

Article

Bike Sharing and the Economy, the Environment, and Health-Related Externalities

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Abstract: In recent years, bike-sharing has experienced rapid development; however, controversies about the externalities of bike-sharing programs have arisen as well. While bike-sharing programs have impacts on traffic, the environment, and public health, the social impacts, the management, and sustainable development of bike-sharing has also been of interest. The debate regards whether there are externalities, as well as whether and how such externalities can be determined. Based on the rapidly diffused bike-sharing in China, this paper quantitatively explores bike-sharing externalities. Specifically, this paper estimates the impacts of bike-sharing on the economy, energy use, the environment, and public health. The empirical results show that bike-sharing programs have significant positive externalities. The bike-sharing systems can provide urban residents with a convenient and time-saving travel mode. We find that the bike-sharing dramatically decreases traffic, reduces energy consumption, decreasing harmful gas emissions, improves public health generally, and promotes economic growth. This study contributes to a better comprehension of the externalities of bike-sharing and provides empirical evidence of the impacts of bike-sharing. Findings suggest that bike-sharing can play a critical role in the process of urban transportation development and provide information useful for urban transportation policies.

Keywords: bike-sharing; externality; economic growth; emission reduction; health effect

1. Introduction

Along with the growing levels of residents' travel demand, personal transportation plays an essential role in our lives. Especially in recent years, the numbers of personal cars have seen rapid growth. For example, ownership of personal vehicles in China has risen from 18.48 million in 2005 to 163.30 million in 2016 [1]. The growing levels of personal cars impose externalities on society, the economy and the environment, which has attracted the attention of academia [2–6]. Cars can increase employment, productivity, and economic growth [7], but most attention has been on their negative externalities. According to the literature [5,6,8–10], cars entail energy dependence, negative environmental effects (air pollution and noise annoyance), public health issues, road damage, accidents, congestion, and the overuse of public spaces in cities. Policy makers need to solve these negative externalities.

Solutions to negative externalities, such as Pigouvian taxes [11–14] or cap-and-trade systems [15–17], have been proposed from an economic point of view. Some policies, such as those of land use and transport planning [18,19], incentives to public transport, and information campaigns [20],

can be combined with corrective instruments. In addition, regulations or new technology could play a role [5]. In recent years, “transport sharing” has become increasingly popular across the globe, which is designed not only to reduce negative externalities but also to satisfy the demand of residents’ travel needs and economic development.

Bike-sharing, as a form of shared transportation, has received increasing attention in recent years. The basic premise of bike-sharing programs is sustainable transportation. Objectives associated with bike-sharing programs include increased cycle usage and mobility options, an improved first/last mile connection to other travel modes, reduced transport congestion and energy consumption, reduced environmental impacts, and improved public health [21–24]. However, controversies regarding the implementation process, such as the waste of resources as well as bicycle maintenance and management [25], have emerged. Therefore, two crucial questions consist in whether there are externalities, as well as whether and how such impacts can be estimated.

Many studies on bike-sharing have focused on qualitative evaluation and discussion. For example, Gleason and Miskimins present various methods of making bikes more available in federal lands, and explore how elements of successful bike programs may be adapted for federal lands settings [26]. Nair et al. analyze the functioning of a large-scale bicycle sharing system in Paris to provide insights for policy makers [27]. Some quantitative studies have taken a closer look at bike-sharing safety and the repositioning problem [28,29]. However, there are few empirical studies to comprehensively explore the externalities of bike-sharing. Theoretically speaking, bike-sharing programs would have impacts on public transportation, transport congestion, energy use, the environment, and personal health. Limited by essential data, in this paper, we only attempt to quantitatively explore the externalities of bike-sharing on the economy, fuel use, harmful emissions, and health in Beijing, China. The study contributes to a better comprehension of the externalities of bike-sharing, and provides empirical evidence for the impacts of bike-sharing. The findings will be important and useful for urban transportation policies.

This paper estimates economy, environment, and health externalities of a bike-sharing program in Beijing. In the last two years, bike-sharing, used with mobile apps, has been prominent in Chinese cities. The online bike-sharing service is different in the following ways: customers can easily locate and unlock shared bikes using mobile apps on a smart phone; shared bikes can be rented and returned to any public area instead of one fixed location. Different online bike-sharing platforms in China are distinguished by color. Of the 20 largest bike-share programs in the world, all but four are in China. Therefore, China is ideal for exploring and analyzing the externalities of bike-sharing.

This paper is organized into three main sections. First, the framework of this paper and the methods used to estimate the externalities of bike-sharing are introduced. Next, key findings are described. Finally, the results are summarized and some implications are provided.

2. Methods and Materials

2.1. Estimation Strategy

This paper attempts to explore the externalities of bike-sharing program in Beijing. Bike-sharing is a good option for short trips across the city, and is convenient, healthy, and environmentally friendly. Based on existing studies, we estimate the externalities of bike-sharing in the following ways: First, a bike-sharing system solves “the last mile” problem [23] and complements existing urban traffic. It can improve the first or the last mile connection to other traffic modes. In addition to traveling to bus stops or subway stations from home on foot, residents can now use a bicycle-sharing service, which is convenient and time-saving. In this paper, we call this externality the “supplement effect.” Second, bike riding is a green and low-carbon way to travel. Apart from solving the first/last mile problem, bike-sharing can partly replace travel modes of heavy pollution and energy consumption, such as cars and motorcycles. Such alternatives can influence overall energy consumption and further cut

the emissions of pollutants. We call this externality the “substitution effect.” Third, the changes of emissions will have impacts on public health, which is called the “health effect.”

In this paper, we mainly estimate these three externalities in Beijing. Figure 1 shows the overall estimation strategy used in this study. In Figure 1, the arrows represent the estimation approach and indicate a causal relation.

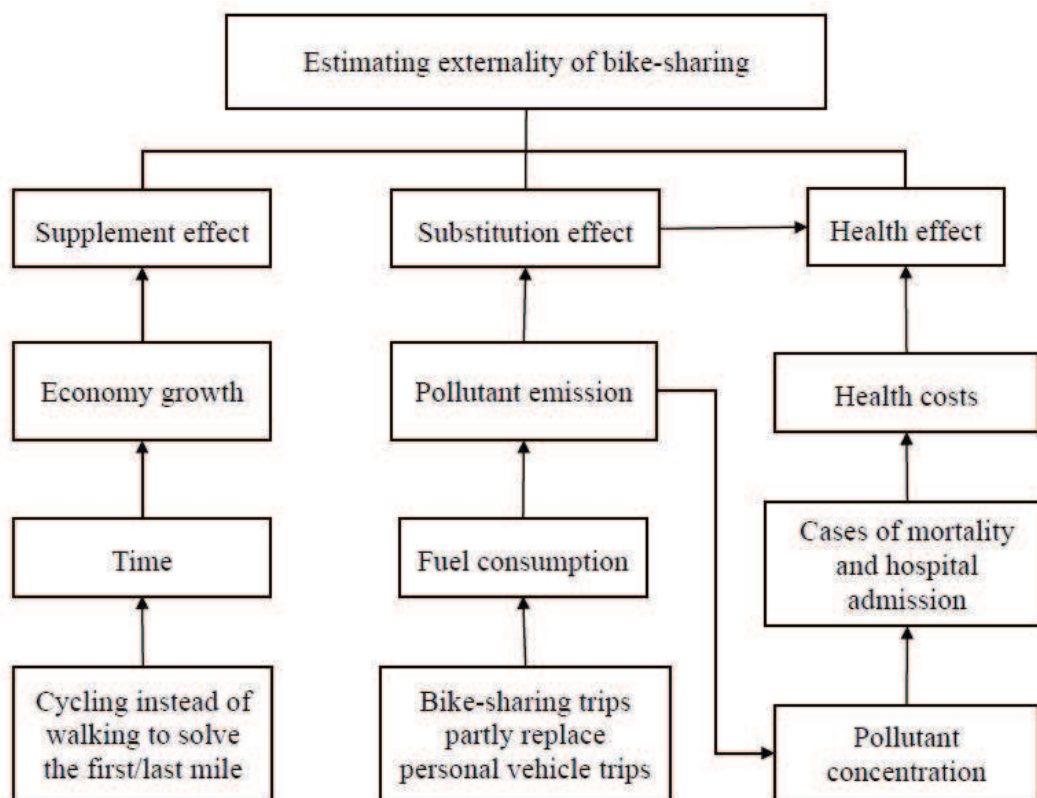


Figure 1. Estimation strategy.

2.2. The Estimation of the “Supplement Effect”

As mentioned before, the bike-sharing system provides an effective solution to the first/last mile problem. Residents travel between their homes and bus stops and between subway stations and workplaces on foot. Now, with a bike-sharing service, workers can reduce this travel time by commuting back and forth by bicycle. Therefore, a bike-sharing service can increase residents’ leisure time. According to economists, leisure time has a real impact on the economy [30–33]. We can estimate the “supplement effect” through the following steps:

First, we calculate the change in commute time when an office worker chooses bike-sharing instead of walking from home to bus stop or from station to workplace. In this paper, we consider two periods: the morning peak and the evening peak in Beijing. The changed time can be estimated through the method of distance moved over the increased speed.

$$t_s = \frac{d_c}{v_{bm} - v_{fm}} + \frac{d_c}{v_{be} - v_{fe}} \quad (1)$$

where t_s stands for the change in time per person per day. d_c represents the one-way distance of the commute, including from home to station and from station to workplace. v_{bm} and v_{fm} stand for the riding speed and walking speed in the morning peak, respectively. v_{be} and v_{fe} refer to the riding speed and walking speed in the evening peak, respectively. Most data is obtained mainly from The Annual Report of Beijing Transport Development of 2016 [34].

Second, we estimate the economy effect due to the change in time. Many existing studies suggest that leisure time has a significant impact on economic growth. For example, some studies find that an increase in leisure time of 1% would increase GDP per capita by 6.628% in America, 3.26% in Denmark, and 1.86% in Japan [33,35]. Therefore, we estimate the externalities of bike-sharing on the economy by

$$y_1 = \frac{t_s}{t_l} \times \alpha \times y \quad (2)$$

where y_1 refers to the economic growth due to the supplement effect. t_s stand for the change in time per person because of the bike-sharing service. t_l is the leisure time per person, which is obtained from the current literature [33]. y is a proxy for economy development, which is estimated through the per capita GDP of Beijing here. α is the coefficient between leisure time and economy. In our analysis, we estimate the supplement effect under different modes. It is also noteworthy that the users of bike-sharing services are not only workers, but also students and other residents. Here we mainly estimate the impact based on office workers. Therefore, the supplement effect of bike-sharing is undervalued here.

2.3. The Estimation of the “Substitution Effect”

As defined above, the substitution effect indicates that a bike-sharing system provides a green travel mode, and riding can replace certain high-energy-consuming travel modes. The government of Beijing has enacted a series of policies to develop such green travel modes. In 2016, Beijing Municipal Commission of Transport enacted “The Traffic Development Plan of the 13th Five-Year Period of Beijing,” proposing that Beijing will develop green travel modes and build a convenient and comfortable bicycle system. Moreover, the Beijing Municipal General Office has brought forward a plan to further restrict motor vehicle travel and to reduce the use of personal cars [36]. Based on these policies, we designed an experimental scenario. We selected 2015 as the baseline year. According to “The Traffic Development Plan of the 13th Five-Year Period of Beijing,” the ratio of green travel will be greater than 70% in Beijing by the end of the 13th Five-Year period. The Beijing Municipal Commission of Transport further proposes that the proportion of green travel will be as high as 75% by the end of 2020. Therefore, in such a scenario, we assume that 75% of bike-sharing kilometers traveled will replace personal cars to estimate the substitution effect. Further, we estimate the changed energy consumption and emission with a source-specific emission inventory for China. Thus, the substitution effect is estimated by the following equations.

First, we estimate the kilometers traveled provided by the existing bike-sharing service:

$$KT = d_a \times V \times r \quad (3)$$

where KT refers to the bike-sharing kilometers traveled. d_a stands for the average daily distance of bicycles, and r is the turnover rate per day, which is obtained from The Annual Report of Beijing Transport Development of 2016 [34]. V is the stock of existing bike-sharing, which is obtained from the Beijing Municipal Commission of Transport.

Then, the changed energy consumption can be calculated by the following equation:

$$F = 75\% \times KT \times FE \quad (4)$$

where F stands for the consumption of the fuel. In our design, bike-sharing replaces personal cars, which mainly burn gasoline. FE is the fuel economy of gasoline, which is obtained from the study by Yang and He [37].

We multiply the emission coefficients by KT to calculate the resulting harmful emissions:

$$E = 75\% \times KT \times EF \quad (5)$$

where E represents harmful gases emissions, and EF refers to the emission coefficient. Due to the limited data on other pollutants, this paper estimates emissions only for CO_2 , SO_2 , NO_2 , CO , PM_{10} , and $\text{PM}_{2.5}$. The data we use is displayed in Table 1. Here, we present five kinds of emissions. SO_2 is not included because the emission of SO_2 is estimated based on a method that is different from Equation (5).

Based on the “Compiling Technology Guide of Air Pollutant Emissions Inventory of Road Vehicles,” the SO_2 emissions are estimated based on the mass balance of sulfur by the following equation:

$$E_{\text{SO}_2} = 2.0 \times 10^{-6} \times F \times \beta \quad (6)$$

where β is the annual sulfur content of the fuel, whose unit is ppm. The unit of F is tons.

Table 1. Emission coefficients of different urban transportation tools.

Emission Coefficient (g/km)	CO ^a	NO ₂ ^a	PM _{2.5} ^a	PM ₁₀ ^a	CO ₂ ^b
Bus (diesel)	1.62	8.64	0.126	0.14	73.8
Texi (gasoline)	2.25	0.095	0.003	0.003	178.6
Personal Car (gasoline)	0.46	0.017	0.003	0.003	178.6

^a The emission coefficients of each pollutant of different traffic tools are from “Compiling Technology Guide of Air Pollutant Emissions Inventory of Road Vehicles” issued by Ministry of Environmental Protection in 2015. ^b The emission coefficients of CO_2 , please see the study by Ma et al. [38].

2.4. The Estimation of the “Health Effect”

The health effect of bike-sharing is based on the substitution effect. When the harmful emissions change, the pollutant concentration level will be influenced. This will impact public health. We firstly use a simplified fixed box model to estimate the changes of air pollutant concentrations. Because of the unobvious health effect resulting from CO_2 and the limited analysis of SO_2 , this paper estimates the health effect only for SO_2 , NO_2 , PM_{10} , and $\text{PM}_{2.5}$ pollutants. Learning from other studies [37,39,40], we can estimate the changes in pollutant concentrations directly with the following equation:

$$\frac{E_2}{E_1} = \frac{C_2 - b}{C_1 - b} \quad (7)$$

where C_1 and C_2 are the annual average pollutant concentration of the baseline level and the changed pollutant concentration ($\mu\text{g}/\text{m}^3$), respectively. E_1 and E_2 are the baseline annual emission and the changed emission, respectively. b is the background concentration of each pollutant under natural condition, whose unit is $\mu\text{g}/\text{m}^3$ (as displayed in Table 2).

Table 2. Air concentration and background concentration of each pollutant in 2015, Beijing.

Air Pollutants ($\mu\text{g}/\text{m}^3$)	SO ₂	NO ₂	PM ₁₀	PM _{2.5}
Baseline concentration ^a	14	50	102	81
Background concentration ^b	8	10	35	22.75

^a For the baseline concentration, the data is from Tables 8–19 of the 2016 China Statistic Yearbook: the air quality of the main environmental protection cities. ^b For the background concentration of SO_2 , please see the study by Cai et al. [41]. For the background concentrations of NO_2 and PM_{10} , see the studies by Cai et al. [41] and Wu et al. [42]. We use 0.65 as the $\text{PM}_{2.5}$ – PM_{10} conversion factor [39].

According to Equation (7), we can estimate the change in each pollutant concentration. The health effect can then be assessed using exposure–response functions. In our analysis, all the exposure–response functions take a linear form, which is widely applied in human health risk assessments [43–45]. Here, we only calculate health effects that include non-fatal health outcomes

(respiratory hospital admission, cardiovascular hospital admission, and asthma attack) and mortality (total mortality, respiratory mortality, and cardiovascular mortality).

$$Case_{n,i} = ER_{n,i} \times C_i \times P \times M_n \quad (8)$$

where $ER_{n,i}$ stands for exposure–response coefficients for mortality from different causes n and pollutant i , C_i is the concentration of pollutant i , and P is the population. M_n refers to the mortality rate from different causes n .

$$Case_{j,i} = ER_{j,i} \times C_i \times P \quad (9)$$

where $ER_{j,i}$ represents exposure–response coefficients for non-fatal health outcome j and pollutant i .

Finally, the numbers of health cases are valued in terms of RMB yuan with multiplying by unit values. The detailed data of the exposure–response coefficients for mortality and non-fatal health outcomes, and the unit values can be found in Tables 3 and 4 in the study by He and Qiu [40].

3. Estimation Results

In this study, we estimate the externalities of the bike-sharing program in Beijing in terms of the supplement effect, the substitution effect, and the health effect. To estimate the supplement effect of bike-sharing, the first step was to estimate the change in commute time for office workers, which is calculated on the basis of the difference between riding speed and walking speed. Our result, estimated by Equation (1), shows that each worker who uses the bike-sharing service saves an average of 8 min per day. In this paper, we use the average distance of commuting and average bike riding speed published by Beijing Municipal Commission of Transport. It is noteworthy that this method may underestimate the result if we consider congestion. This extra time has an impact upon economic growth and efficiency. According to [33,35], leisure time had a weak negative effect on the economy of China before 2011. However, an approximate quadratic curve has been found to suit the relationship between leisure time and Chinese economic development. After 1996, leisure time had a positive effect on the economy [33]. In addition, the results of the negative effect are based on the period 1980–2011 and 1994–2011, respectively. In recent years, China has seen rapid development, so we have reasons to believe that leisure time had a positive effect on the economy of China in 2015. Therefore, we estimate the supplement effect under three different modes: the U.S. mode, the Danish mode, and the Japanese mode. The estimation results show that the per capita GDP of Beijing would increase by RMB55.72 yuan, and the total GDP of Beijing would increase by about RMB1.20 billion yuan in the American model. Following the Danish template, Beijing’s per capita GDP would increase by RMB27.41 yuan, and GDP would increase by about RMB592.25 million yuan. Moreover, in the Japanese model, the per capita GDP of Beijing would increase by RMB15.63 yuan, and the GDP would increase by RMB337.87 million yuan. This estimation shows that a bike-sharing program can have a great positive effect on the city’s economic development.

As per Equations (4)–(6), the substitution effect of bike-sharing was estimated by calculating changes in energy and emissions. Results indicate that, when the demand for personal car use is partly replaced by bike-sharing, energy consumption and air pollutant emissions (emission quantities and concentrations) both decline correspondingly. To be more specific, compared with the baseline year 2015, if 75% of the kilometers traveled by bicycle replaced that amount of kilometers traveled by cars, energy consumption would be reduced by nearly 225.06 thousand tons. Furthermore, the emission of CO₂ from road transport in Beijing would decrease by nearly 616.04 thousand tons, and emissions of SO₂, NO₂, and CO would decrease by 22.50, 58.64, and 1586.66 tons, respectively. The reduced amount of PM₁₀ and PM_{2.5} emissions would both total 10.35 tons. These results are displayed in Table 3. The negative in Table 3 means that, compared with 2015, in the scenario where car driving is partly replaced by bike-sharing, energy consumption and air pollutant emissions decline correspondingly. We can also see that the concentration of PM_{2.5} and PM₁₀ would decrease by 2.539 μg/m³ and 2.841 μg/m³, respectively. The reduced levels of SO₂ and NO₂ are relatively small, i.e., 0.283 μg/m³

and 0.422 $\mu\text{g}/\text{m}^3$, respectively. The results indicate that the bike-sharing program of Beijing has a positive environmental effect.

Table 3. Estimated harmful gases changes, compared with 2015.

	CO ₂	CO	SO ₂	NO ₂	PM _{2.5}	PM ₁₀
Emission (tons)	−616,036	−1586.66	−22.5	−58.64	−10.35	−10.35
Concentration ($\mu\text{g}/\text{m}^3$)	−	−	−0.283	−0.422	−2.539	−2.841

Limited by the availability of CO₂ and CO. Here, we do not estimate the concentration changes of the two pollutants.

In addition, we also estimate the public health benefits of bike-sharing in Beijing. The results show that bike-sharing has a positive effect on public health. Table 4 presents the reductions of fatal and non-fatal outcomes and of the economic costs resulting from the reduction of pollutant emissions. It is important to emphasize that the reductions in mortalities and hospital admissions induced by PM_{2.5} and PM₁₀ are greater than those from SO₂ and NO₂, confirming the great severity of fine particulate matter on public health. For the corresponding health costs, it is estimated that the economic losses would decrease by about RMB2420.57 million yuan. Most of the total cost reduction is due to reduced concentrations of PM_{2.5} and PM₁₀. These estimates provide empirical support for the much greater importance of fine particulate matter. In addition, cycling can increase physical activity, which is good for public health [46,47]. Because of the limitation of data, in this paper, we do not calculate the health effect reduced from the increased activity. However, we can note that, even without considering the increased activity, the bike-sharing program has a positive effect on public health.

In all, bike-sharing dramatically decreases traffic, reduces energy consumption, decreases the emissions of harmful gases, improves public health, and promotes economic growth. The numerical estimations of the supplement effect, the substitution effect, and the health effect shown in this paper show that the bike-sharing program has substantial positive externalities.

Table 4. Estimated reduction in burden of disease and health costs

	Total Mortality	Respiratory Mortality	Cardiovascular Mortality	Respiratory Hospital Admission	Cardiovascular Hospital Admission	Asthma Attack
SO₂						
Health outcomes ^a	−25	−5	−7	−2580	−9830	−17,817
Health costs ^b	−21.08	−4.03	−5.61	−17.33	−102.11	−0.61
NO₂						
Health outcomes ^a	−59	−10	−17	−3936	−11,900	−30,207
Health costs ^b	−50.40	−8.25	−14.36	−26.43	−123.60	−1.03
PM_{2.5}						
Health outcomes ^a	−116	−20	−34	−13,568	−49,338	−129,513
Health costs ^b	−99.26	−17.50	−29.16	−91.11	−512.48	−4.40
PM₁₀						
Health outcomes ^a	−87	−11	−30	−132,281	−27,558	−214,957
Health costs ^b	−74.71	−9.82	−25.47	−888.27	−286.25	−7.31
Total						
Health outcomes ^a	−287	−46	−87	−152,366	−98,627	−392,495
Health costs ^b	−245.45	−39.61	−74.59	−1023.14	−1024.44	−13.34

^a Unit: one case. ^b Unit: millions of RMB yuan.

4. Conclusions

Bike-sharing has expanded rapidly throughout the world in recent years. Bike-sharing programs are designed to meet the increasing travel demand and to reduce the corresponding negative externalities of personal cars. However, the impacts of bike-sharing in the implementation process have been unclear. This study attempts to quantitatively explore the externalities of the bike-sharing

program of Beijing on the economy, fuel consumption, the environment, and public health. The results provide empirical evidence for the impacts of bike-sharing across the world, and provide important and useful information for urban transportation policies.

Overall, our study finds that the bike-sharing programs have positive externalities. According to our estimation, the supplement effect, the substitution effect, and the health effect resulting from bike-sharing programs are all positive. Specifically, bike-sharing programs can help residents save time, which further promotes the economic development of the city. In our study, we estimated the supplement effect of bike-sharing, as a connection to other modes of urban traffic. Our results show that bike-sharing in Beijing can help each worker save an average of 8 min per day. This additional time can increase the total GDP of Beijing by about RMB1.20 billion, 592.25 million, and 337.87 million yuan according to American, Danish, and Japanese models, respectively. In addition, under a scenario where 75% of kilometers traveled by bicycle replaces that amount of kilometers traveled via personal vehicle in Beijing, fuel consumption is reduced by 225.06 thousand tons. Accordingly, air pollutant emissions and concentrations both decline (Table 3), which constitutes a further positive impact on public health. Our results show that bike-sharing would decrease health costs by about RMB2420.57 million yuan. However, it is important to note that, in our study, we only estimate the impact of bike-sharing on office workers, not all urban residents. Moreover, we do not consider the health impact of increased activity resulting from increased bike usage. Therefore, the estimation would undervalue the impacts of bike-sharing.

In summary, the results gained from this paper provide a better understanding of the externalities of bike-sharing programs. We found that bike-sharing programs have positive externalities on the economy, energy use, the environment, and public health. Although bike-sharing programs have some negative externalities, such as bicycle maintenance and management, we believe that the negative externalities are controllable. The findings of this paper can provide empirical evidence for policy makers in urban communities that want to explore bicycle-sharing systems. In general, bike-sharing programs can play a critical role in the process of urban transportation development. Moreover, the externalities of bike-sharing are not limited to aspects of the economy, the environment, and health. Bike-sharing is also helpful for urban congestion, noise pollution, etc. Therefore, ongoing research in areas such as congestion, noise pollution, social benefits, and safety is still needed.

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