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Sustainability Assessment of Bus Low-Fare Policy Considering Three Stakeholders of the Public, Bus Enterprises and Government: A Case Study of Shenzhen, China

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Abstract: In order to quantitatively evaluate the sustainability of bus low-fare policy, this study establishes a sustainability evaluation index system for bus low-fare policy by using the PSR (Pressure–State–Response) model. Based on the matter–element extension model and entropy weight method, the sustainability evaluation model of bus low-fare policy is constructed. Finally, taking Shenzhen as an example, this study compares and analyzes the sustainability changes of bus fare policy in 2006, 2012 and 2016. The results show that the sustainability of the bus fare policy does not depend on the attribute of the fare (profit-making fares or public welfare fares): the sustainability of bus low-fare policy is closely related to the supporting fiscal subsidy system. Compared with the cost regulation subsidy system, the quota subsidy system is more conducive to the sustainability of bus low-fare policy. This study provides a decision-making reference for the sustainable development of urban bus low-fare policy.

Keywords: bus fare policy; sustainability evaluation; fiscal subsidy; PSR model; matter–element extension model; entropy weight method

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1. Introduction

According to the theory of public goods, the urban public bus is a kind of quasi-public goods, which has both public welfare and profitability [1]. From the total level of social welfare, the bus fare must take into account both fairness and efficiency by implementing price control. At the same time, in order to compensate for the policy losses of bus enterprises caused by the price control, the government generally provides fiscal subsidies to them to ensure their survival and development [2]. Therefore, "government pricing accompanied with subsidies" has become the practice of public bus development in many countries [3].

The Chinese government has offered the bus priority policy for more than ten years [4]. The bus low-fare policy is one of the main measures to support the priority policy since it can significantly reduce the travel costs of the public and play the role of price leverage to attract more riders to use buses [5–7]. However, there is an "unsustainable" risk in the implementation of the bus low-fare policy. Beijing is an example. In Beijing, the bus fare was reduced on 1 January 2007 across the board, with a low-fare scheme, starting with CNY 1, 40% off the bus cards and 20% off the student tickets. The actual average bus fare was CNY 0.58 per person per trip, becoming the lowest bus fare in China. Since then, the amount of bus subsidies has increased year after year, from more than CNY 4 billion to more than CNY 20 billion, a five-fold increase in seven years, which caused a great fiscal burden on the local government. Under this pressure, the Beijing government had to adjust the bus low-fare scheme in 2014. The average bus fare after the fare adjustment was about

CNY 1.30 per person per trip. It was found that about 95% of the surveyed bus enterprises had operating losses due to the bus low-fare policy, and the government fiscal subsidies actually received by the enterprises can only cover about 35.9% of the operating costs [8].

The above example illustrates that although the bus low-fare policy can reduce the travel cost of the public and attract more people to use buses, excessively low fares will not only impose an excessive fiscal burden on the government but also harm the economic interests of bus enterprises, ultimately resulting in a mandatory change in or even termination of the policy. How to ensure the sustainable implementation of the bus low-fare policy should be the primary problem faced by policymakers and managers, as well as an important issue in the field of urban public transport. While abundant studies have theoretically established fare optimization models and regulation mechanisms from various perspectives [9–11], which provide many ideas for the better implementation of bus fare policy, the evaluation of bus low-fare policy from the perspective of sustainability is still necessary to identify its weaknesses and make improvements. According to Brundtland's definition of sustainability, a sustainable public transport system is generally considered both meeting the current travel needs of residents and the future needs of future generations [12]. Thus, the sustainability of bus low-fare policy here refers to the ability to maintain low fares to safeguard the requirements of current and future generations. Unlike whole public transport sustainability, the sustainability of bus low-fare policy is affected by the behavior choices of the multiple stakeholders. To this end, this study establishes a sustainability evaluation index system and constructs a sustainability evaluation model to quantitatively measure the sustainability of bus low-fare policy. This study provides theoretical support for the sustainable development of the bus low-fare policy.

The contribution of this study is clear. First, we address the research gap in previous studies by evaluating the sustainability level that the bus low-fare policy belongs to and initially exploring the influence factors of low-fare policy sustainability. Second, based on the PSR model framework, the public bus system is simulated as a dynamically balanced ecosystem, and a multi-level and multi-perspective evaluation index system for the bus low-fare policy sustainability is constructed. The evaluation index system can better reflect the dynamic change mechanism of the factors related to each stakeholder under the influence of the low-fare policy. Third, we apply the entropy weight matter–element extension model to the sustainability evaluation of bus low-fare policy, which not only solves the problem of conflicts and contradictions among some evaluation indicators but also takes advantage of the entropy weight method to avoid the bias caused by subjective factors, eventually making the evaluation results more objective.

2. Related Work

Sustainable development has reached a consensus in all fields of the world. Transport sustainability is the mainstream of sustainable development goals [13]. As a key component of urban transportation systems, the role of public transport has been established as a critical element in promoting sustainable development due to its affordability, efficiency and convenience [14]. From the description by the previous literature, public transport sustainability generally can be broadly and narrowly defined [15]. In a broad sense, the development of public transport coordinates with the urban economy, society, and environmental resources [16,17]. In a narrow sense, dynamic transit bus networks, smart technological support and effective fare policy are also related to the sustainable development of public transport [18,19]. The sustainability of bus fare policy is an important element of public transport sustainability that cannot be ignored. Prior studies have found rich research results on the impact of public transport fare on the whole public transport system, which have laid a theoretical foundation for this study.

Over the years, a large number of empirical studies have been conducted investigating the impact of public transport fare on ridership attraction [20–26]. Fare elasticity is defined as the percentage change in public transport demand after a one percent change in the fare, under the assumption that all other factors are kept constant [27]. The industry standard for fare elasticity is called the Simpson–Curtin rule: the demand for transit service declines by one-third for every one percent increase in fare, i.e., the fare elasticity is −0.33 [28]. In the absence of more effective information, many U.S. transit properties still rely on this rule when projecting the likely effects of a proposed fare policy [29]. Correspondingly, fare reduction is a significant factor in attracting bus users [30]. Given the 2017 public transport fare policy change introduced in South East Queensland, Australia, Liu et al. (2019) examined how the fare policy reform affects public transport ridership through a set of statistical analyses and spatial lag regression [26]. Their findings show that public transit ridership can be boosted by reducing the fare cost per journey. In summary, many researchers have provided evidence that a low fare can reduce the travel cost of the public and provide an initial motivation to encourage people to use buses more [31].

Public transport subsidies are justified for three factors: the existence of economies of scale and the Mohring effect in public transport services; price distortions or externalities in competitive modes; and distributional issues [32]. Fare revenues are the main source of income for public transport operators [33]. Meanwhile, it has proved to be extremely costly to provide high-quality bus services; thus, subsidies to public transport are also part of the costs covered by the government and offer incentives to improve service levels [34,35]. Due to the low-fare policy, fare revenues cover a lower proportion of costs, and public transport subsidies have to be greatly increased. Pucher and Kurth (1995) analyzed the reasons for the success of five metropolitan regions, namely Hamburg, Munich, the Rhein-Ruhr region, Vienna and Zurich, in attracting more public transport riders and increasing or at least stabilizing public transport's share of modal split [36]. They found that the low fare made public transport operators unable to make ends meet and threatened the supply quality of the public transport service, but adequate government financial support is crucial to its continued improvement in service quality.

Regarding the interactions among fares, bus service quantity and quality, ridership attraction and fiscal subsidies, Jin et al. (2019) concluded that the ridership attraction depends on both the bus service and fare level, while higher fares allow bus operators to provide a better service [37]. A good but expensive bus service and a cheap but low-quality bus service seem to offer a choice. From the viewpoint of maximizing social welfare, lower fares are preferable. Therefore, to ensure bus service quantity and quality at lower fares, the government has to provide more subsidies for bus operators. In this regard, Figure 1 intuitively depicts the general relationships among bus fare, fiscal subsidy, bus service quantity and quality and ridership attraction. The relationships among these variables are very important for the subsequent policy evaluation.

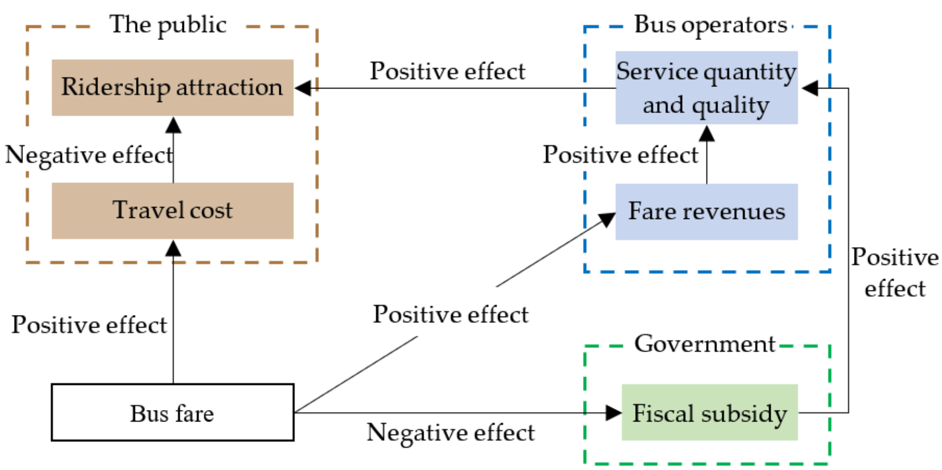

Figure 1. The general relationships among bus fare, fiscal subsidy, service quality and ridership attraction.

3. Establishing the Sustainability Evaluation Index System

3.1. Application of PSR Model

The PSR model (Pressure–State–Response) was first proposed by David J. Rapport and Tony Friend in 1979, and was further refined, eventually forming a set of theoretical frameworks for studying environment, resources and sustainability. P (pressure) describes the impact of human and social activities on the environment; S (state) presents the state and changes of the environment under the influence of human factors; and R (response) describes the repair and remedial measures taken by human society in response to environmental destruction [38]. These three aspects show the changes and dynamic mechanism of things under the combined effect of multiple factors, and answer the three basic questions related to sustainable development: why, what happened, and how to do it. They are suitable for the study of sustainable development. Since the PSR model has the advantages of wide index coverage, the ability to reflect the dynamic creation mechanism of multiple subjects and clear causality, it has been applied to many research fields, such as the evaluation of urban entrepreneurship environment [39], the assessment of enterprise green innovation [40] and the evaluation of urban rail transit sustainable development [41]. These studies show that the PSR model is not limited to the evaluation of natural resources and the environment, but also can further expand its research scope.

The urban public bus system is similar to an ecosystem. The multiple stakeholders involved in the bus fare policy (i.e., the public, bus enterprises and the government) will interact with each other and are always in a dynamic equilibrium. Specifically, the bus low-fare policy has a negative or positive pressure on all stakeholders. Then, different stakeholders make different responses to cope with the pressure. These responses further have an impact on the performance of a bus system, which can be described by bus service quantity and quality [42]. The bus system forms an organic dynamic cycle under the effect of bus fare policy, as shown in Figure 2. It can be seen that the PSR model is applicable to the sustainability evaluation of bus low-fare policy.

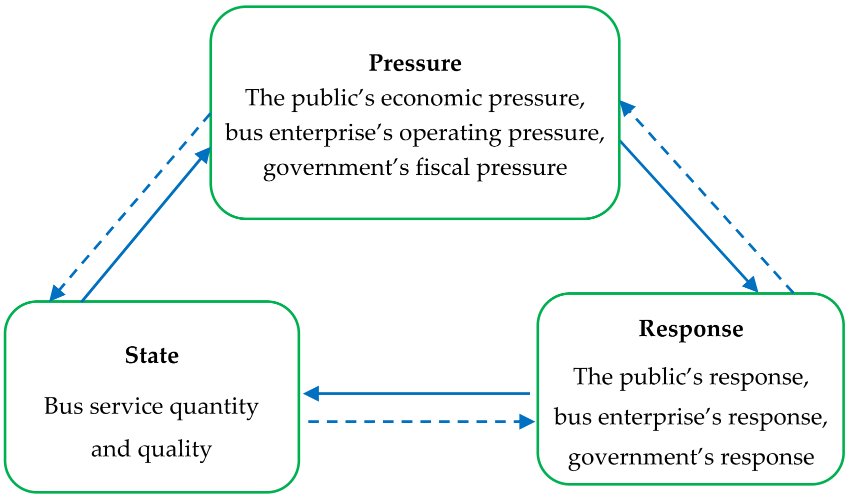

Figure 2. PSR framework to bus low-fare policy sustainability.

3.2. Evaluation Indicator Selection

According to the PSR model, the sustainability evaluation indexes of bus low-fare policy contain three aspects: pressure indicators, state indicators and response indicators. Combined with theoretical research and practical difficulties, this study selects eleven indicators to evaluate the sustainability of bus low-fare policy, as shown in Table 1. It should be noted that the selection of these indicators follows three principles: (1) the selected indicator is affected by the bus fare policy, and there are interactions between indicators. (2) Considering the impact of external variables on the bus system (e.g., population, economic level, etc.), evaluation indicators prefer relative values rather than absolute values.

For example, we choose mode split rate instead of ridership, service coverage instead of the length of lines and the number of stations, and the ownership ratio instead of the number of vehicles. (3) Avoid repetition between indicators. It is worth mentioning that there are competitive and complementary relationships between buses and rail transit, private cars, ridesourcing and other transportation modes [43–45]. The availability, travel costs and service level of these transportation modes collectively determine the travel behavior of urban residents, and further impact the service status of buses. Therefore, the sustainability of bus low-fare policy may be affected by all modes of transportation. Among the above indicators, the indicator of "bus modal share in motorized travel" represents the residents' choice behavior under the combined effect of bus low-fare policy and all modes of transportation, and the indicators of bus service quantity and quality, such as "bus service coverage" "bus ownership ratio" and "departure frequency", represent the service status of buses under the bus low-fare policy and the competition and cooperation of all transportation modes.

Table 1. Sustainability evaluation index system for the bus low-fare policy.

Aspect	Indicator	Symbol	Positive Tendency
Pressure	Per capita bus costs as a percentage of disposable income (%)	C_1	–
	Passenger revenue as a percentage of operating costs (%)	C_2	+
	Bus subsidy as a percentage of fiscal revenue (%)	C_3	–
State	Bus service coverage (%)	C_4	+
	Bus ownership ratio (vehicles/10,000 population)	C_5	+
	Departure frequency (vehicles/h)	C_6	+
	Average operating speed during morning and evening peak hours (km/h)	C_7	+
	Mean crowding during morning and evening peak hours (%)	C_8	–
Response	Bus modal share in motorized travel (%)	C_9	+
	Operating cost per vehicle—kilometer (CNY)	C_{10}	–
	Proportion of subsidy linked to performance (%)	C_{11}	+

3.2.1. Pressure Indicators

Bus fares directly affect the public's travel costs; thus, the main pressure on the public caused by bus fares is economic pressure. Hereto, we adopted the indicator of "bus costs as a percentage of disposable income" to represent the public pressure. The larger the value of this indicator, the greater the economic pressure of the public.

As the main operators of a public bus, the main pressure caused by the bus low-fare policy is the operating pressure due to the reduction in fare revenue. If the fare revenue is significantly reduced, the bus enterprises will suffer serious losses once the fiscal subsidies are insufficient or not available, which will affect the enterprises' normal operation. In this regard, we chose the indicator of "passenger revenue as a percentage of operating costs" to represent the pressure of bus enterprise. The larger the value of this indicator, the lower the operating pressure of the bus enterprise.

The low-fare policy is inevitably accompanied by high fiscal subsidies. Generally speaking, the lower the fare is, the higher the amount of subsidy there tends to be. As the makers of the bus fare policy, the government hopes to achieve certain social benefits through the low-fare policy on the one hand, and on the other hand hopes that it does not pay excessive fiscal expenditures [46]. Therefore, the main pressure on the government caused by the bus low-fare policy is fiscal pressure. The indicator of "bus subsidy as a percentage of fiscal revenue" is selected to represent the pressure of the government. The larger the value of this indicator, the higher the fiscal pressure of the government.

3.2.2. State Indicators

The bus low-fare policy makes bus enterprises suffer from operating losses and threatens the supply quantity and quality of bus services [8,36]. Regarding the quantity of bus services, the scale of bus lines, stations and fleets have been recognized as being representative of the bus service quantity [4]. Hereto, we adopted the indicator of "the coverage rate within 500 m of bus stations (namely the bus service coverage)" and "the number of buses per 10,000 members of the population (namely the bus ownership ratio)" to represent the bus service quantity. The larger the value of the two indicators, the greater the bus service quantity.

The bus service quality is a complex multidimensional construct [47,48]. For a bus trip, attributes of bus service quality involve walking time to/from the station, waiting time for the vehicle, traveling time and comfort in the bus [49,50]. Among them, the waiting time, traveling time and comfort will be affected by the increase in bus demand caused by the low-fare policy [37]. Thus, the indicators of "departure frequency", "average operating speed during morning and evening peak hours", and "mean crowding during morning and evening peak hours" were selected. The larger the values of departure frequency and average operating speed, the better the bus service quality, while the smaller the values of mean crowding, the better the bus service quality.

3.2.3. Response Indicators

The attractiveness of a public bus compared to personal transport determines the demand for the bus system [51]. A number of empirical studies have demonstrated that the lower the fare, the more attractive the bus is to travelers [37,52]. This is exactly the main reason why many countries implement the bus low-fare policy to alleviate traffic congestion. Therefore, the main response of the public to the low-fare policy is the shift of travel mode choice behavior. In this study, we use the indicator of "bus modal share in motorized travel" (i.e., the proportion of bus travels to the total number of motorized travels) to represent the public's response. The larger the value of this indicator, the more positive the public's response.

Faced with the operating pressure brought by the low-fare policy, the most likely response of bus enterprises is to adjust their operating scheme to reduce their operating costs; or even to obtain as many fiscal subsidies as possible through speculative behavior, which eventually leads to the increase in operating costs and low operational efficiency [53,54]. Therefore, we selected the indicator of "operating cost per vehicle-kilometer" to represent the response of bus enterprises. The larger the value of this indicator, the more negative the response of bus enterprises.

In order to avoid the negative response of bus enterprises, and stimulate their market autonomies and the supply efficiency of bus services, the government's usual response measure is to link the subsidy amount with incentives and their performance. In this regard, we selected the indicator of "proportion of subsidy linked to performance" (i.e., the subsidy amount linked to performance as a percentage of the total subsidy) to represent the government's response. The larger the value of this indicator, the more positive the response of the government.

4. Constructing the Sustainability Evaluation Model

As seen from the sustainability evaluation index system established above, the sustainability evaluation of bus low-fare policy is a complex evaluation issue with multiple levels and multiple indicators, and there are incompatible and contradictory relationships among some evaluation indicators, such as the indicators between the public's economic pressure, bus enterprises' operating pressure and the government's fiscal pressure. The matter–element extension method is a widely used multi-element evaluation method proposed by Cai (1999) [55]. It has the advantages of an intuitive processing process and rich evaluation results. Compared with traditional evaluation methods, the matter–element extension method can deal with the contradictions in complex systems from both quantitative and qualitative perspectives [38]. Therefore, it is suitable for evaluating the sustainability of bus low-fare policy. The specific steps are as follows.

4.1. Determination of Sustainability Ranking

Sustainability ranking is a qualitative description of evaluating the sustainability of bus low-fare policy. Based on previous research and expert opinions, the sustainability of bus low-fare policy in this study is divided into five levels:

$$D = \{D_1, D_2, D_3, D_4, D_5\} \tag{1}$$

where D_1 represents the highest level of bus low-fare policy sustainability, i.e., the bus low-fare policy is highly sustainable; D_2 represents a higher level of bus low-fare policy sustainability, i.e., the bus low-fare policy is relatively sustainable. D_3 represents a critical level of sustainability, i.e., the bus low-fare policy can meet the basic requirements of sustainable implementation, but this sustainability is weak and can easily be broken. D_4 represents a lower level of bus low-fare policy sustainability, i.e., the bus low-fare policy sustainability is low and the bus low-fare policy cannot achieve long-term sustainable implementation; D_5 represents the lowest level of bus low-fare policy sustainability and corresponding measures are needed to change the situation.

4.2. Determination of the Matter–Element to Be Evaluated, the Classical Field and the Limited Field

In this study, the matter–element to be evaluated refers to the sustainability of bus low-fare policy. The matrix form of the matter-element is

$$R = (P, C, V) = \begin{bmatrix} P & c_1 & v_1 \\ & c_2 & v_2 \\ & \cdots & \cdots \\ & c_n & v_n \end{bmatrix} \tag{2}$$

where P denotes the bus low-fare policy to be evaluated; C denotes the sustainability evaluation indexes; V denotes the actual value of the evaluation index C; and n is the number of evaluation indicators for the bus low-fare policy sustainability, which is equal to 11.

The classical field refers to the corresponding value range of each indicator when the sustainability of bus low-fare policy is located at a certain level, denoted as R_j. The matrix form of the classical field in this study is

$$R_j = \begin{bmatrix} N_j & c_1 & v_{j1} \\ & c_2 & v_{j2} \\ & \cdots & \cdots \\ & c_n & v_{jn} \end{bmatrix} = \begin{bmatrix} N_j & c_1 & < a_{j1}, b_{j1} > \\ & c_2 & < a_{j2}, b_{j2} > \\ & \cdots & \cdots \\ & c_n & < a_{jn}, b_{jn} > \end{bmatrix} \tag{3}$$

where $v_{ji} = <a_{ji},b_{ji}>$ is the classical field of the i-th evaluation indicator at the j-th evaluation level; a_{ji} and b_{ji} are the lower and upper limits of the classical field, $j = 1, 2, \ldots, 5$, $i = 1, 2, \ldots, 11$.

The limited field refers to the range of all possible values of eleven evaluation indicators for the bus low-fare policy sustainability, denoted as R_p. Its matrix form is as follows:

$$R_p = \begin{bmatrix} N_p & c_1 & v_{p1} \\ & c_2 & v_{p2} \\ & \cdots & \cdots \\ & c_n & v_{pn} \end{bmatrix} = \begin{bmatrix} N_j & c_1 & < a_{p1}, b_{p1} > \\ & c_2 & < a_{p2}, b_{p2} > \\ & \cdots & \cdots \\ & c_n & < a_{pn}, b_{pn} > \end{bmatrix} \tag{4}$$

where $v_{pi} = <a_{pi},b_{pi}>$ is the limited field of the i-th evaluation indicator; a_{pi} and b_{pi} are the lower and upper limits of the limited field, $i = 1, 2, \ldots, 11$.

4.3. Determination of Weights

The weight refers to the value assigned to each indicator by the decision maker according to the importance of the indicator. There are two main methods for weighting indicators: subjective and objective. The subjective weighting method mainly relies on the researcher's professional knowledge and experience to determine the weight of indicators. It is highly subjective and emphasizes the decision maker's intention, but ignores the data information of the indicators [56]. The objective weighting method calculates the weight based on a mathematical method according to the original data [57]. The results do not depend on the subjective judgment of the researcher and have a strong mathematical theory basis. Policy sustainability evaluation has not yet formed a unified system. Using personal preferences to determine weights can easily lead to a bias. In order to reduce the intervention of subjective factors and obtain more objective results, we employed an objective weighting method, namely the entropy weight method, to empower the indicator.

The entropy weight method, proposed by Shannon and Weaver (1948) [58], determines the importance of every indicator by utilizing the probability theory to compute uncertain information (entropy) [59]. The greater the entropy value, the greater the impact of the indicator on the comprehensive evaluation. The calculation steps are as follows:

(1) Calculating the lower bound serial information entropy ${E_i}^-$, upper bound serial information entropy ${E_i}^+$ and serial information entropy E_i.

$$E_i^- = -(\ln n)^{-1} \sum_{j=1}^{m} (p_{ji}^- \cdot \ln p_{ji}^-) \tag{5}$$

$$E_i^+ = -(\ln n)^{-1} \sum_{j=1}^{m} (p_{ji}^+ \cdot \ln p_{ji}^+) \tag{6}$$

$$E_i = (E_i^- + E_i^+)/2 \tag{7}$$

where $p_{ji}^- = a_{ji} / \sum_{j=1}^{m} a_{ji}$, $p_{ji}^+ = b_{ji} / \sum_{j=1}^{m} b_{ji}$, $0 \ln 0 \equiv 0$.

(2) Calculating the importance degree d_i of each evaluation indicator.

$$d_i = 1 - E_i \tag{8}$$

(3) Calculating the weight w_i of the i-th sustainability evaluation indicator for the bus low-fare policy. Its calculating formula is as follows:

$$w_i = d_i / \sum_{i=1}^{m} d_i \tag{9}$$

4.4. Calculation of Correlation Degree

The correlation degree refers to the degree of conformity of the i-th sustainability indicator value of the bus low-fare policy with the same indicator' classical domain at the j-th evaluation level (i = 1, 2, . . ., 11, j = 1, 2, . . ., 5), denoted as $K_j(v_i)$. Its expressions are as follows:

$$\rho(v_i, v_{ji}) = \left| v_i - \frac{1}{2}(a_{ji} + b_{ji}) \right| - \frac{1}{2}(b_{ji} - a_{ji}) \tag{10}$$

$$\rho(v_i, v_{pi}) = \left| v_i - \frac{1}{2}(a_{pi} + b_{pi}) \right| - \frac{1}{2}(b_{pi} - a_{pi}) \tag{11}$$

$$K_j(v_i) = \begin{cases} \frac{-\rho(v_i, v_{ji})}{|v_{ji}|}, v_i \in v_{ji} \\ -\rho(v_i, v_{ji}) - 1, v_i \notin v_{ji} \text{ and } \rho(v_i, v_{pi}) = \rho(v_i, v_{ji}) \\ \frac{\rho(v_i, v_{ji})}{\rho(v_i, v_{pi}) - \rho(v_i, v_{ji})}, v_i \notin v_{ji} \text{ and } \rho(v_i, v_{pi}) \neq \rho(v_i, v_{ji}) \end{cases} \tag{12}$$

where $\rho(v_i, v_{ji})$ denotes the distance between point v_i and interval v_{ji}; $\rho(v_i, v_{pi})$ denotes the distance between point v_i and interval v_{pi}.

4.5. Determination of Sustainability Level

(1) Determining the sustainability level of each evaluation indicator

The larger the value of $K_j(v_{\rm i})$, the more $v_{\rm i}$ is in conformity to $v_{\rm ji}$. Thus, the sustainability of the indicator $v_{\rm i}$ belongs to the level $D_{\rm m}$ when max[$K_j(v_i)$] = $K_m(v_i)$.

(2) Determining the sustainability level of bus low-fare policy

$$K_j(P) = \sum_{i=1}^{n} w_i \cdot K_j(v_i) \quad (13)$$

where $K_j(P)$ denotes the multi-index degree of correlation of the bus low-fare policy at the j-th evaluation level. Generally, the sustainability of bus low-fare policy belongs to the level D_m when max[$K_j(P)$] = $K_m(P)$.

5. Case Study

5.1. Study Area

Shenzhen is a mega-city located in the Guangdong–Hong Kong–Macao Greater Bay Area and is one of the most important innovation and technology centers in China. As of 2022, the total area of Shenzhen is 1997.47 km^2, with a GDP of CNY 32.39 billion, a permanent population of 17.66 million, and an urbanization rate of 99.79% [60]. With the rapid development of society and economy, the Shenzhen Municipal People's Government issued the "Implementation Opinions on Prioritizing the Development of Urban Public Transport" in February 2007 to cope with the increasingly prominent contradiction between traffic supply and demand, which made Shenzhen one of the earliest cities in China to implement the bus priority policy, and also one of the first cities to create the "Public Transport City Construction Demonstration Project" in China. Since then, Shenzhen has vigorously developed the bus system and established it as the mainstay of public transport. From 2007 to 2022, the number of buses in Shenzhen increased from 8188 to 16,252, and the length of operating bus lines increased from 11,627 km to 20,645 km. The quantity of bus services nearly doubled. As of now, the 500 m coverage rate of public transport stations in Shenzhen has reached 100%, achieving the full coverage of public transport services.

With the implementation of the bus priority policy, the public bus industry in Shenzhen has experienced a return from marketization to public welfare. Accordingly, Shenzhen's bus fares have also changed from profit-making fares to public welfare fares. In 2007, Shenzhen issued the "Notice on Reducing Public Bus Fares". The new bus fares were reduced by up to 74%. Subsequently, the municipal government issued the "Shenzhen Public Bus Fiscal Subsidy and Cost Regulation Program (Trial)" in the next year and began to implement the subsidy policy of cost regulation. However, with the implementation of the bus low-fare policy, the amount of Shenzhen's bus fiscal subsidies continued to rise, from CNY 1 billion in 2008 to CNY 5.053 billion in 2012. At the same time, in order to obtain more subsidies, bus enterprises continued to expand their cost inputs, which ultimately led to a continuous increase in operating costs per vehicle-kilometer. The municipal government soon realized that cost-based subsidies would not be sustainable [61]. Hereto, for the purpose of improving the efficiency of bus subsidies and controlling the subsidy scale, Shenzhen changed the bus subsidy system from cost regulation to quota subsidy in 2014. The reform process of public buses in Shenzhen is shown in Table 2.

In general, the experience of bus fare reform in Shenzhen provides an important reference for other cities in China. Taking Shenzhen as an example to carry out a case study on the sustainability evaluation of bus low-fare policy is representative. Further, in order to investigate the factors that affect the sustainability of bus low-fare policy, the bus fare policies in 2006, 2012 and 2016 were selected for sustainability evaluation, namely the profit-making fare policy, the bus low-fare policy with a cost regulation subsidy and the bus low-fare policy with a quota subsidy.

Table 2. The reform process of public buses in Shenzhen and sample selection.

Period	Attribute of the Fare	Fiscal Subsidy System	Sample Selection
Before 2007	Profit-making fares	N/A	2006
2007–2013	Public welfare fares (the low-fare policy)	Cost regulation system (The government formulates various standard costs. The cost inputs of bus enterprises that meet the standard range can be subsidized, and the profit return of 6% of the regulation cost can be obtained)	2012
Since 2014	Public welfare fares (the low-fare policy)	Quota subsidy system (The government determines the total amount of subsidies according to the bus services scale provided by bus enterprises, and deducts them based on the assessment results of bus service quantity and quality)	2016

5.2. Policy Evaluation

Referring to previous research and expert opinions while also considering real-world data, we obtained the classical field and limited field of each evaluation indicator at each sustainability level, as shown in Table 3. Thereafter, The specific index weights in Table 4 were calculated based on Formulas (5)–(9).

Table 3. The classical field, limited field and weight.

Indicator	Classical Field					Limited Field
	D_1	D_2	D_3	D_4	D_5	
C_1	[0, 5]	[5, 8]	[8, 12]	[12, 15]	[15, 20]	[0, 20]
C_2	[80, 100]	[60, 80]	[40, 60]	[20, 40]	[0, 20]	[0, 100]
C_3	[0, 1]	[1, 2]	[2, 4]	[4, 6]	[6, 10]	[0, 10]
C_4	[95, 100]	[90, 95]	[80, 90]	[60, 80]	[0, 60]	[0, 100]
C_5	[20, 30]	[15, 20]	[10, 15]	[5, 10]	[0, 5]	[0, 30]
C_6	[12, 20]	[6, 12]	[4, 6]	[3, 4]	[0, 3]	[0, 20]
C_7	[25, 40]	[20, 25]	[15, 20]	[10, 15]	[0, 10]	[0, 40]
C_8	[0, 63]	[63, 73]	[73, 83]	[83, 93]	[93, 100]	[0, 100]
C_9	[50, 100]	[40, 50]	[30, 40]	[20, 30]	[0, 20]	[0, 100]
C_{10}	[2, 4]	[4, 6]	[6, 7]	[7, 8]	[8, 12]	[2, 12]
C_{11}	[50, 100]	[30, 50]	[20, 30]	[10, 20]	[0, 10]	[0, 100]

Table 4. Index weight.

Indicator	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
Weight	0.086	0.097	0.140	0.054	0.103	0.129	0.082	0.053	0.092	0.028	0.137

The single-index degree of correlation $K_j(v_i)$ (i = 1, 2, . . ., 11; j = 1, 2, . . ., 5) and multi-index degree of correlation $K_j(P)$ (j = 1, 2, . . ., 5) are calculated using Formulas (10)–(13). According to the evaluation criteria in Section 4.5, Table 5 presents the sustainability level of each evaluation indicator and overall performance in 2006, 2012 and 2016.

Table 5. The evaluation results of the bus fare policy sustainability in 2006, 2012 and 2016.

Evaluation Results	2006	2012	2016
C_1	D_4	D_2	D_1
C_2	D_2	D_3	D_3
C_3	D_1	D_3	D_2
C_4	D_3	D_2	D_1

Table 5. *Cont.*

Evaluation Results	2006	2012	2016
C_5	D_4	D_3	D_3
C_6	D_3	D_3	D_2
C_7	D_3	D_2	D_2
C_8	D_3	D_3	D_4
C_9	D_3	D_1	D_1
C_{10}	D_2	D_4	D_4
C_{11}	D_5	D_3	D_1
Overall	D_3	D_3	D_2

5.3. Result Analysis

As seen from Table 5, the sustainability of Shenzhen's bus fare policy in 2006, 2012 and 2016 is at the level of D_3, D_3 and D_2, respectively. That means the profit-making fare policy and the bus low-fare policy with a cost regulation subsidy both have a critical level of sustainability and can meet basic requirements of sustainable implementation, while the bus low-fare policy with a quota subsidy has a higher level of sustainability. These results suggest that (1) from the perspective of sustainability, the bus low-fare policy for public welfare is not necessarily better than the profit-making fare policy. In other words, the sustainability of the bus fare policy does not depend on the attribute of the fare. (2) The sustainability of bus low-fare policy may be related to the supporting bus subsidy system. Next, to further explore the impact of the fare scheme and subsidy system on the sustainability of bus fare policy, we separately analyzed the changes in the sustainability of the three aspects of evaluation indexes.

The changes in the sustainability of pressure indicators are shown in Figure 3. It can be seen that after the bus fare reduction in 2007, the sustainability of the "bus costs as a percentage of disposable income" increased significantly in 2012; at the same time, the sustainability of the two indicators "passenger revenue as a percentage of operating costs" and "bus subsidy as a percentage of fiscal revenue" decreased. These indicate that the low-fare policy alleviated the economic pressure of the public, but increased the operating pressure of bus enterprises and the fiscal burden of the government. This is in line with our expectations. The implementation of the low-fare policy and cost regulation system led to a significant change in the composition of economic benefits for bus enterprises, changing from "fare revenues" to "fare + subsidy revenues". Therefore, the operation strategy of bus enterprises was also been adjusted in order to increase profits as much as possible. They began to pursue more fiscal subsidies by raising regulation costs, which eventually led to an increase in bus subsidies year by year and a sharp decline in the sustainability of the "bus subsidy as a percentage of fiscal revenue".

Subsequently, after adjusting the bus subsidy system from a cost regulation to a quota subsidy, the sustainability of the "bus subsidy as a percentage of fiscal revenue" improved in 2016 compared with that in 2012, suggesting the quota subsidy system reduced the government's fiscal pressure. This is mainly because the total amount of subsidies received by bus enterprises under the quota subsidy system depends on the scale of bus services they provide. The service scale in the quota subsidy system includes several indicators, such as annual operating passenger mileage, annual passenger volume, etc. As a result, bus enterprises began to pay attention to expanding the service scale by canceling bus lines with high repetition rates and low passenger flow, increasing the frequency of departures and so on, which ultimately improved the operational efficiency of the bus system. Moreover, the sustainability of the "bus costs as a percentage of disposable income" continued to increase in 2016. This is mainly because the disposable income of residents increased from CNY 40,742 to CNY 48,695 between 2012 and 2016 [62]. Thus, the economic pressure of the public further decreased.

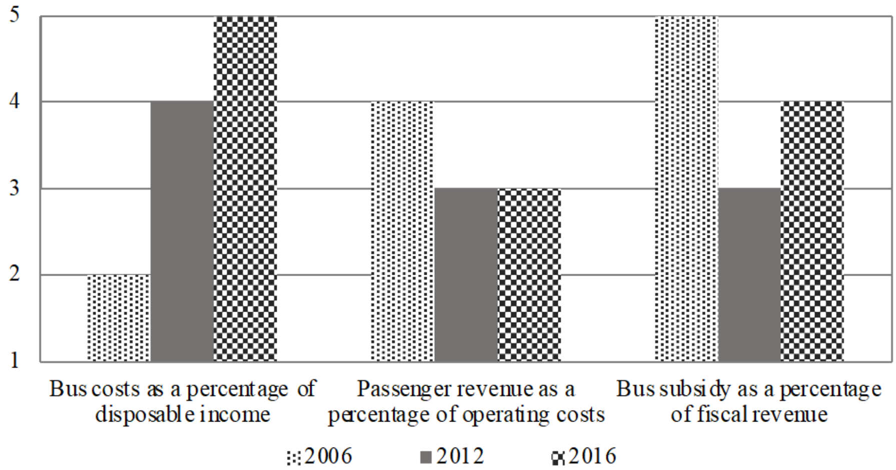

Figure 3. The changes in the sustainability of pressure indicators.

Figure 4 intuitively presents the changes in the sustainability of state indicators. As shown, after the bus fare reduction, the sustainability of "bus service coverage", "bus ownership ratio" and "average operating speed during morning and evening peak hours" increased in 2012, and the sustainability of the other two indicators remained unchanged. Overall, the bus service performance did not worsen or even improve with the reduction in bus fares, while the cost regulation system instead promoted an increase in the bus service quantity. This is mainly because, under the cost regulation subsidy system, the profit of bus enterprises in Shenzhen is decoupled from the operating income, but is directly proportional to the total regulation costs. In order to increase their profits, bus enterprises began to obtain more government subsidies through the operation strategy of expanding cost input, such as adding new bus lines and purchasing vehicles, which to some extent solved the problem of inadequate bus service supply in remote urban areas [63]. Then, after adjusting the bus subsidy system from cost regulation to quota subsidy, the sustainability of the indicators of "bus service coverage" and "departure frequency" improved in 2016, indicating that the quota subsidy system further improved the bus service performance because it was linked to the evaluation results of bus service quantity and quality. Meanwhile, the sustainability of the "mean crowding during morning and evening peak hours" decreased, suggesting that the bus low-fare policy attracted more passengers.

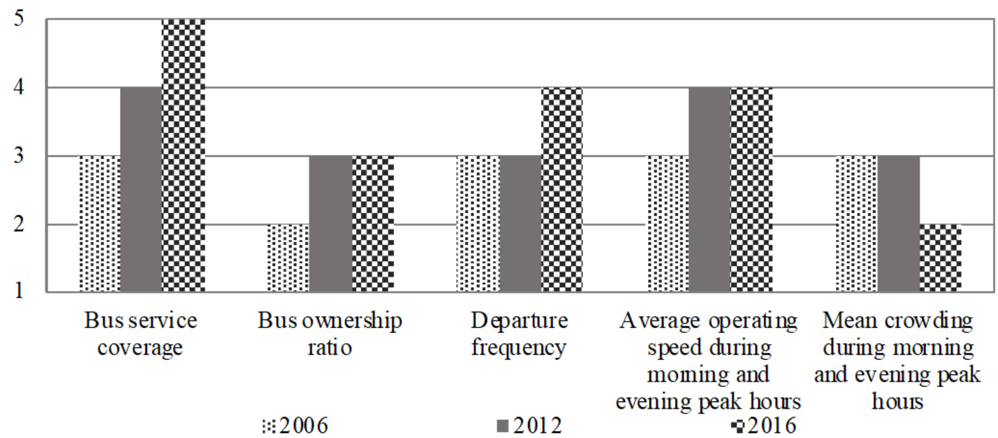

Figure 4. The changes in the sustainability of state indicators.

The changes in the sustainability of response indicators are provided in Figure 5. As can be seen, after the implementation of the bus low-fare policy, the sustainability of the "bus modal share in motorized travel" improved significantly in 2012, indicating that the public increased the use of buses and had a positive response to the low-fare policy. At the same time, the sustainability of the "operating cost per vehicle-kilometer" decreased, reflecting that the bus enterprises made a passive response to the low-fare policy. So in other words, bus enterprises input more costs to obtain more subsidies under the subsidy system of cost regulation, and this behavior eventually led to an increase in operating costs. This performance is consistent with the conclusions of previous studies [46,64]. Finally, the sustainability of the "proportion of subsidy linked to performance" rose continuously from 2006 to 2016, suggesting that the government responded positively to the low-fare policy by adjusting the subsidy system in response to the speculative behavior of bus enterprises.

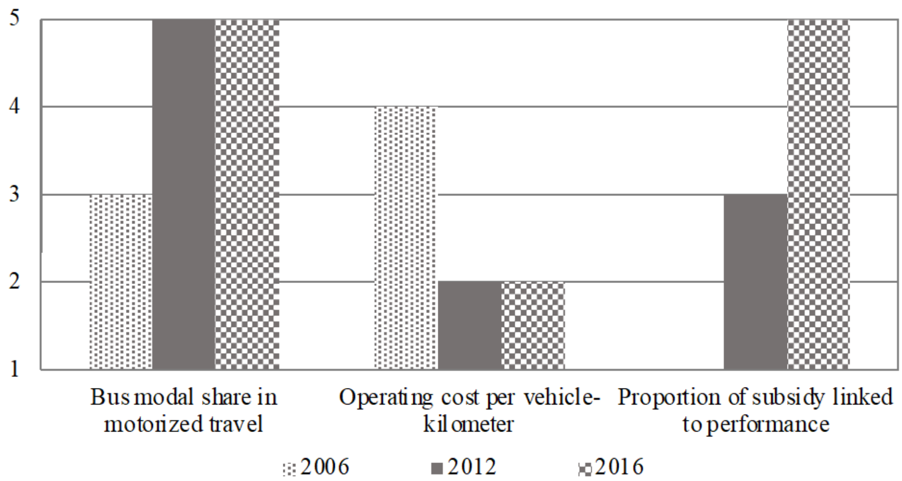

Figure 5. The changes in the sustainability of response indicators.

To sum up, under the cost regulation subsidy system, bus enterprises focused more on how to increase cost inputs to obtain more subsidies, and paid less attention to the public's travel demand and the efficiency of bus service supply. Although the combination of the bus low-fare policy and cost regulation subsidy system increased the sustainability of indicators related to the bus service state, it decreased the sustainability of the "bus subsidy as a percentage of fiscal revenue" and "operating cost per vehicle-kilometer". Compared with the cost regulation subsidy system, the quota subsidy system measured the subsidy amount based on the scale of bus services, and evaluated the bus service provided by bus enterprises in multiple dimensions and multiple indicators. Therefore, the quota subsidy system can relieve the financial pressure of the government, guarantee the quantity and quality of bus services, and control the operation cost of bus enterprises. The quota subsidy system has a positive impact on the sustainability of bus low-fare policy.

6. Conclusions

Based on the practice of bus priority development in China, this study focused on the question of how sustainable the bus low-fare policy is, quantitatively evaluated the sustainability of bus low-fare policy, and initially explored the factors affecting bus low-fare policy sustainability. Firstly, applying the PSR model, this study established a sustainability evaluation index system for the bus low-fare policy involving three stakeholders, i.e., the public, bus enterprises and the government, from three aspects of pressure, state and response. Then, taking into account the incompatibility and contradiction among the sustainability evaluation indexes, the matter–element extension method and entropy weight method were combined to construct a sustainability evaluation model for the bus low-fare policy. Due to the unique and representative process of bus reform in Shenzhen, China, Shenzhen was selected as the case study to compare and analyze the changes in the sustainability of bus fare policy in 2006, 2012 and 2016. The bus fare policies in these three periods, respectively, represented the profit-making fare policy, the bus low-fare policy with cost regulation subsidy and the bus low-fare policy with quota subsidy. Finally, two findings were obtained from this case study. First, from the perspective of sustainability, the bus low-fare policy for public welfare is not necessarily better than the profit-making fare policy. Second, the sustainability of bus low-fare policy is closely related to the supporting bus subsidy system. Specifically, compared with the cost regulation subsidy system, the quota subsidy system is more conducive to the sustainable implementation of the bus low-fare policy.

The following policy implications of the above findings are worthy of declaring. Policymakers should understand the bus low-fare policy's unsustainable risk and its corresponding weaknesses. First, the sustainability of bus fare policy is not related to the attribute of the fare (profit-making fares or public welfare fares). Second, the low fare should be limited relative to the operating costs of public bus system, and an excessively low fare is unsustainable. Third, the bus low-fare policy should not only consider the public's economic affordability, the operating costs of bus enterprises and the government's fiscal capacity, but also be linked with the actual bus service quantity and quality, and appropriately deduce the possible responses of three stakeholders (the public, bus enterprises and the government). Fourth, an inappropriate fiscal subsidy system will seriously restrict the sustainable implementation of the bus low-fare policy; thus, the low-fare policy should not be formulated separately from the financial subsidy system.

Nevertheless, there are three limitations of this study resulting from the lack of available high-quality data. First, since the data of eleven indicators for the bus low-fare policy sustainability were collected by different administrations, they are not uniform across different cities and different years. For example, some cities have "bus modal share in motorized travel", while others have "bus modal share in all travel modes". A city might have data for "bus subsidy as a percentage of fiscal revenue" but not for "per capita bus costs as a percentage of disposable income". For a particular indicator, Shenzhen had data for 2016 but not for 2019 or 2020. Thus, it is limited to extend the research results to a wider range of cities because of the single case. Second, regarding the evaluation index system, this study adopted a series of quantitative indicators related to the three stakeholders of the public, bus enterprises and the government, but ignored qualitative indicators and other stakeholders, such as the public's perception of the low-fare policy, the interests of environmental groups or private car owners. Third, the macroeconomic environment and technological innovation in cities have an impact on sustainable urban mobility [65], but this study only considers factors within the public transport system. Therefore, future research should consider more evaluation indicators and cities under different regulatory and fare pricing schemes to achieve a more comprehensive assessment and further investigate influencing factors of the bus low-fare policy sustainability.

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