoretical model to analyze the use of a policy that combined a voluntary approach to controlling nonpoint-source pollution with a background threat of an ambient tax (or losing government subsidies) if the voluntary approach was unsuccessful in meeting the pre-specified environmental goal [30]. Lu analyzed the strategic choice of interaction between sewage companies and environmental protection authorities with an evolutionary game theory method [31]. Yang *et al.* argued potential policy alternatives could be generated for water resource management and pollution control with game mode [32]. Zou and Hu established the game model of the government's environmental regulation and company's pollution treatment with the game theory [33]. As the foundation of institutions, all the games of resource allocation should be sorted out once the political rules were confirmed [34]. System is a balance of potential social game [28]. Irene *et al.* proposed Game theory as a decision making tool was adapted to analyze the various inter-plant water integration schemes in an in an eco-industrial park [35]. Jørgensen *et al.* proposed the dynamic state-space games to formulate and analyze intertemporal decision-making problems in the economics and management of pollution [36]. Wang *et al.* introduced influential factors of company decisions into the evolutionary game model [37]. Shen argued that Government and company behavior were based on limited rational dynamic repeated game in the process of environmental protection [38]. Yuan and Geng revealed that environmental policies were the most important factor affecting the development of environmental industry with game theory [39]. Hu and Wang suggested that enterprises should invest in and finance the environmental protection industry in order to achieve the long-term benefits [40]. In summary, the institutional evolutionary game theory provides an effective approach to investigate the environmental issues. In practice, there are many factors, other than the type of pollutants and emission scales, that the government needs to consider when formulating the sewage charge system or tax subsidy. This includes the degree of impacts of same pollution charges standard and tax subsidies on different types of industry in terms of environmental management and pollution production decisions. Therefore, the development of the environmental protection industry is subject to the above factors, and their relations have shown a nonlinear dynamic process. Therefore, a novel game model of incremental sewage charges system among government, polluting enterprises, and the environmental protection industry is proposed in this study. The findings provide a useful reference for the process of formulating and evaluating environmental policies, particularly sewage charges policies.

2. Mechanism Analysis

There are negative externalities of environmental pollution and the publicity of environmental resources. Therefore, government should consider the social welfare as a system and improve environmental quality continuously by means of formulating appropriate environmental policies. The social welfare including the entire country, polluting enterprises, environmental protection industry, as well as the public, should be taken into consideration. As the country represents the public interests, its ultimate goal is to achieve the maximization of social welfare. Social welfare mainly consists of the profit of polluting enterprises and environmental protection industry, consumer surplus, environmental damage, and sewage charges. Among these, the profit of polluting enterprises and environmental protection industry is influenced by their own business strategies. The larger the profit the greater social welfare will be generated. Environmental damage is mainly caused by discharged pollutants from polluting enterprises. There is a correlation between pollutant emissions and production volume. Therefore, the degree of environmental damage is finally determined by the strategy of production and pollution control of polluting enterprises. Environmental damage has negative externality, which will reduce social welfare. In order to control environmental pollution, the government should collect fees for discharged pollutants, which belongs to social welfare. The sewage charges will be dedicated to improving environmental quality, such as investing in environmental protection initiatives.

The aim of polluting enterprises in the game model is to maximize their own interests, *i.e.*, achieving optimal profit under the context of environmental policies by means of enacting the production strategy and emission disposal strategy. The main factors affecting polluting enterprises' profit include: price and cost of its own products, its pollution treatment strategy, price of environmental protection industry's product, and the government's sewage charges. Product of polluting enterprises, directly aimed at consumers, associated with a demand curve in which production volume decreases along with a price cut. In general, if the technological innovation is not achieved in the short term, the unit cost of production remains unchanged. Additionally, the emission disposal strategy of polluting enterprises also has a great influence on its profit. Environmental protection industry and polluting enterprises are crucial parts of the industry chain. The environmental protection industry provides products or services for polluting enterprises. Therefore, the interests of the environmental protection industry are largely influenced by the production strategy of polluting enterprises. The environmental protection industry also pursuits the maximal profit. As environmental protection has positive effects, the realization of the interests of the environmental protection industry needs the support of environmental policies. The major factors influencing the profits of environmental protection enterprises include market demand potential, the government's sewage charges, and polluting enterprises' production strategies. Polluting enterprises and the environmental protection industry pursue the maximum individual interest in the game process. The pollution control cost of environmental protection enterprises generally increases with the amount of discharged pollutants. Therefore, polluting enterprises will a choose pollutant disposal strategy when the sewage charges are greater than the pollution control costs charged by environmental protection firms, or *vice versa*. Therefore, the government can achieve the maximization of social welfare through formulating and collecting fees for discharging pollutants. Sewage charges influence the production and pollution treatment strategy of polluting enterprises indirectly. The environmental protection industry will adjust their production strategy according to the pollution treatment strategy of polluting enterprises in order to ensure the maximization of their own profits [15]. The mechanism of the government's environmental policies affecting polluting enterprises and environment protection enterprises is described in Figure 1.

Figure 1. Mechanism analysis of environmental protection system affecting polluting enterprises and environmental protection industry.



3. Methods

The purpose of sewage charge is a common approach over the world to prevent and control environmental pollution, which in turn helps to improve the environmental quality. Normally, sewage charge is higher with the higher requirements of environmental governance. As a result, sewage charge showed an ascending trend. In general, there are two ways for defining the sewage charge standard. The first approach is a linear increasing according to the pollutant scale. The second approach is the incremental nonlinear increasing in accordance with the amount of pollutants discharged. The sewage charge standard, defined by the second approach, is generally greater than that of the first approach, therefore, it has drawn a higher degree of attention from the industry.

This paper introduces a game model with an incremental mode of sewage charges with an aim to analyze the game behavior among the government, polluting enterprises, and environment protection enterprises. The game behavior is among the government, polluting enterprises, and environment protection enterprises, analyzed with the incremental mode of sewage charges by introducing game model. The parameters of the proposed game model are:

- Game participants have completed reciprocal information and acted at the same time. It belongs to the complete information static game.
- Game participants are fully rational. The goal of the government is to realize the maximum overall social welfare. Polluting enterprises and the environmental protection industry pursues the maximum profit. The environmental policies of the government are mainly formulating standards for sewage charges. Variables of polluting enterprises' decision-making are mainly production Q_1 and the amount of pollution emissions u. A variable of environmental protection firm's decision-making is the production volume of environment protection product Q_2.

$$W = L_1 + L_2 + S_1 + S_2 + T - L_3 \tag{1}$$

The overall social welfare is described as Equation (1). In which, the profit of polluting enterprises is L_1, the profit of the environmental protection industry is L_2, the environmental damage of pollution is L_3, the income of the government's collection of sewage charges is T, the consumer surplus of polluting enterprises is S_1, and the consumer surplus of the environment protection industry is S_2 [11].

The function for market demand of products from polluting enterprises is calculated as Equation (2).

$$P_1 = a_1 - b_1 Q_1 \tag{2}$$

where P_1 is the price of product. It is assumed that the amount of products from polluting enterprises increases according to the increase of discharged pollutants. There is a linear relationship between u and Q_1.

$$u = kQ_1 \tag{3}$$

Assume that the incremental charge mode of sewage charge is adopted instead of the same fee per unit of pollutants (*i.e.*, linear approach). Namely, the total sewage charges T is an increasing nonlinear function of the pollutants (u) discharged from polluting enterprises.

$$T = tu^2 + tu \tag{4}$$

Each unit of pollutants emission is charged at a rate of t. It is charged at a rate of tu^2 for every increase of quantity of u^2.

The damage of environmental pollution is determined by the types of pollutants and the conditions of polluted environment. Environmental damage is unified with monetary unit of measurement, which is shown in Equation (5),

$$L_3 = \gamma u - L_0 \tag{5}$$

where L_3 represents environmental pollution loss, L_0 represents the assimilative capacity of environmental pollution. When the pollutants are in the range of 0-L_0, the environment can perform natural purification without producing pollution damage.

During the pricing process of environmental protection industry, sewage charges and the demands of the polluting enterprises are the main influencing factors. It is supposed that the marginal cost MC of environmental protection enterprises is composed of basic unit management cost C_0 and pollution control cost C_1. C_0 is the sunk cost such as the plants and equipment as the initial investment from environmental protection industry. The more pollutants produced, the greater the marginal cost for management. It is assumed that there is a positive linear relationship between the management cost and pollutant quantity u, as shown in Equation (6).

$$MC = C_0 + C_1 = C_0 + \alpha k Q_1 \tag{6}$$

where α represents the cost of disposing per unit of pollutants. It is assumed that polluting enterprises produce kQ_1 pollutants, associated with Q_1 amount of products. When the product price of the environmental protection firm is P_2, the condition for profit maximization of the environmental protection industry is shown as Equation (7).

$$P_2 = MR = MC \tag{7}$$

$$P_2 = C_0 + \alpha k Q_1 \tag{8}$$

It is assumed that there is a linear relationship between product quantity of environmental protection industry and the quantity of pollutants.

$$Q_2 = \beta u \tag{9}$$

where β represents the quantity of environmental products that are required to dispose a unit of pollutants.

According to Equations (3) and (4), sewage charges for final unit of pollutants collected by the government is,

$$MT = dT / dQ_1 = 2tk^2 Q_1 + tk \tag{10}$$

As the marginal cost of environmental protection cost is $MC = C_0 + \alpha k Q_1$, when $MT = MC$, Equation (11) is formulated.

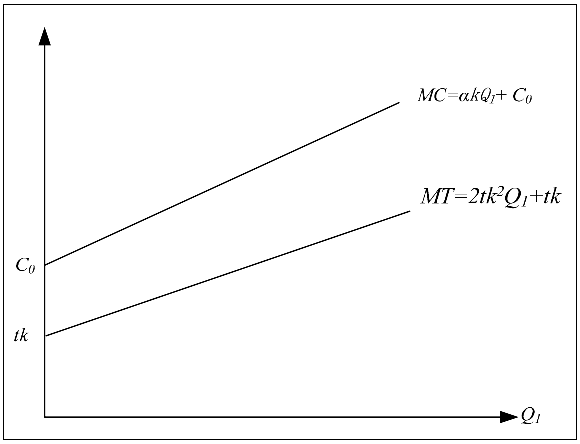
$$Q_1* = \frac{C_0 - tK}{(2tK - \alpha)K} \tag{11}$$

where Q_1* represents the critical production of polluting enterprises.

Polluting enterprises will make choices of game strategy according to the following different conditions:

- The initial pollution treatment cost of the environmental protection industry as C_0. When $C_0 > tk$, and the slope of MC is larger than that of MT, namely $\alpha k > 2tk^2$, then $t < \min(\frac{C_0}{K}, \frac{\alpha}{2K})$. The result is shown in Figure 2.

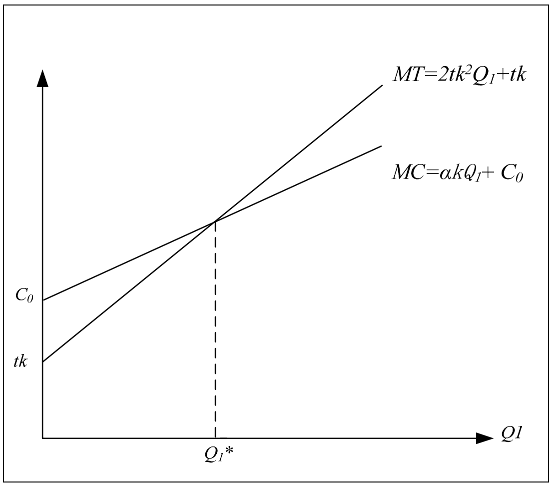
Figure 2. Government marginal sewage charges with environmental protection enterprises marginal treatment costs on condition of $\alpha k > 2tk^2$.



The initial pollution control cost of the environmental protection industry $C_1 = \alpha k Q_1$ is increasing, due to the sewage charges by the government. Therefore, when the marginal pollution treatment cost of the environmental protection industry is larger than the marginal sewage charges (t), namely $MC > MT$, polluting enterprises will choose to pay sewage charges.

- The initial pollution treatment cost of the environmental protection industry as C_0. When $C_0 > tK$, and the slope of MC is smaller than that of MT, namely $\alpha k < 2tk^2$, which is $\frac{\alpha}{2K} < t < \frac{C_0}{2K}$. The result is shown in Figure 3.

Figure 3. Government marginal sewage charges with environmental protection enterprises marginal treatment costs on the condition of $\alpha k < 2tk^2$.



Q_1* is the equilibrium quantity. The production volume of polluting enterprises as Q_1. When $Q_1 > Q_1*$, the discharge fees for the part excessive to the equilibrium quantity are substantially high. Polluting enterprises will choose to engage environmental protection firm to treat pollutants. When $Q_1 < Q_1^*$, polluting enterprises will choose to pay sewage charges.

- When C_0 < tK, and the slope of MC is larger than that of MT, namely $\frac{C_0}{2K} t < \frac{\alpha}{2K}$, the result is shown in Figure 4.

When $Q_1 > Q_1*$, the discharge fees for the part excessive to the equilibrium quantity are substantially high, polluting enterprises will choose to pay sewage charges. When $Q_1 < Q_1*$, polluting enterprises will choose to engage environmental protection industry to treat pollutants.

- When $C_0 < tk$, and the slope of MC is smaller than that of MT, namely $t > \max(\frac{C_0}{K}, \frac{\alpha}{2K})$, the result is shown in Figure 5.

Figure 4. Government marginal sewage charges with environmental protection industry marginal treatment costs on condition of $\frac{C_0}{K} < t < \frac{\alpha}{2K}$.

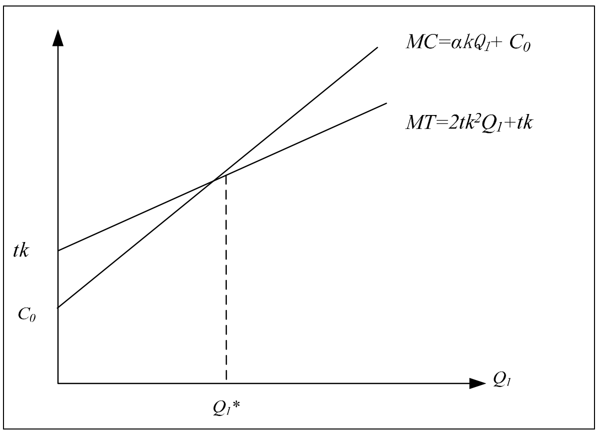
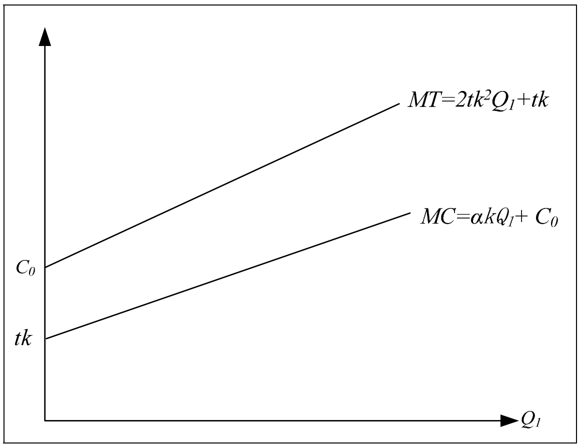


Figure 5. Government marginal sewage charges with environmental protection industry marginal treatment costs on condition of $t > \max\left(\frac{C_0}{K}, \frac{\alpha}{2K}\right)$.



Sewage charges increases relatively faster than that of the disposal cost. Therefore, polluting enterprises will determine the production volume according to market demands and meanwhile engage environmental protection industry to treat pollutants.

Equation (12) shows the profit analysis of environmental protection industry at the balanced production.

$$L_2 = (P_2 - C_0)Q_2 = \alpha k Q_1 Q_2 \tag{12}$$

According to Equation (11) and $Q_2 = \beta K Q_1$, when the profit of an environmental protection firm is maximized, it can be expressed as:

$$L_2 = \alpha k Q_1 Q_2 = \alpha\beta k_2; Q_1{}^{*2} = \alpha\beta K^2 \left(\frac{C_0 - tK}{(2tk - \alpha)K}\right)^2 = \frac{\alpha\beta(C_0 - tK)^2}{2tK - \alpha} \tag{13}$$

Equation (13) is the function of the impacts of governmental sewage charges on the environmental protection industry's profits. It is a direct manifestation of how the environmental policies affect the development of environmental protection industry. Among these factors, α, β, *k*, and C_0 are market environmental parameters that cannot be adjusted and changed manually in short term. Therefore, environmental policy is the only factor influencing the development of the environmental protection industry. With the production strategy of the environmental protection industry and the pollution control strategy of polluting enterprises play little role in developing the environmental protection industry.

The profit function of environmental protection industry achieves the maximum value when $dL_2 / dt = 0$. There is a direct relationship between the profit maximization of the environmental protection industry and *t*, C_0 and *k*. Therefore, in order to elevate the firm's profit, the government's sewage charges *t* should be taken into consideration. In addition, the technical level of the environmental protection industry is another relevant factor.

According to Figures 2–5, the strategy choice of polluting enterprises either to control pollutants or to pay sewage charges depends mainly on the deviation between *t*, $\frac{C_0}{K}$ and $\frac{\alpha}{2K}$.

Figure 2 shows that when *t* determined by the government is relatively smaller, the constraint effect on polluting enterprises is smaller. Then, polluting enterprises will still choose to discharge pollutants. Although the sewage charges are collected, there have been damage to the environmental quality.

Figure 3 shows that even if the government determined lower sewage charges t, polluting enterprises will still be encouraged to choose environmental protection related services and products. This can be achieved if environmental protection industry can effectively reduce the cost of pollution treatment (*i.e.*, the marginal cost curve is relatively alleviated) through technological innovation (with government tax subsidies or other supporting policies).

As shown in Figure 4, the polluting enterprises will choose pollution management strategy in the first instance with the condition of higher sewage charges t. When the production volume excesses the equilibrium quantity, sewage charges will be paid for the exceeded part.

Figure 5 revealed if the government formulated higher sewage charges t, and the cost of the environmental protection industry is relatively lower, the enterprise will completely choose to dispose pollution instead of paying discharge fees. This shows that the government measures are to make it compulsory for polluting enterprises to adopt the environmental protection strategy.

In short, a game model is introduced in this paper among government, polluting enterprises and environmental protection industry with incremental mode of sewage charges in order to analyze the game behavior of government, polluting enterprises and environment protection industry under four different scenarios. Analysis revealed that the polluting enterprises' strategy towards pollution treatment is affected directly by the level of sewage charges. The pollution enterprises are more likely to pay sewage charges rather than pollution treatment, unless a higher sewage charge policy in place together with a reduction of the treatment cost of environmental protection industry. These findings provide a useful reference for enacting environmental policy and environmental protection industry development plan.

4. Empirical Analysis

4.1. Data Collection

In China, sewage charges are determined by local governments according to local conditions. The sewage charges collection is the responsibility of local environmental protection authorities. The formulation of sewage charges varies from region to region according to the different levels of local economic development and environmental pollution in China.

The Chinese authorities have provided the official statistics of the environmental protection industry in 2004. However, such official statistics have not been compiled nationwide since then. Therefore, these data related to environmental protection industry need to be, first, sorted. The income of the regional environmental protection industry is obtained from China's environmental protection industry research report [41], China Statistical Yearbook [42], and Li *et al.* [43]. Investment on environmental pollution control is obtained from the China Environment Statistical Yearbook [44]. The revenue of sewage charges and number of organizations paying sewage charges are obtained from the official website of the Bureau of Statistics of China [45]. The profits of the environmental protection industry are arrived by means of income of regional environmental protection industry minus investment on environmental pollution control. These statistics are shown in Table 1.

Table 1. Statistics of environmental protection industry and sewage charges in different regions of China in 2010.

Regions	Income of Environmental Protection Industry (billion RMB)	Investment on Environmental Pollution Control (billion RMB)	Number of Organizations Paying Sewage Charges	Revenue of Sewage Charges (million RMB)	Region Classification
Beijing	426.3	2.31	1921	35.75	LDR
Tianjin	276.73	1.10	3984	180.42	LDR
Hebei	632.22	3.71	27973	1372.48	HR
Shanxi	266.82	2.07	10446	1662.99	HR
Inner Mongolia	1200	2.39	6017	1029.34	LUR
Liaoning	1000	2.07	27568	1206.30	HR
Jilin	120	1.24	24187	418.77	LDR
Heilongjiang	259.22	1.31	10984	438.83	LDR
Shanghai	961.29	1.34	5455	248.28	LDR
Jiangsu	3410	4.66	34566	2026.12	HR
Zhejiang	2557.5	3.34	30536	1014.73	LDR
Anhui	357.3	1.80	14404	528.56	LUR
Fujian	400	1.30	20006	352.45	LDR
Jiangxi	236.28	1.57	7521	478.07	LUR
Shandong	1278.8	4.84	17685	1506.86	HR
Henan	600	1.32	16489	917.91	LUR
Hubei	600	1.47	9969	375.42	LDR
Hunan	643	1.07	12433	542.61	LUR
Guangdong	1700	14.16	62578	941.38	LDR
Guangxi	95	1.64	8833	466.73	LUR
Hainan	59.87	0.24	919	36.05	LUR
Chongqing	245.69	1.76	6928	377.26	LUR
Sichuan	270	0.89	7602	585.67	LUR
Guizhou	50	0.30	7595	453.04	LUR
Yunnan	72.24	1.06	7395	292.14	LUR
Tibet	5.075	0.003	4688	8.82	LUR
Shanxi	327.7	1.79	5177	478.93	LDR
Gansu	41.21	0.64	8489	213.07	LUR
Qinghai	13.50	0.17	1241	66.24	LUR
Ningxia	16.90	0.35	2897	146.90	LUR
Xinjiang	54.37	0.78	7089	416.88	LUR

Notes: HR stands for higher sewage charges region; LDR stands for lower sewage charges and developed region; LUR stands for lower sewage charges and undeveloped region.

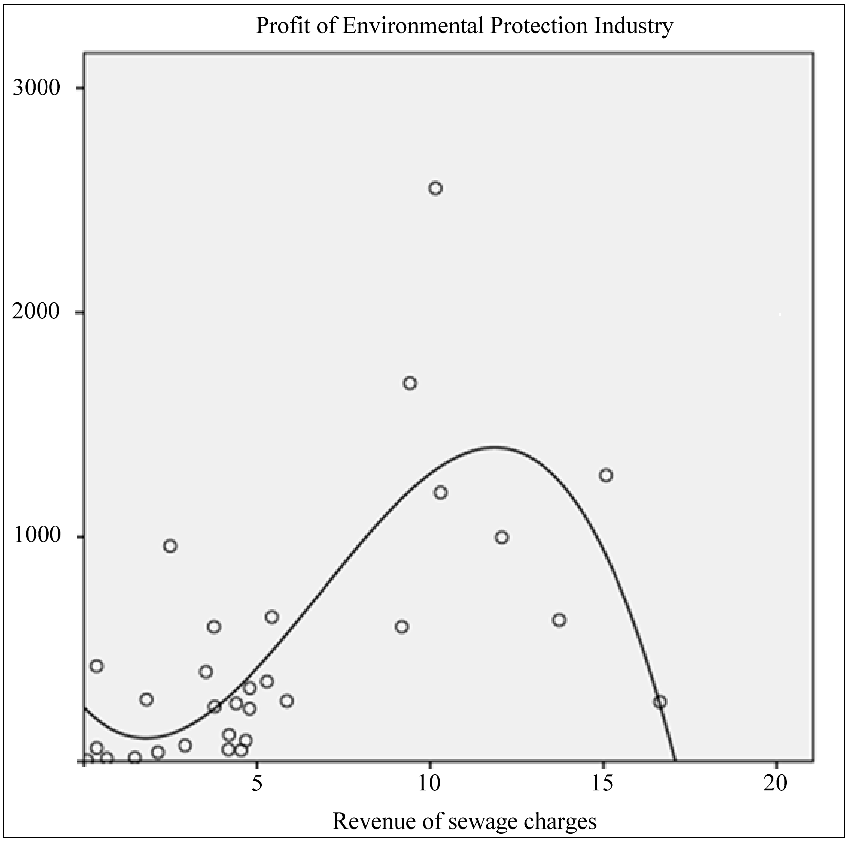
4.2. Results and Discussion

STATA is a useful software tool for data analysis and database management which has been widely adopted in environmental protection related studies [46–48]. *STATA* software was employed to undertake statistical analysis of the data shown in Table1. t value was 4.9 and 4.43, respectively, and the coefficient was significant under 1% of significance level. F value was 18.40. This indicated that the equation was highly significant at the condition of $p = 0.0000$. R^2 was 83%, which indicated that the model could explain 83% of the data with a high goodness of fit. The scatter plot of the *STATA* statistical results is shown in Figure 6. All the variables passed the test, which suggests that the explanatory variables are reasonable and in consistence with the actual situation. The game model result of provincial environmental protection industry in China is described as Equation (14),

$$\begin{aligned} L_2 = &-1.62t^3 + 28.35t^2 \\ &(4.9) \quad (-4.43) \end{aligned} \tag{14}$$

where L_2 and t represent the profit of environmental protection industry and sewage charges, respectively.

Figure 6. The scatter plot of environmental protection industry and sewage charges in different regions of China in 2010.



The result of the regression model accords with practical significance that the model represents, *i.e.*, there exists nonlinear relationship between the profits of the environmental protection industry and government's sewage charges. This is basically in line with the conclusions of Equation (13). Although Equation (14) is obtained via static game model analysis, it can still reflect the formulation of environmental policies and the development of the environmental protection industry. It can be further explored whether the environmental policy made by government can play an effective role in the game between environmental protection industry and polluting enterprises.

As shown in Table 1, the regional development of environmental protection industry in China is extremely uneven. The environmental protection industry in eastern regions is much more developed than that in other regions by virtue of the economic strength and ability of investment. By contrast, the central and western regions saw slower development of the environmental protection industry due to comparatively weaker economic status. The income of environmental protection industry accounts more than 58% of the national outputs nation in eastern regions with most contributions from Jiangsu, Zhejiang, Shandong, Guangdong, Shanghai, Beijing, Tianjin, and other provinces and cities. The total income of the environmental protection industry in western regions (including Guangxi, Sichuan, Guizhou, Yunnan, Gansu, Qinghai, Xinjiang, Ningxia) is less than 20% of that in Jiangsu.

A further analysis of Equation (14) shows, when t is equal to 1.167 billion RMB, the profits of the environmental protection industry will reach the maximum, and the overall social welfare during the game equilibrium will be achieved. When the sewage charge $t > 1.167$ billion RMB, the income of the environmental protection industry will decrease due to the increase of sewage charges. Local governments need to lower the sewage charge standards to improve social welfare, encourage the technical updating of environmental protection industry, and reduce the pollution control cost of enterprises. When the sewage charge $t < 1.167$ billion RMB, the profit of the environmental protection industry will increase due to the increase of sewage charges. Local governments need to raise the sewage charge standards, push the polluting enterprises to take measures for pollution control and promote the further development of the environmental protection industry [11].

Table 1 shows that sewage charges in Hebei, Shanxi, Liaoning, Jiangsu, and Shandong are higher than 1.167 billion RMB. The profits of the environmental protection industries in these regions decrease with the increases of sewage charges. However, it also shows that there are more stringent requirements of environmental control in these regions. Especially in Jiangsu Province, the output value of the environmental protection industry ranked first across the nation, accounting for 8.2% of local GDP. These local governments need to lower the sewage charge standards. The environmental protection industry must improve the level of scientific and technological innovation so that cost is reduced. There are still large potentials for the environmental protection industry in these regions.

Sewage charge of any of other 25 regions is less than 1.167 billion RMB. This indicates that a lower overall intensity of collecting fees which did not reach the optimal level of environmental quality and social welfare in China. It also indicated the overall scale of China's environmental protection industry is relatively small despite a rapid growth. It generally falls far behind that of Europe and the United States [41]. The average sewage charges paid by the polluting enterprises in Beijing, Tianjin, Shanghai, Hainan, Yunnan, Gansu, Tibet, Qinghai and Ningxia are far less than 1.167 billion RMB. However, the profits of the environmental protection industries in these regions varied significantly. For instance, the profit of the environmental protection industry in Shanghai is 189.3 times of that of Tibet, albeit only 28.2 times more in terms of sewage discharge. This is mainly due to the local economic development approach and the sewage charges policy formulated by the local government. Figures 2 and 3 shows that the polluting enterprises are not proactive to dispose pollution as the government's sewage charges are relatively lower. This situation will lead to inevitable damage to the natural environment. Therefore, in order to achieve improvement of environmental quality and social welfare, within the game between government and polluting enterprises, the first step is to increase the sewage charges.

The above analysis revealed that sewage charges of local governments varied significantly in different regions of China. The method of sewage charges is not applied as an effective leverage to regulate the behavior of polluting enterprises. The following recommendations are proposed to improve the current practice and situation.

(1) During the development of sewage charges, the local government should place more focus on the social welfare of the entire society rather than simply aiming for taxation revenue for sake of environmental protection. It is imperative to consider the coping measures of polluting enterprises as a game player, and to achieve the purpose of environment management through developing environmental protection industry as much as possible.

The intensity of discharge levy would directly affect the local environmental quality and social welfare to a great extent. As a result, governments of different regions need to formulate a reasonable standard of sewage charges, according to different types of pollutants discharged and economic development patterns. Incremental type of sewage charges standard is more effective than linear mode.

(2) It is proposed that different standards are adopted in different regions in order to maintain its effectiveness. The whole country can be divided into three kinds of regions, *i.e.*, regions with higher sewage charges, regions with lower sewage charges and underdeveloped economy, and regions with lower sewage charges and developed economy. The higher sewage charges regions are Hebei, Shanxi, Liaoning, Jiangsu, and Shandong. Lower sewage charges and undeveloped regions are Inner Mongolia, Anhui, Jiangxi, Henan, Hunan, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Gansu, Qinghai, Ningxia, and Xinjiang. Lower sewage charges and developed regions are Beijing, Tianjin, Jilin, Heilongjiang, Shanghai, Zhejiang, Fujian, Hubei, Guangdong, and Shanxi (see Table 1). In regions with higher sewage charges, it is necessary to reduce the original sewage charge standards. However for Shanxi, a province with rich coal resources in China, its economic development mainly relies on coal mining and processing. The excessive reliance on coal resources has resulted in an unreasonable economic structure and serious environmental degradation. Accordingly, Shanxi has increased the level of sewage charges for several times. For instance, the "Notice on implementation of the action plan for the prevention and control of atmospheric pollution in Shanxi Province" was issued in 2013, which specified that the level of sewage charges will be further increased and the scope will be extended [49]. For regions with lower sewage charges and underdeveloped regions, such as Tibet, Xinjiang and Qinghai, considering the local economy condition, environmental damage caused by the economic development is limited which has yet to affect the quality of life of local residents. Therefore, it is recommended to maintain the current sewage charge standards in a short-term basis. When the local economy conditions develop to a higher level, to the authorities should consider increase sewage charges standard appropriately. For regions with lower sewage charges and developed economy condition (such as Shanghai, Beijing, Tianjin, Guangdong, Jilin), it is proposed to increase sewage charges and strengthen the supervision on the implementation of environment protection policy at the central government level. For instance, as the capital city, Beijing has made a great deal of effort on pollution treatment, as well as improving the air quality. In 2014, the level of sewage charges for SO_2, NO_x and other pollutants increased by 14 to 15 times of the original level and has become the highest level in the 31 regions [50]. It was reported that the leverage function is strengthened since the implementation of the new collection standards.

(3) At present, China's environmental issues are not only related to the enforcement of environmental law and supervision of local governments, but also relevant to the relatively lower level of

science and technology of the environmental protection industry in China. The environmental management cost is higher associated with comparatively lower technical level of the industry. Illegal discharging of pollutants is not unusual as some polluting enterprises tried to escape from the substantial cost of environmental treatment. Therefore, it is imperative to enhance the technological level of environmental protection industry. Technological innovation can reduce the environmental management cost and improve the profits of the environmental protection industry, as well as sustaining competitiveness against international environmental protection industry.

5. Conclusions

This study developed a novel game model based on incremental mode to analyze the mechanism of dynamic interactions between environmental policies, environmental protection industry, and polluting enterprises. The influence of polluting enterprises on pollution treatment strategy and the development of environmental protection industry, with high or low sewage charges standards of four kinds of modes are analyzed. It is concluded that the pollution treatment strategy of polluting enterprises depends on the government's sewage charges to a large extent. Policy pressure of higher sewage charge and reduced treatment cost of the environmental protection industry help to promote the development of the environmental protection industry.

This research provides useful implications for environmental policies. It is revealed in this study that the polluting enterprises' strategy towards pollution treatment is affected directly by the level of sewage charges. First of all, the current collection method of sewage charges needs to be improved. The incremental mode of sewage charges is proposed to address the deficiency associated with the current collection method. Secondly, the sewage charges levy level should be increased gradually based on the economic development conditions of different regions. On the other hand, the level of sewage charges should not be increased without a limit, otherwise, the overall social welfare will not reach an optimal level. Thirdly, the scope of the sewage charges should be extended according to the environmental management requirements. This measure has been implemented in some regions. For instance, volatile organic sewage has been levied in China since 2013 in order to improve environmental quality. Some provinces, such as Jiangsu, Guangdong, and Jilin have recently issued legislations for sewage charges of dust emissions from building construction sites.

The *STATA* software was employed in this study to carry out a statistical analysis of the development status of environmental protection industry of 31 regions in China, in 2010. The results indicate that the overall intensity of discharge penalty is low in China, and sewage charges are not applied as an effective leverage to regulate the behavior of polluting enterprises. In view of the actual development of the environmental protection industry in China, it is proposed that different regions (*i.e.*, higher sewage charges region, lower sewage charges and undeveloped region, lower sewage charges and developed region) adopt different collecting standards so that the environmental policy is more purposively. For regions with higher sewage charges, it will be more useful to decrease the sewage charge standards. For regions with lower sewage charges and underdeveloped economy can maintain the original standard of sewage charges considering their level of economy and environment status.

For regions with lower sewage charges and developed economy condition, sewage charges need to be increased.

There are other factors that affect the development of the environmental protection industry such as the technology, institutional and policy implementation, *etc.* The technological level is undoubtedly one of crucial factors to be considered when planning and developing the environmental protection industry. It can not only improve the profit level of the industry, but also improve the effectiveness of environmental treatment. In addition, environmental policies, legislations and regulations also play a critical role in promoting the development of environmental protection industry. For instance, the "Action plan for prevention and control of atmospheric pollution". issued in 2013, has created a number of opportunities for the environmental protection industry. such as desulfurization and denitrification. Future research opportunities exist to investigate the impacts of these factors on the environmental protection industry.

Acknowledgments

This research is supported by Award Fund for Young Scientists of Shandong Province (no. BS2012SF015), Program for New Century Excellent Talents (no. NCET-11-1030), National Natural Science Foundation of China (no. 41301640), Humanities & Social Sciences Project of Shandong Province (no. 14-ZZ-JG-02), and Soft Science Research Plan of Shandong Province.

Author Contributions

The study was designed by Qingsong Wang and Xueliang Yuan. The data from yearbooks and professional websites are retrieved by Lixin Zhou and Mingxia Sun. The results were analyzed by Lixin Zhou and Qignsong Wang. The policies related to the research are reviewed by Ruimin Mu. Model design and English corrections were completed by Jian Zuo.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Yao, J. A multi-objective (energy, economic and environmental performance) life cycle analysis for better building design. *Sustainability* **2014**, *6*, 602–614.
2. Yuan, X.L.; Zuo, J.; Ma, C.Y. Social acceptance of solar energy technologies in China—End users' perspective. *Energy Policy.* **2011**, *39*, 1031–1036.
3. Carlo, C.; Emanuele, M. Energy and climate change in China. *Environ. Dev. Econ.* **2012**, *17*, 689–713.
4. Liu, Y.Q.; Xu, J.P.; Luo, H.W. An integrated approach to modelling the Economy-Society-Ecology system in urbanization process. *Sustainability* **2014**, *6*, 1946–1972.
5. Yuan, X.L.; Zuo, J. Transition to low carbon energy policies in China—From Five-Year plan perspective. *Energy Policy* **2011**, *39*, 3855–3859.

6. Sun, X.F.; Han, B.P.; Liu, Y.J.; Wei, Y. The impact and strategy for environmental industry of China's post-WTO. *Energy Environ. Prot*. **2003**, *17*, 5–12.
7. Motta, R.S.D. Analyzing the environmental performance of the Brazilian industrial sector. *Ecol. Econ.* **2006**, *57*, 269–281.
8. Zhang, Z. Game analysis of environmental protection industry related subject. *Shandong Soc. Sci.* **2012**, *4*, 157–159. (In Chinese)
9. Keisuke, H. Environmental innovation and policy harmonization in international oligopoly. *Environ. Dev. Econ.* **2013**, *18*, 162–183.
10. Shu, J.Y. Taxation on pollution emission to protect environment. *Environ. Prot.* **1999**, *4*, 44–46. (In Chinese)
11. Stavins, R.N. Experience with market-based environmental policy instruments. *Handb. Environ. Econ.* **2003**, *1*, 355–435.
12. Yuan, Y.J. *Environmental Economics*; China Financial Economic Publishing Press: Beijing, China, 2006.
13. Yang, Y.L. *Resoures Economy Development*; Science Press: Beijing, China, 2004.
14. Montginoul, M.; Rinaudo, J.D. Controlling households' drilling fever in France: An economic modeling approach. *Ecol. Econ.* **2011**, *71*, 140–150.
15. Hahn, R.W. Economic prescriptions for environmental problems: How the patient followed the doctor's orders. *J. Econ. Persp.* **1989**, *3*, 95–114.
16. Pretty, J.; Brett, C.; Gee, D.; Hine, R.; Mason, C.; Morison, J.; Rayment, M.; Dobbs, T. Policy challenges and priorities for internalizing the externalities of modern agriculture. *J. Environ. Plan. Manag*. **2001**, *44*, 263–283.
17. Bressers, H. The impact of effluent charges: A dutch success story. *Policy. Stud. Rev.* **1995**, *7*, 43–58.
18. Bergman, L. General equilibrium effects of environmental policy: A CGE modelling approach. *Environ. Resour. Econ.* **1991**, *1*, 43–61.
19. Lighart, J.E.; Vander, P.F. Environmental policy, tax incidence, the cost of Public Funds. *Environ. Resour. Econ.* **1999**, *13*, 187–207.
20. Yan, Z.K.; Yi, B.; Wang, Z.W. Reviews on development of China environmental protection industry in 2004. *China Environ. Prot. Ind.* **2005**, *11*, 10–15. (In Chinese)
21. Maynard, S. The theory and the evolution of animal conflict. *J. Theory Biol.* **1974**, *1*, 209–221.
22. Klaus, R. Redefining innovation-eco-innovation research and the contribution from ecological economics. *Ecol. Econ.* **2000**, *32*, 319–332.
23. Mendoza, A.J.; Clemen, R.T. Outsourcing sustainability: A game-theoretic modeling approach. *Environ. Syst. Decis*. **2013**, *33*, 224–236.
24. Sechi, G.M.; Zucca, R.; Zuddas, P. Water costs allocation in complex systems using a cooperative game theory approach. *Water. Resour. Manag.* **2013**, *27*, 1781–1796.
25. Scott, H.B.; Fernandez, L. *Game Theory with Economic Applications*; Addison Wesley Press: Boston, MA, USA, 1997.
26. Liu, Y.; Lu, Z.N. Study on the relationship between evolutionary game theory and system analysis. *North Econ.* **2007**, *15*, 6–7. (In Chinese)

27. Jones, S. Game theoretic framework for risk reduction decisions. *Environ. Sci. Tech.* **1996**, *30*, 128–132.
28. Kreps, D.M. *Game Theory and Economic Modeling*; C Laredo Press: Oxford, UK, 1990.
29. John, A.; Lista, J.A.; Masonb, C.F. Optimal institutional arrangements for transboundary pollutants in a second-best world: Evidence from a differential game with asymmetric players. *J. Environ. Econ. Manag.* **2001**, *42*, 277–296.
30. Segerson, K.; Wu, J. Nonpoint pollution control: Inducing first-best outcomes through the use of threats. *J. Environ. Plan. Manag.* **2006**, *51*, 165–184.
31. Lu, F.Y. Evolutionary game analysis on environmental pollution problem. *Syst. Eng. Theory. Pract.* **2007**, *9*, 148–152.
32. Yang, Z.F.; Zeng, Y.; Cai, Y.P.; Tan, Q. An integrated game-theory based model for trans-boundary water resources management in north China: A case study in the Guanting reservoir basin, Beijing. *Int. J. Softw. Eng. Knowl. Eng.* **2008**, *18*, 461–483.
33. Zou, W.J.; Hu, P. The government and the enterprise environmental behavior: Game and game equilibrium improvement. *Theor. Mon.* **2009**, *31*, 161–164. (In Chinese)
34. Young, H.P. *Individual Strategies and Social Structure: The Evolution Theory of System*; Shanghai People's Publishing House: Shanghai, China, 2008.
35. Irene, M.L.C.; Raymond, R.T.; Dominic, C.Y.F.; Anthony, S.F.C. Game theory approach to the analysis of inter-plant water integration in an eco-industrial park. *J. Clean. Prod.* **2009**, *17*, 1611–1619.
36. Jørgensen, S.; Martín-Herrán, G.; Zaccour, G. Dynamic games in the economics and management of pollution. *Environ. Model. Assess.* **2010**, *15*, 433–467.
37. Wang, Y.; Luo, J.; Chen, T.P.; Yin, Z.H. Analysis of dynamic evolution game for enterprise pollution control of strategic alliance. *Stat. Decis.* **2011**, *27*, 68–71. (In Chinese)
38. Shen, L. A research on Chinese environment protection supervision mechanism: An evolutionary game theory analyses. *Manag. Rev.* **2011**, *23*, 46–51. (In Chinese)
39. Yuan, Y.J.; Geng, D.H. The transmission mechanism of environmental policies and sustainable development on environment protect industry of China-based on research of government and pollutant corporation and environment protect corporation. *China Ind. Econ.* **2010**, *28*, 65–74. (In Chinese)
40. Hu, G.; Wang, W.J. Game analysis of investing and financing enterprise behavior in environmental protection industry. *J. Xidian. Univ. (Soc. Sci. Ed.)* **2007**, *17*, 70–73.
41. CCID. China's Environmental Protection Industry Research Report. Available online: http://wenku.baidu.com/view/04374845b307e87101f69612.html (accessed on 6 November 2013).
42. NBS, National Bureau of Statistics. *China Environment Statistical Yearbook 2011*; China Statistic Press: Beijing, China, 2011.
43. Li, S.; Chen, Y.L.; Chen, G. Environmental protection industry development and regional environmental quality improvement. *J. Zhongnan Univ. Econ. Law* **2011**, *5*, 3–7. (In Chinese)
44. NBS, National Bureau of Statistics. *China Statistic Yearbook 2011*; China Statistic Press: Beijing, China, 2011.

45. NBS, National Bureau of Statistics. Sewage Charges Levied for Each Region in 2010. Available online: http://www.stats.gov.cn/tjsj/qtsj/hjtjzl/hjtjsj2010/t20111229_402788828.htm (accessed on 10 November 2013).
46. Franzen, A.; Vogl, D. Two decades of measuring environmental attitudes: A comparative analysis of 33 countries. *Glob. Environ. Chang.* **2013**, *23*, 1001–1008.
47. Buckley, C.; Carney, P. The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level. *Environ. Sci. Policy* **2013**, *25*, 118–126.
48. Parodi, S.; Santi, I.; Marani, E.; Casella, C.; Puppo, A.; Vercelli, M.; Stagnaro, E. Risk of non-hodgkin's lymphoma and residential exposure to air pollution in an industrial area in northern italy: A case-control study. *Arch. Environ. Occup. Health* **2014**, *69*, 139–147.
49. PGSP, People's Government of Shanxi Province. Notice on Implementation of the Action Plan for the Prevention and Control of Atmospheric Pollution in Shanxi Province. Available online: http://www.shanxigov.cn/n16/n8319541/n8319612/n8321663/n16932389/n17533814/n17610687/17610834.html (accessed on 15 July 2014).
50. Xinhua News. Beijing Significantly Increased Sewage Charges Standard. Available online: http://news.xinhuanet.com/local/2014-05/06/c_1110563808.htm (accessed on 15 July 2014). (In Chinese)