

Article

Study on the Optimized Mode of Waste Governance with Sustainable Urban Development—Case from China's Urban Waste Classified Collection

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Abstract: With the rapid growth of developing countries, their urban waste is increasing at the same pace, which, in turn, is worsening the environmental pollution and leading to an urgent demand for waste governance. Different waste governance modes will produce different social welfare levels. According to the principles of economics of maximizing the benefit of limited resources, the mathematical models of the three waste governance modes of government, market, and mixed government–market are constructed separately in this paper, and then comparisons are made as to which mode is optimal. The results show that, from the perspective of consumer surplus and producer surplus, the mode by government is optimal, while the mode by market is optimal from the perspective of total social surplus. Since the government acts as the provider of waste governance in China, its allocation of waste governance mode is not optimal from the perspective of total social surplus, as a result of which it fails to restrain the environmental pollution caused by garbage growth most effectively. Nevertheless, since the equilibrium point of waste governance quantity is dynamic, there is still much room for the optimization of waste governance in China, which will certainly inject new impetus to the high quality and sustainable development of its cities.

Keywords: sustainability; governance mode; waste classified; equilibrium; externality

1. Introduction

From the British Industrial Revolution to the middle of the 20th century, western developed countries experienced the golden period of urbanization, and realized a complete transformation from agricultural society to industrial society and from a rural society to an urban society. Subsequently, urbanization has entered a stage of improving the level of modernization in developed countries and rapid expansion in developing countries. In 1987, the United Nations Commission on Environment and Development (UNCED) formally put forward the proposition of sustainable development in the report entitled “*Our Common Future*”. Urbanization has been recognized as a “global issue” since sustainable development became a research focus.

Urbanization is an “endogenous source” of development and a key to cracking many of today’s common challenges. In “*The Future We Expect*”, the main outcome of the United Nations Conference on Sustainable Development in Rio de Janeiro in 2012, as a continuation and response to “*Our Common Future*”, the concept of “*think urban*” was proposed. From this, “sustainable development” further focused on “sustainable urban development”, which has become a crucial factor in addressing such global challenges as climate change and as how to achieve global sustainable development.

Sustainable urban development depends on the level of planning and governance. The “International Guidelines on Urban and Territorial Planning” adopted by the 25th Governing Council of UN-Habitat in 2015 provides a universally applicable reference frame for urban planning to guide policy reform of urban governance around the world. The *New Urban Agenda*, one of the important results of the United Nations Third Conference on Housing and Sustainable Urbanization in 2016, emphasizes that governance bodies such as UN member states and local governments, non-governmental organizations and professional groups must join forces to promote sustainable urban development. Urban waste classified collection is to promote sustainable urban development through different governance subjects from an environmental perspective.

The acceleration of urbanization has also led to the continuous growth of urban waste production, which has become an important factor affecting sustainable urban development. According to the statistics from the authoritative data, each person on the planet can produce an average of about 300 kg of garbage per year. It will take only 60 years for this garbage to make a wall, 5 m high and 1 km wide, to circle the earth. Some developing countries characterized by “garbage besieged cities” have begun to emerge due to urbanization. According to the Organization for Economic Co-operation and Development, in 2016, China’s municipal solid waste production reached 234 million tons, an increase of 88% compared to that in 1996. Now, China’s urbanization development is in a critical transition from a period of low-quality development to that of a high-quality one. This paper is of great significance for developing countries to create high-quality urban development paths and to improve the quality of life for all people in the world as proposed in the United Nations Habitat III *New Urban Agenda*.

Based on the externality and equilibrium theory of public goods and the cases taken from the Chinese government-led urban waste classification and collection, this study constructs mathematical models for three waste governance modes, which are mode by government, mode by market, and mode by mixed government–market. By comparing and analyzing the consumer surplus, producer surplus, and total social surplus of three different governance modes, this paper will provide a theoretical framework for the determination of urban waste governance mode in developing countries to determine the optimal provider of waste governance.

Providers of waste governance play an important role in the process of controlling environmental pollution caused by urban waste. Three main stakeholders are involved in the governance of waste: suppliers (providers of waste governance), demanders (consumers of waste governance), and the rest of society. There are three modes of waste governance now, which, as mentioned above, are mode by government, mode by market, and mode by mixed government–market. The providers of these three modes are the government, private enterprises operating under market provisions, and a combination of government and private enterprises, respectively.

This paper aims to explore which governance mode will produce the optimal economic welfare by establishing mathematical models of different waste governance modes based on economic tools, then employing equilibrium theory to solve the economic welfare generated by each governance mode, and finally comparing the governance modes with the largest economic welfare according to the numerical analysis.

The paper will put forward some suggestions on the option of waste governance modes, which will function as a supplement to the literature of urban sustainable development.

After the literature review, the remaining part of the paper is organized as follows: the introduction of materials and methods in Section 3, the result shown with the change of equilibrium point in waste governance under the influence of the increase of waste quantity and the improvement of its treatment technology in Section 4, discussion on the social welfare produced by the three different governance modes in Section 5, and conclusion in Section 6.

2. Literature Review

In 1975, Northam [1] put forward the classic three-stage theory of urbanization, the process of which was outlined as an S-shaped curve, with the early stage (the urbanization level <30%),

the medium stage (the urbanization coverage between 30% and 70%), and the later stage (urbanization proportion >70%), which correspond to early, mid, and last stages of industrialization, respectively.

The connotation of sustainable urban development mainly has two aspects. First, sustainable development means that the three major systems of society, environment and economy are simultaneously sustainable [2], based on which it is clearly not enough for sustainable urban development to satisfy only one system. Second, sustainable development must take into account not only the fairness of contemporary interests but also the distribution of interests between contemporary and future generations [3]. As an important approach to realize people-oriented sustainable urbanization, urban environmental renewal has attracted increasing attention from both government and society [4]. Walter et al. [5] believe that if people want to realize sustainable urban development, they must reasonably use their own resources in a friendly way and pay attention to the efficiency of use not only for contemporary people, but also for future generations. Tjallingii, for example, argues that sustainable cities should be “responsible cities” and that contemporary environmental problems must not be left to future generations or a wider range. While et al. [6] believe that environmental friendliness should be a characteristic of sustainable urban development.

Many literatures have studied the causes of waste generated by man. Han et al. [7] show that consumption level is an important factor affecting the generation of urban domestic waste. Ogunjuyigbe et al. [8] further point out that the consumption structure of residents will also have an important impact on the total amount and composition of urban household garbage. Some literature has analyzed the relationship between socio-economic factors and the generation of urban household waste, such as GDP [9], household or per capita disposable income [10], and consumption expenditure [6]. Qu et al. [11] believe that middle-income households will tend to generate more household waste than low-income and high-income households. In addition to the overall consumption level, consumption structure is also the research object. For example, the paper [12] analyzes the impact of the proportion of residents’ consumption of food and clothing on the generation of urban waste. The research by Oribe-Garcia et al. [13] provides new ideas for the factors affecting urban domestic waste. Their research shows that both population density and unemployment rate will have a reducing effect on urban domestic waste.

The close relationship between environment and economy reinforces the importance of waste governance. According to the statistics of the Ministry of Environmental Protection in 2015 [14], China’s annual economic losses due to environmental pollution and ecological damage account for about 6% of its GDP. At present, there are two opposite viewpoints about sustainability in economics: one is the view of weak sustainability [2] and the other is the view of strong sustainability [3]. The fundamental difference between the two is whether the relationship between natural capital and human capital is alternative or complementary. The former holds that the relationship between natural capital and human capital is alternative while the latter insists it is complementary rather than alternative. In recent years, although the influence of the view for strong sustainability has gradually gained the upper hand, the opposing idea has not been excluded.

With people’s continuous pursuit of the higher quality of their lives, the urban environment, and especially waste governance, has attracted more and more attention [15]. The governing body of the urban waste plays a very important role in improving the quality of the urban environment, for example in solving the negative externality problems caused by urban waste [16].

Wertz earlier discussed the issue of classifying and collecting urban waste [17], and then there have been more and more literatures about the relationship between stakeholders in waste classification from the perspective of government policies, environmental benefits and recycling motivations. Caebel and Buekens argue that only the input and action of management authorities can promote waste governance into a virtuous circle. Sanneh et al. [18] believe that only with more and more stakeholders’ participation can urbanization in developing countries achieve sustainable waste governance. Bergeron [19] clarified the importance of managers in formulating policies to encourage waste recycling, and argued that decision-makers in urban waste classification need to avoid doubling and overlapping of functions

among stakeholders. As Bednar [20] and Millimet [21] have stated, although the environmental federalism has received widespread attention worldwide, determining the optimal allocation of environmental authority at all levels of government remains a challenge. Considering the urgent need for sustainable urban development, Constantinescu et al. [22] advocate increasing citizen participation in the decision-making process, as it can produce better results and can hold people accountable.

The available literature shows that sustainable urban development includes environmentally sustainable development, and increasing urban waste worsens environmental pollution. The provider of waste governance plays an important role in curbing waste pollution of the environment. We will further study how to employ an economic model to determine whether the allocation of a provider of waste governance is optimal.

Differently from other literatures, this paper will establish a mathematical model in order to find the economic surplus produced by different waste governance modes as well as which one produces the largest total surplus through numerical analysis, so as to provide reference for the choice of the optimal provider of waste governance.

3. Materials and Methods

In the research, some economic tools are used to establish the equilibrium model of supply and demand for waste governance. In addition to the assumption of variables (e.g., Section 3.2), the model is also based on the following circumstances. Firstly, the development of urbanization is accompanied by the growth of waste, which will worsen the environment. Secondly, although the increasing waste worsens the environment, its governance can restrain the deterioration (e.g., Section 3.3), resulting in increased demand for waste governance (e.g., Section 3.1). Lastly, different stages of waste governance have different impacts on the environment (e.g., Section 3.4).

3.1. Urbanization and Urban Waste Governance

Economic development has produced a continuous increase of municipal solid waste, which is particularly phenomenal in developing countries. For example, as the economy has grown rapidly over the past 30 years, China has become a high-yielding country for urban waste. Economic development is also closely related to the progress of urbanization. Based on Northam's three-stage urbanization theory, Fang et al. [23] revised it into a four-stage sustainable urban development theory, as is illustrated in Figure 1.

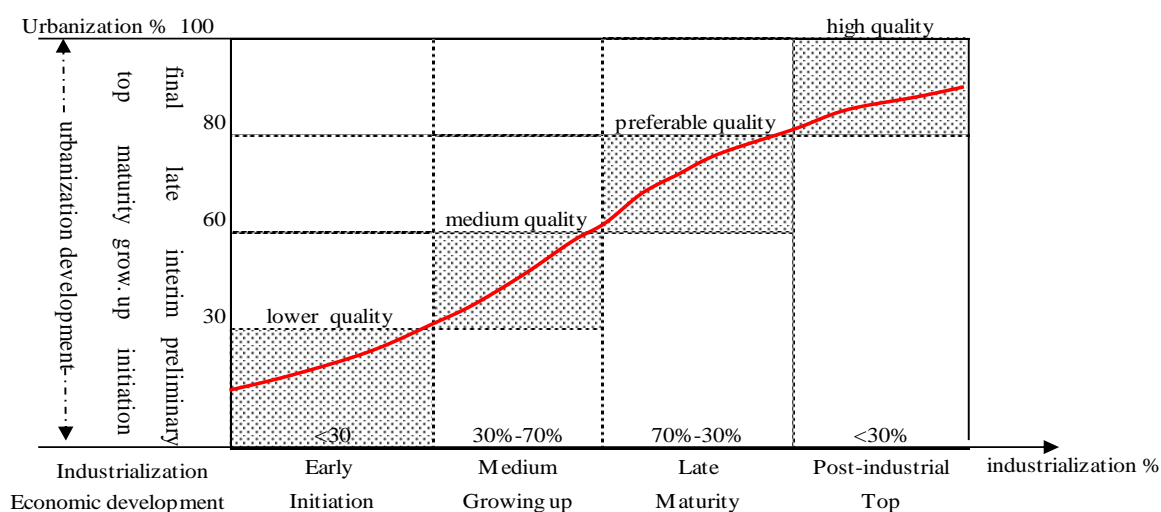


Figure 1. The stages of urbanization development with economic development.

Although economic development has raised the level of urbanization, it has led to the growth of waste, and a need for waste governance, as shown in Figure 2.

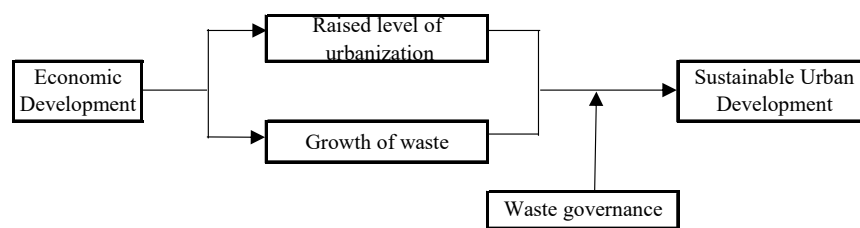


Figure 2. Economic development, waste governance and sustainable urban development.

3.2. Variable Assumptions

The disorderly disposal of urban solid waste has a strong negative externality. Without effective governance, it will pollute the environment. Conversely, strengthening the governance can reduce its pollution to the environment. Different governance modes will produce different supply and demand for waste governance. Therefore, in order to facilitate the analysis of the supply and demand model of waste governance, the definitions of the variables associated with the model are listed in Table 1. The definition of variables is based on the equilibrium theory of economics and the basic tool used to measure the economic welfare.

Table 1. Definition of variables.

| EP. | Environmental Pollution |
|-------------|--|
| W | The amount of urban solid waste |
| \bar{w} | The amount of pollution sources other than waste |
| p | Price of urban waste governance, which is the function of the quantity of waste governance, $p = p(q)$ |
| q | Quantity of urban waste governance |
| λ_1 | Effect coefficient of urban solid waste on environmental pollution |
| λ_2 | Effect coefficient of urban waste governance on environmental pollution |
| R | Revenue of urban waste governance |
| MR | Marginal revenue of urban waste governance |
| C | Cost function of urban waste governance |
| MC | Marginal cost function of urban waste governance |
| CS | Consumer Surplus of urban waste governance |
| PS | Producer Surplus of urban waste governance |
| GS | Government subsidies on urban waste governance |
| SS | Total social benefits of urban waste governance |

3.3. Assumptions of Effect on Urban Environmental Pollution

It is assumed that the urban environment is mainly polluted by fouling of land, air, and water (Zhou et al. [24]). Thus, the environmental pollution function is as follows:

$$EP = F(w, \bar{w}, q) \quad (1)$$

There are two main variables that affect the urban environment. One variable is W , and it means that environmental pollution will increase as the amount of urban solid waste rises without waste governance. Another variable is q , and it means that environmental pollution will decrease as the quantity of urban waste governance rises.

The full differential for (1) is as follows:

$$d(EP) = \frac{\partial F(w, \bar{W}, q)}{\partial W} dW + \frac{\partial F(w, \bar{W}, q)}{\partial \bar{W}} d\bar{W} + \frac{\partial F(w, \bar{W}, q)}{\partial q} dq \quad (2)$$

Thus, the effect coefficient of urban solid waste and urban waste governance are obtained respectively as follows:

$$\lambda_1 = \frac{\partial F(w, \bar{W}, q)}{\partial W} > 0 \quad (3)$$

$$\lambda_2 = \frac{\partial F(w, \bar{W}, q)}{\partial q} < 0 \quad (4)$$

3.4. Assumptions of the Stage of Urban Waste Governance

Equations (3) and (4) imply that W and q have completely opposite effects on EP . From the perspective of the single factor affect, EP will increase as W rises, and EP will be restrained as q rises. The overall impact on the environmental pollution depends on the magnitude between λ_1 and λ_2 . It is assumed that there are three different stages of urban waste governance, which are shown in Figure 3.

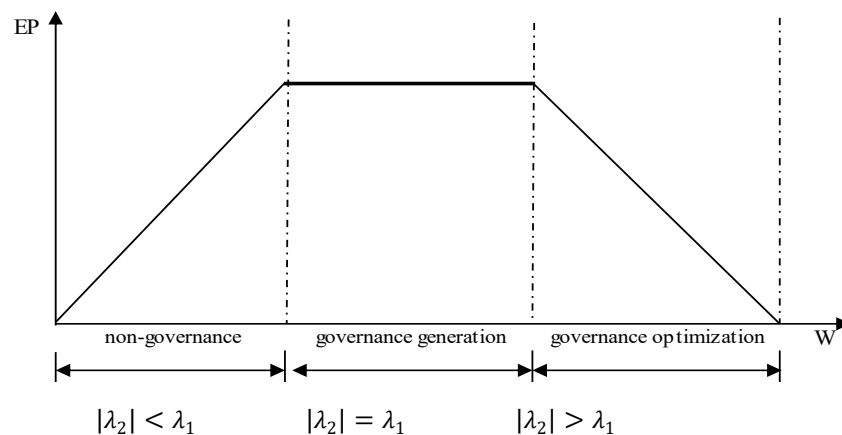


Figure 3. The three stages of urban waste governance impact on EP.

Figure 3 illustrates the following three stages. First, non-governance; in the early days of urban establishment, the impact of urban waste on the environmental pollution is negligible because of very little waste. As the level of urbanization and the population increases, the amount of urban solid waste will continue to grow. If it is not governed, namely $|\lambda_2| < \lambda_1$, urban environmental pollution will increase with the rise of waste. Second, governance generation; the negative externality of urban waste will gain prominence with the increase of waste in the absence of governance. With the emergence of negative externality and the gradual increase requirements in quality of life, demand for waste governance will gradually increase. When waste governance starts to work and $|\lambda_2| = \lambda_1$, the effect of urban waste and effect of waste governance on the environmental pollution are offset against each other. Third, governance optimization; when the urban area expands rapidly, people also begin to realize the importance of waste governance to environmental pollution. The equilibrium point of waste governance will change dynamically with the change of the supply and demand curve, which will be optimized continuously to maximize the social benefit of limited resources.

The marginal revenue and marginal costs produced by different governance modes are different. Therefore, it is necessary to compare the consumer surplus, producer surplus, and total social surplus generated by different governance modes to determine which governance mode is optimal.

4. Results

As the level of urbanization and the urban population are upgraded in developing countries, the amount of urban waste will gradually increase. Increasing waste will lead to more serious

environmental pollution, which will eventually raise the demand and price for waste governance. The change of the revenue curve and marginal revenue curve will be employed to illustrate the change of demand and price of waste government. Revenue is the supplier's income from selling a product or providing a service at the unit price, equal to price times quantity, $R = p \times q$; Marginal revenue is the first derivative of the revenue function with respect to q .

The revenue function and the marginal revenue function of the waste governance are as follows:

$$R = P(q, \bar{q}_i) \times q \quad (5)$$

$$MR = \frac{\partial R}{\partial q} = \frac{\partial P(q, \bar{q}_i)}{\partial q} \times q + P(q, \bar{q}_i) \quad (6)$$

where, $\bar{q}_i (i = 1, 2, \dots, n)$ refer to other factors that affect the price of waste governance except the quantity of waste governance, such as the size of the population and residents' environmental behavior. \bar{q}_i is fully characterized by $\frac{\partial p}{\partial \bar{q}_i} > 0$.

Cost is the expenditure of the supplier to produce a product or provide a service, including fixed costs and variable costs. The marginal cost is the first derivative of the cost function with respect to q .

Assume that the cost function and marginal cost function of the waste governance are as follows:

$$C = C(q, \bar{q}_j) \quad (7)$$

$$MC = \frac{\partial C}{\partial q} = \frac{\partial C(q, \bar{q}_j)}{\partial q} \quad (8)$$

where $\bar{q}_j (j = 1, 2, \dots, m)$ represent other factors that affect the cost of waste governance in addition to the quantity of waste governance, such as environmental policy orientation and waste disposal technology. \bar{q}_j is fully characterized by $\frac{\partial C(q, \bar{q}_j)}{\partial \bar{q}_j} < 0$.

In developing countries, waste governance is a gradual process. Suppose there is an initial state of waste governance, and the marginal revenue function and marginal cost function are MR_1 and MC_1 , respectively. The initial equilibrium point appears at $MR_1 = MC_1$, which is expressed in q_1^* and shown in Figure 4, and it can be get

$$MR_1(q_1^*, \bar{q}_i) = \frac{\partial R}{\partial q_1^*} = \frac{\partial P(q_1^*, \bar{q}_i)}{\partial q_1^*} \times q_1^* + P(q_1^*, \bar{q}_i) \quad (9)$$

$$MC_1(q_1^*, \bar{q}_j) = \frac{\partial C}{\partial q_1^*} = \frac{\partial C(q_1^*, \bar{q}_j)}{\partial q_1^*} \quad (10)$$

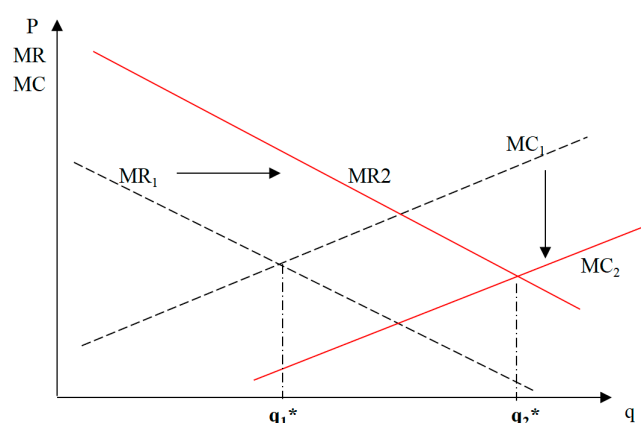


Figure 4. Equilibrium changes as MR and MC move.

As the size of the population becomes larger and larger, \bar{q}_i changes to \bar{q}_i' . As a result, the demand and price for waste governance will increase. MR is a decreasing function, so when $\bar{q}_i' > \bar{q}_i$, $MR(q_1^*, \bar{q}_i') > MR(q_1^*, \bar{q}_i)$. That means that MR_1 will shift to the right to MR_2 . With the strengthening of environmental policy orientation and improvement of waste disposal technology, \bar{q}_j changes to \bar{q}_j' . MC is an increasing function, so when $\bar{q}_j' > \bar{q}_j$ there is $MC(q_1^*, \bar{q}_j') < MC(q_1^*, \bar{q}_j)$. That means MC_1 will move down to MC_2 .

The new marginal revenue function and the marginal cost function are MR_2 and MC_2 , respectively. Then the new equilibrium point will only appear at the point where $MR_2 = MC_2$, which is represented as q_2^* illustrated in Figure 4, and it can get

$$MR_2(q_2^*, \bar{q}_i') = \frac{\partial R}{\partial q_2^*} = \frac{\partial P(q_2^*, \bar{q}_i')}{\partial q_2^*} \times q_2^* + P(q_2^*, \bar{q}_i') \quad (11)$$

$$MC_2(q_2^*, \bar{q}_j') = \frac{\partial C}{\partial q_2^*} = \frac{\partial C(q_2^*, \bar{q}_j')}{\partial q_2^*} \quad (12)$$

Figure 4 shows that in the long run, the equilibrium of waste governance is a dynamic process, from the non-government stage to the governance generation stage, and finally entering the governance optimization stage. During the dynamic process, a new and increasing optimal equilibrium will appear. We will discuss and compare the utility of different governance modes as follows.

5. Discussion

Urban waste has the characteristics of private goods, such as urban domestic waste. Citizens are consumers and direct beneficiaries of waste governance. Economics is basically the study of how to maximize social benefits on the premise of limited resources, that is, to maximize the benefits of stakeholders. Stakeholders in this study include suppliers and consumers of waste governance. Consumer surplus measures the benefits to consumers of participation in waste governance: consumer surplus = value to buyers – amount paid by buyers; while producer surplus measures the benefits of producers receiving form participation in waste governance: producer surplus = amount received by sellers – cost to sellers [25].

According to welfare economics, the function of government is to maximize total social welfare, which is equal to the sum of consumer surplus and producer surplus minus government subsidies: total social welfare = consumer surplus + producer surplus – government subsidy [25]. That is to say, a provider of waste governance should be optimized to maximize total social welfare from the perspective of welfare economists.

Hal [26] put forward several calculation methods of consumer surplus. In this study, waste governance is regarded as a kind of commodity or service, in which the supplier is the body of the waste governance, while the demand side includes residents and society. When supply and demand are equal, that is, when the supply curve and the demand curve intersect, the point of intersection is called the equilibrium point.

The following will turn attention to discussing and comparing the consumer surplus, producer surplus and total social surplus of different governance bodies.

The supply of waste governance is endowed with the equation $p = a + tq$ ($a, b > 0$). The demand of urban waste governance for residents is calculated by $p = c - kq$ ($c, d > 0$), and the total demand of society is $p = b - kq$ ($e > 0$). The equilibrium quantity of the three governance modes is illustrated as Figure 5.

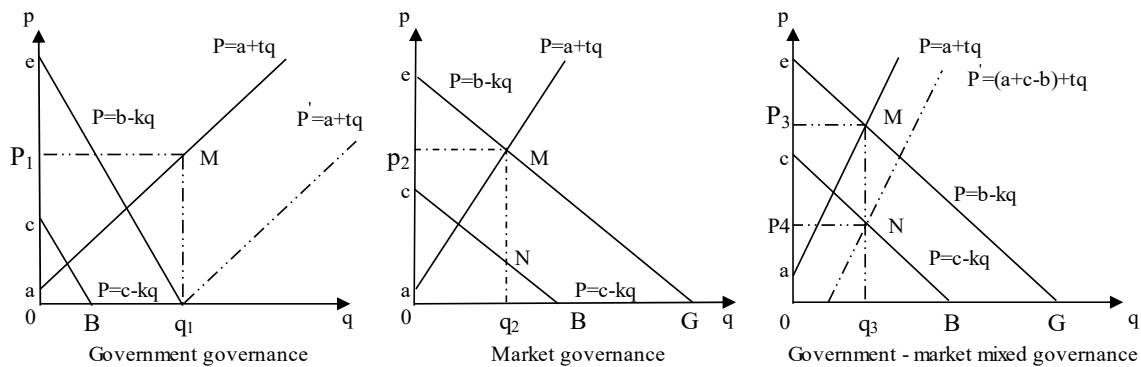


Figure 5. Equilibrium quantity of the three governance modes.

5.1. Government Governance

Because of the “moral reverse choice”, residents and society will maximize the enjoyment of government-provided governance services, until the marginal utility of waste governance become 0; therefore, the governance price under government governance will lose constraints. Graphically, the maximum aggregate social demand is q_1 , and the supply curve shifts to the right where it intersects with q_1 ; that is, the government must provide q_1 to meet the total demand of residents and society. Since the provider of waste governance is the government, the price paid by residents is 0, that is $p = 0$, and the producer surplus is 0. Total social welfare includes government subsidies and consumer surplus, so CS, PS, GS, and SS are given by:

$$CS_1 = \int_0^{q_1} (b - kq) dq = \frac{b^2}{2k} \quad (13)$$

$$PS_1 = \int_a^{p_1} \left(\frac{p}{t} - \frac{a}{t} \right) dp = \frac{tb^2}{2k^2} \quad (14)$$

$$GS_1 = p_1 q_1 = \frac{ab}{k} + \frac{tb^2}{k^2} \quad (15)$$

$$SS_1 = CS_1 + PS_1 - GS_1 = \frac{b(bk - 2ak - tb)}{2k^2} \quad (16)$$

5.2. Market Governance

When the market acts as the provider of waste governance, the equilibrium quantity is determined by the supply and the resident demand, and then the equilibrium point is q_2 . Due to the externality of urban resident waste, its price is determined by the aggregate social demand at the value of q_1 . Assuming that the equilibrium points of the market as the provider of waste governance is (q_2, p_2) , then CS, PS, and SS are as follows:

$$CS_2 = \int_0^{q_2} (b - kq) dq - P_1 q_1 = \frac{1}{2} k \frac{(b - a)^2}{(t + k)^2} \quad (17)$$

$$PS_2 = \int_a^{p_2} \left(\frac{p}{t} - \frac{a}{t} \right) dp = \frac{t(b - a)^2}{2(t + k)^2} \quad (18)$$

$$SS_2 = \int_0^{q_2} [(b - kq) - (a + tq)] dq = \frac{(b - a)^2}{2(t + k)} \quad (19)$$

5.3. Mixed Government–Market Governance

Under the mixed governance mode, the equilibrium point is the intersection point M of the waste governance supply curve and the social aggregate demand curve, which is marked as (q_3, p_3) . The externalities caused by waste, shown by line segment MN, which is the vertical distance between the social aggregate demand curve and the residents' demand curve in Figure 5, are borne by the government. The price paid by residents for waste governance is P_4 , and the difference between P_3 and P_4 is subsidized by the government. Therefore, the supply curve of waste governance will shift downward and intersect with point N. The supply curve, after government subsidies, should be changed to $P' = (a + c - b) + tq$. Therefore, CS, PS, and SS are obtained as follows:

$$CS_3 = \int_0^{q_3} (b - kq) dq - p_4 q_3 = \frac{(b - a)(2tb + 3kb - 2tc - 2ck - ak)}{2(t + k)^2} \quad (20)$$

$$PS_3 = \int_a^{p_3} \left(\frac{p}{t} - \frac{a}{t} \right) dp = \frac{t(b - a)^2}{2(t + k)^2} \quad (21)$$

$$SS_3 = \int_0^{q_3} [(e - kq) - (a + tq)] dq - (p_3 - p_4)q_3 = \frac{-(b - a)^2}{2(t + k)} \quad (22)$$

5.4. Numerical Analysis

In this section, which governance mode is optimal is examined from the three perspectives of CS, PS, and SS. To do this, numerical examples are constructed to illustrate the welfare from each governance mode. The following initial values are used: $a = 5$, $t = 2$, $c = 10$, $k = 1$, and $b = 20$.

We get $CS_1 = 200$, $CS_2 = 12.5$, $CS_3 = 62.5$; $PS_1 = 400$, $PS_2 = 25$, $PS_3 = 25$; $SS_1 = -300$, $SS_2 = 37.5$, and $SS_3 = -37.5$.

According to the calculation results it can be compared:

$$CS_1 > CS_3 > CS_2;$$

$$PS_1 > PS_2 = PS_3;$$

$$SS_2 > 0 > SS_3 > SS_1.$$

The result of the analysis with the aid of basic analytical tools in economics shows the intersection of the supply curve of waste governance and the demand curve is an equilibrium point, which represents a way of resource allocation and can be measured by economic welfare, that is, total social surplus. If this allocation maximizes the total surplus, the resource allocation method is effective.

What the numerical analysis reveals is a general and verifiable result. From the perspective of the total surplus of three models, when the market is in charge, the total social surplus is the largest (the most effective), while it is the smallest (the most ineffective) when the government is in charge. From the perspective of surplus indicators within a single provider, when the provider of waste governance is either the government or the market, producer surplus is greater than consumer surplus, while when the role is played by mixed government–market, consumer surplus is greater than producer surplus.

In China today, the provider of waste governance is the government. In 2018, it was the government that implemented national household waste classification policy and financed all waste treatment. Residents were not required to pay any waste treatment fee. The result of the analysis based on the model shows that producer surplus is greater than consumer surplus in China's method of waste governance. This is because residents tend to maximize the use of free waste governance services so that the supply of waste governance is maximized correspondingly. As the price of waste governance loses its constraint, the price curve is moved upward, and the producer surplus is the area below the price and above the supply curve, and thus the producer surplus is greater than the consumer surplus.

Yet it was found meanwhile that with the government as the provider of waste governance, serious loss of production utility was caused as the result of all the waste governance services enjoyed by residents and the society totally paid by the government, added to by the fact that both individual marginal utility and social marginal utility are less than marginal cost, which causes serious loss of production utility. This is why the total social surplus of the mode by government is the smallest.

6. Conclusions and Prospect

As a developing country, China's economic development will inevitably result in urban expansion at the expense of a parallel growth in urban waste. In order to achieve the goal of high-quality sustainable development, China must allocate the provider of waste governance effectively to curb the environmental pollution caused by waste growth. The paper establishes the functional relationship between different stakeholders and the equilibrium model of supply and demand in the process of waste governance. Economic welfare generated by different waste governance modes can be measured with the aid of the basic tool of supply and demand equilibrium in economics. The model assumes that the development of urbanization goes through four stages, and that waste governance experiences three stages.

As is shown above, of the three modes of waste governance, the government is not able to reach the optimal allocation of resources because the total surplus is the smallest when it governs. In our model, the equilibrium point is dynamic. It can transform from the governance mode with the smallest total surplus to that with higher total surplus; in other words, a more effective provider of waste governance can be allocated through optimization. The results of the numerical analysis of the model are consistent with the three waste governance stages of non-governance, governance generation, and governance optimization. When the total social surplus generated by the provider in the process of waste governance is negative or its allocation is ineffective, it fails to control the environmental pollution caused by waste growth, namely $|\lambda_2| \leq \lambda_1$, corresponding to the stage when China is a developing country that has not yet completely gotten rid of poverty.

The result of the study in this paper shows that China's current allocation of providers of waste governance is not optimal and there are still limitations in effectively restraining waste from environmental pollution. Nevertheless, since the equilibrium point of waste governance quantity is dynamic, there still is a lot of room for the optimization of waste governance, which will certainly inject a new impetus into the high quality and sustainable development of Chinese cities.

In the future, we will further explore the mechanism of how both waste quantity and waste disposal technologies mastered by providers of waste governance affect the environment.

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