Profit versus sustainability in bike-sharing

Huiyi Litan[1], Ke Rong[2], Youran Wu[3], Danxia Xie[4], Hanzhe Zhang[5], and Dong Zhao[6],[7]

Monday, October 17, 2022

ABSTRACT

Bicycling is a green transportation mode that is essential for the sustainability of population-dense cities. Bike-sharing is an emerging business-to-consumer (B2C) model that sustains bicycling and complements other public transits. By 2021, the number of shared bikes in China had grown to 437 million and its revenue to 1.31 billion US dollars. Previous research has focused on businesses' profit-maximizing decisions but has not considered the societal sustainability impacts of these decisions that often conflict with the environment. Our research fills this gap by building a novel game-theoretic model in which a bike-sharing firm will make decisions regarding the trade-off between the accessibility (quantity) and sustainability (quality) of its bikes to maximize its rate of return. Our analysis deduces that the firm with more financial capital attains higher platform performance by prioritizing accessibility over sustainability. Our theoretical results are consistent with evidence from the bike-sharing industry. We offer government policies that can correct firms' excessive drive for profit over sustainability.

Keywords: Bike-sharing economy, platform strategies, accessibility, sustainability

[1] lthy19@mails.tsinghua.edu.cn; Institute of Economics, School of Social Sciences, Tsinghua University, Beijing, China.
[2] R@tsinghua.edu.cn; Institute of Economics, School of Social Sciences, Tsinghua University, Beijing, China.
[3] youranw@upenn.edu; The Wharton School, University of Pennsylvania, Philadelphia, Pennsylvania, USA.
[4] xiedanxia@tsinghua.edu.cn; Institute of Economics, School of Social Sciences, Tsinghua University, Beijing, China.
[5] hanzhe@msu.edu; Department of Economics, Michigan State University, East Lansing, Michigan, USA.
[6] dz@msu.edu; School of Planning, Design, and Construction, and Department of Civil and Environmental Engineering, Michigan State University, East Lansing, Michigan, USA.
[7] All authors contributed equally and are ordered alphabetically.

1. Introduction

Bike-sharing is an intelligent system that provides clean and healthy transportation in smart cities (DeMaio, 2009; Qiu and He, 2018; Si, 2018; Eren and Uz, 2020). Shared bikes are associated with various environmental benefits, such as reduced energy consumption, reduced carbon dioxide emissions, air quality, residents' health, and reduced traffic congestion (Pelechrinis et al., 2019; Wang and Zhou 2017; Zhang and Mi 2018; Chen, Zhang et al. 2022). Bike-sharing has been adopted around the world, in Barcelona, Chicago, Delft, Singapore, and Warsaw, to name a few (Zhang et al., 2015; Shen et al., 2018; Bieliński et al., 2019; Faghih-Imani et al., 2017; Freund et al., 2019; Ma et al., 2020; Macioszek et al., 2020; Yang et al., 2021). In China, bicycling is a major choice for public transit, paralleled only by bus and subway (Ma et al., 2019). In 2017, bike-sharing had spread to 200 cities with around 309 million registered users in China. In 2021, the number of sharing bikes in China reached 437 million and its revenue grew to 4.39 billion USD (Statista, 2022). In comparison, America's largest bike-sharing firm, New York City's Citi Bike, has 10,000 bikes and 236,000 subscribers, Paris has 21,000 shareable bikes, and London has 16,500.

The bike-sharing industry has been overcrowded in the recent past, whereby many startup companies emerged and competed (i.e., rush effects; Xie, 2018). In 2017, many bike-sharing companies collapsed, and survivors entered another round of competition. The bike-sharing industry was criticized for its greater emphasis on bike accessibility (i.e., *quantity*), which often has negative environmental consequences and relatively little emphasis on bike usability and reusability (i.e., *quality*). One undesirable byproduct of fierce competition was environmental waste in the form of abandoned bikes: Many failed companies were not able to put their bikes to productive use after they failed (Figure 1). In Beijing, almost 200,000 bikes were broken or abandoned in 2019, and about 10 million bikes retired in 2020 (Jiemian, 2019).

Figure 1. Environmentally wasted bikes after failed competition (Erzhile, 2019)

We define quantity-focused growth in the bike-sharing context as the wide provision of bikes and consequently higher consumer accessibility, which is often enabled by greater financial capital. According to BigData-Research, Ofo's cumulative number of bikes was 150% higher than Mobike's in March 2017. We define quality-focused growth as a high technology level, greater user comfort, and better durability. For example, bikes from Meituan Bike are equipped with location-based services, GPS tracking, Bluetooth unlocking, and QR code scanning. Quantity-focused growth is not sustainable and causes many problems, such as resource misallocation and social inefficiencies (Rong et al., 2019); negative externalities and resource waste; and the over-occupancy of public spaces, with millions of abandoned bicycles piled everywhere. Surprisingly, most bike-sharing companies that failed early seem to have been quality-focused. Overall, there is a lack of systematic understanding of why the less sustainable quantity-focused growth could dominate the bike-sharing competition.

We model the competition between a quantity-focused strategy and a quality-focused strategy in the bike-sharing market. The model helps explain why quantity-focused growth is dominant, and how the sustainable quality-focused growth can be facilitated. We develop a duopoly game in which bike-sharing firms choose their optimal growth strategy to match more consumers who are distributed in a certain geographic area. Each firm is endowed with initial funding (e.g., from venture capital) and has two dimensions of choices to compete in this matching game: (1) spend money to increase the number and availability of bikes to consumers (the quantity-focused strategy); or (2) spend money to improve the technology, travel comfort, and attractiveness to consumers (the quality-focused strategy).

This study shows that in equilibrium, most of the money will be spent to increase the quantity of bikes when the size of available funding is small. Interestingly, when two competing bike-sharing firms are asymmetric in their available funding, the firm with more access to funds tends to spend a larger share on increasing the quantity to get a higher return rate than the firm with less funding. Our study reveals a vicious cycle in the bike-sharing industry whereby the company with more investment must spend more on quantity instead of quality for a higher return rate to attract more investment, which results in oversupply and redundancy. Consequently, the firm with higher quality is more likely to be knocked out of the market.

We discuss the mechanisms behind this result. Note that in the first few years of shared bikes, the pool of potential consumers was much larger than the pool of shared bikes. If a firm's bike is unavailable at a particular location, there is no chance for the firm to attract a potential consumer, even if its technological level is very high. That is, the company with a higher technological level will only have an advantage if its bikes are in the same location as their competitors' bikes. Therefore, increasing the quantity, which will help increase market share, becomes the optimal strategy of the firm with more investment.

Given the equilibrium outcome—whereby firms are more likely to value economic profit over sustainability—we offer the following governmental solutions and management insights from several perspectives. First, from the perspective of market competition, the government should regulate the number of shared-bike providers in one city by granting a fixed number of operating licenses to avoid both monopoly and excessive competition. Second, from the perspective of externality, the government could charge a tax to internalize the cost of negative externalities for oversupplied platforms. Third, from the perspective of technology improvement, the government should give subsidies to platforms to encourage technological progress.

The contributions of this paper are as follows. First, we build an innovative theoretical model to study the bike-sharing industry and conduct an in-depth analysis. Second, we provide new understandings of the bike-sharing industry by introducing our game-theoretic model and examining the quantity-quality competition. Third, we pay special attention to innovative firms when they face financing problems and discuss ways in which the results can be generalized to other firms, and even industries, in the current era of mass innovation.

The trade-off between quantity and quality in competition is not well addressed in the economics literature, although it is often explored from a biological or sociological perspective. Dixit (1979) constructs a precise model to describe oligopolistic competition with respect to both quality and quantity decisions. He argues that product specification is the most important strategy when entry can be controlled. More recently, Yang and Nie (2017) establish a two-stage dynamic game model to analyze the effects of asymmetric competition on the food industry in terms of product substitutability and find a higher equilibrium point for quality and production under the Cournot quantity competition model. Alvisi and Carbonara (2020) analyze the effects of introducing a product that consists of a proportion of two imperfectly substitutable products and identify its positive potential influence on consumer surplus. Soriguera and Jiménez-Meroño (2020) study the strategic design of variables for bike-sharing systems, such as the number of bicycles and stations. They find that free-floating configurations may cause problems; for example, bicycles tend to clog up city centers and entail longer walking distance to bikes during peak hours.

Game theory provides a lens through which we can further examine the competition and its features in the sharing economy. Wang and Wu (2017) use a duopoly game to predict that the bike-sharing market should eventually reach a low-price equilibrium. Ma et al. (2018) analyze a four-party game to characterize the interactions among three tiers of brands as well as consumers and identifies the advantages of second- and third-tier brands when competing with first-tier brands. Rong et al. (2019) analyze "redundancy" in the bike-sharing industry with a game-theoretic model and conclude that a monopoly could alleviate redundancy to a certain extent.

Previous research provides the background for bike-sharing competition, especially for China, which is the largest bike-sharing market. For example, Qiu (2016) examines the differences between bike-sharing platforms and aspects of the sharing economy, such as Airbnb and Uber, and posits that bike-sharing marked a significant transformation of the traditional sharing economy. Wang (2017) and Zhang and Wu (2017) argue that there is a lease relationship between consumers and bike-sharing firms, with rent as the main source of revenue for these firms. Wang, Hou, and Zhao (2017) analyze the bike-sharing business model from an online-to-offline (O2O) perspective, while Song and Zhang (2017) conduct SWOT analysis to describe the multi-homing strategy in the bike-sharing industry. Song and Zhang (2017) emphasize the importance for Ofo to produce a breakthrough in technology, improve its core competitiveness, and make up for password loopholes and the lack of GPS positioning.

The paper is organized as follows. Section 2 describes our model. Section 3 analyzes the equilibrium of the model in terms of analytical solutions and simulation results. Section 4 examines relevant case studies and related empirical evidence, and Section 5 offers some concluding thoughts.

2. Model

Suppose two competing firms in the bike-sharing market provide bikes to serve all consumers, who are evenly distributed in a certain geographic area. A consumer can choose to ride her favorite bike at her location and pay the bike-sharing firm that owns the bike. Each of the two bike-sharing firms has two strategies to attract consumers: (1) supply more bikes to the geographic area and increase the distribution density of bikes—i.e., the strategy of increasing *quantity*, and (2) improve the technological level of its bikes—e.g., with GPS tracking, Bluetooth unlocking, and QR code scanning; this is the strategy of increasing *quality*.

Each bike-sharing firm is endowed with a certain amount of investment at the beginning of the simulation. In dealing with its own constraints in terms of available funding from outside investments, a firm maximizes its expected revenue by choosing the quantity of bikes needed to gain a greater share of the market and increasing the quality of its bikes by conducting research and development. Each firm tries to maximize its profit, which may align with the society's goal of maximizing overall welfare and/or the goal of maximizing sustainability.

2.1. Geography of the market

Assumption 1. *The bike-sharing market is composed of many locations (as shown in Figure 2). Consumers are randomly distributed at these locations.*

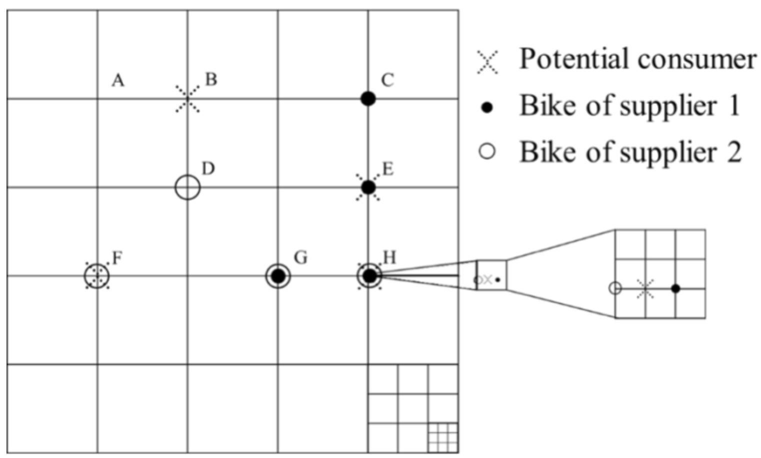

Figure 2. A sample illustration of consumers and shared bikes

We assume that no more than one bike from the same firm can appear at each location (or site). There are two bike-sharing firms, so the maximum number of bikes that can appear at each site is two. The total number of locations in this area is C, so each firm can bring at most C bikes to the market in total. We assume that there is an alternative means of traveling—e.g., taking a taxi—for each consumer.

We assume a fixed single-use price *$P* for each bike trip. Based on the facts in the shared-bike industry, the prices of different bikes are the same. For example, the most popular shared-bike platforms in China—Meituan, Qingju, and Hellobike—charge the same price, 1.5 yuan (about 0.2 USD) per 30 minutes (That's Magazine Online, 2022). Therefore, if there is only one bike at a particular location, a consumer has no choice but to ride that bike. However, the consumer will tend to choose the bike with the higher technological level if there is more than one bike available at a particular location. Equal price across platforms may also be an equilibrium outcome in which individual firms engage in Bertrand-like competition: When consumers choose the bike with the lowest price, firms will price equally in equilibrium even if we allow them to compete on the price dimension.

2.2. Consumers

The total number of consumers is *M*. Consumers are randomly distributed among the *C* locations. We assume $M<C$, and there can be at most one consumer at any location.

A consumer can choose any firm's bike to ride at each site. This means that all consumers can choose bikes. For simplicity, we assume that the cost of walking (i.e., and not riding a shared bike) from one location to an adjacent one is sufficiently high for a consumer to choose some other means of transportation. However, no other form of transportation is available from one location to an adjacent one because of the relatively short distance. That is, it is too far to walk from one location to an adjacent neighbor and too close/expensive for the use of other transportation methods, such as a taxi or driving.

If no bike is available at a particular site, then the consumer will get zero utility. In general, we assume that consumers will have the following preference:

$$U = \begin{cases} 0 & \text{(does not ride any bike)} \\ U_0 + T_1 - P > 0 & \text{(rides the bike of firm 1)} \\ U_0 + T_2 - P > 0 & \text{(rides the bike of firm 2)} \end{cases} \quad (2\text{-}1)$$

The utility function consists of three terms: the basic utility of using a bike U_0; the additional utility brought by the technological level of the shared bike *T*; and the cost of the single-use price expressed by *P*.

When there is only one firm's bike at the same point:

$$P(\text{Bike}_j \text{ is selected} | \text{only bike}_j \text{ is available at the site}) = 1; \quad (2\text{-}2)$$

When bikes from Firm 1 and 2 are available at the same point:

$$P(\text{Bike}_j \text{ is selected} | \text{bikes from both firms are available}) = \frac{T_j}{T_1+T_2}. \quad (2\text{-}3)$$

This functional form is in line with a discrete choice model (Berry et al., 1995, 2004): The probability of choosing a bike is proportional to its technological level. Based on the nature of seeking higher utility, a customer's probability of choosing a bike depends on the utility level associated with it. When only one type of bike is available at a specific location, the customer chooses to ride it to take advantage of the convenience. When the bikes of two competitors are available at the same location, the probability of choosing a bike with a higher technological level should be greater since comfort is associated with greater utility—and this probability should decrease if the technological level of the other bike (the competitor's bike) increases. Hence, we assume that the probability of bike j's being selected is $\frac{T_j}{T_1+T_2}$.

2.3. Bike-sharing firms

At the beginning, each of the two bike-sharing firms (indexed by $j = 1,2$) is endowed with an investment funding of size $I_{j=1,2}$. In the first stage, each firm will conduct research and development and/or invest more cost to obtain bikes of appropriate technological level. Quality improvement is assumed to be equal for the two firms. We then assume the cost of improving a unit level of the bike's technology to be \$$x$. At this stage, firms simultaneously choose the technological level of their bikes. Afterward, each firm will simultaneously decide the number of bikes to produce and bring to the market. All bikes from a firm will adopt the same technology the firm obtained from its research and development stage. We set the production cost per bike as \$$s$, which is equal across the two bike-sharing firms.

With the support of this investment fund, each firm will conduct research and development, and it will simultaneously make decisions concerning the number of bikes to bring to the market. We assume that the cost of improving a unit level of the bike's technology is \$$x$, i.e., research and development efficiency is equal across the two firms and the production cost per bike is \$$s$, which is also the same for each firm.

Therefore, each firm j will choose its bike's technological level T_j, as well as the quantity of bikes N_j to bring to the market, with its own budget constraint I_j. The following budget constraint should be satisfied:

$$sN_j + xT_j \leq I_j.$$

In addition, we assume that the total number of locations C is large, i.e., $N_j < C$. To guarantee one bike at each location demands at least C bikes and costs sC in total. We assume that the size of the investment fund for each firm is not sufficient to provide bikes for all possible locations, and thus $I_j < sC$.

The two firms are fully aware of the current unit price relating to both quantity and technology in the market, and the amount of investment that they receive is also common knowledge in the industry. Under this set of circumstances, the firms make their choices simultaneously and remain strictly committed to their respective decisions.

After a certain number of bikes at a certain level of technology are randomly put on the market, the probability that a bike from firm j is selected by the potential consumer would be

$$P(\text{only firm j's bikes are available at the site}) = \frac{M}{C} \cdot \frac{N_1}{C} \cdot \left(1 - \frac{N_2}{C}\right) \cdot 1 \qquad (2\text{-}4)$$

$$P(\text{both bikes are available but firm j's bike is selected}) = \frac{M}{C} \cdot \frac{N_1}{C} \cdot \frac{N_2}{C} \cdot \frac{T_j}{T_1+T_2} \qquad (2\text{-}5)$$

Firms 1 and 2 provide services under the unified single-use price of the market. The revenue function of Firm 1 would therefore be

$$R_1 = \left[\frac{N_1}{C}\left(1 - \frac{N_2}{C}\right) + \frac{T_1}{T_1+T_2}\frac{N_1}{C}\frac{N_2}{C}\right]\frac{M}{C}P. \qquad (2\text{-}6)$$

According to the above setup, firms must make decisions about the optimal allocation of their available funding to research and development and production, respectively, and essentially face a trade-off between the quality and quantity of the bikes they will eventually bring to the market.

Therefore, the decision problem for Firm 1 is

$$\max_{N_1,T_1} R_1 = \left[\frac{N_1}{C}\left(1 - \frac{N_2}{C}\right) + \frac{T_1}{T_1+T_2}\frac{N_1}{C}\frac{N_2}{C}\right]\frac{M}{C}P \qquad (2\text{-}7A)$$

$$s.t. \, sN_1 + xT_1 \leq I_1$$

where N_1, T_1, I_1, R_1 represent Firm 1's choice concerning the quantity of bikes, its choice concerning the technological level, the size of its available investment fund, and its expected revenue, respectively.

Firm 2 faces a similar decision problem as Firm 1:

$$\max_{N_2,T_2} R_2 = [\frac{N_2}{C}\left(1 - \frac{N_1}{C}\right) + \frac{T_2}{T_1+T_2}\frac{N_1}{C}\frac{N_2}{C}]\frac{M}{C}P \qquad (2\text{-}7B)$$

$$s.t. \, sN_2 + xT_2 \leq I_2$$

We also wish to explain why we assume the firms' primary goal is maximizing revenue rather than maximizing profit. This is because the basic setup, whereby both firms are at the stage of obtaining financing from venture capital—that is, when firms are extremely likely to spend every penny of their investment fund on their competition with rival firms and, as a result, make no profit. Hence, the amount of the total cost is exactly equal to the amount of the investment, i.e., $sN_j + xT_j = I_j$. To attract larger investments of capital during the upcoming financing round, the two firms compete to obtain a higher rate of return on the investment, which can be expressed as $\frac{R-I}{I} = \frac{R}{I} - 1$. It is thus evident that under our assumptions, maximizing revenue is equivalent to maximizing profit and is consistent with the firms' periodic goal.

3. Equilibrium analysis

The two bike-sharing firms make a simultaneous move represented by equations 2-7A and 2-7. This is essentially a matching game: Every firm designs its optimal competitive strategy to match more consumers with its own bikes. Each firm has two dimensions of instruments with which to compete in this matching game: increasing the quantity of bikes (i.e., availability to consumers) and raising the quality of bikes (i.e., traveling comfort and attractiveness to consumers).

In this section, we will solve and analyze this Nash equilibrium.

If $n_1 = \frac{N_1}{C}$, $t_1 = \frac{xT_1}{sC}$, $i_1 = \frac{I_1}{sC}$, $r_1 = \frac{CR_1}{PM}$, then the optimization problem for Firm 1 becomes

$$\max_{n_1, t_1} r_1 = n_1(1 - n_2) + \frac{t_1}{t_1 + t_2} n_1 n_2 \tag{2-8}$$

$$s.t. \, n_1 + t_1 \le i_1$$

where n_1 stands for the geographic density of Firm 1's bikes in the market and t_1 stands for the technological level of Firm 1's bikes. Therefore, r_1 is proportional to firm 1's revenue.

Note that we have previously assumed that $I_j < sC$ and this implies

$$i_j = \frac{I_j}{sC} < 1.$$

The problem for Firm 2 will therefore be similar.

To simplify notation, we can expand the set so that $t_1 = ai_1$, $t_2 = bi_2$, $i_1 = ki_2 = i$. Then the game for the two firms would be

$$\begin{cases} \max\limits_{a} r_1 = (1-a)i\left(1 - \frac{b(1-b)i}{k(ak+b)}\right) \\ \max\limits_{b} r_2 = \frac{(1-b)}{k} i\left(1 - \frac{a(1-a)ki}{ak+b}\right) \end{cases} \tag{2-9}$$

where a and b, respectively, represent the ratios of the technology investment to the total capital chosen by Firms 1 and 2 to improve the technological level. The variable k measures the relative size of the investment funds available to Firms 1 and 2. In the following discussion, we assume that $k \ge 1$, which means that Firm 1 has a relatively larger amount of investment funding.

3.1 Baseline scenario: A symmetric equilibrium of equal endowment

We first consider the symmetric scenario in which Firm 1 and Firm 2 are endowed with the same amount of investment funds ($i_1 = i_2$) at the very beginning. From Equation (2-9), we can derive the best response for each of the two firms:

$$\begin{cases} a = -b + \sqrt{ib(1-b^2)} \\ b = -a + \sqrt{ia(1-a^2)} \end{cases} \tag{2-10}$$

In this symmetric equilibrium, the share of technology investment in its total investment for the two firms can be solved from (2-10):

$$a^* = b^* = \frac{\sqrt{i^2+4}-2}{i}.$$

The rates of return on investment for the two firms is

$$\frac{{r_1}^*}{i_1} = \frac{{r_2}^*}{i_2} = \frac{sC^2}{PM}\frac{{R_1}^*}{I_1} = \frac{(1-a^*)(2-(1-a^*)i)}{2}.$$

We can then derive the following proposition.

PROPOSITION 1

In a symmetric equilibrium in which two firms have the same amount of investment funds available at the beginning:

a) With a low amount of available investment fund, the share of technology investment will be small.

b) As the amount of available investment funding decreases, the share of technology investment will eventually converge on 0.

Proof.

We can take the limit $i \to 0$, to examine $\lim_{i\to 0} a^*$, where $a^* = \frac{\sqrt{i^2+4}-2}{i}$.

By applying the L'Hospital's rule, we can get $\lim_{i\to 0}(\frac{\sqrt{i^2+4}-2}{i}) = \lim_{i\to 0}\left(\frac{i}{\sqrt{i^2+4}}\right) = 0$. That is, $\lim_{i\to 0} a^* = 0$.

Q.E.D.

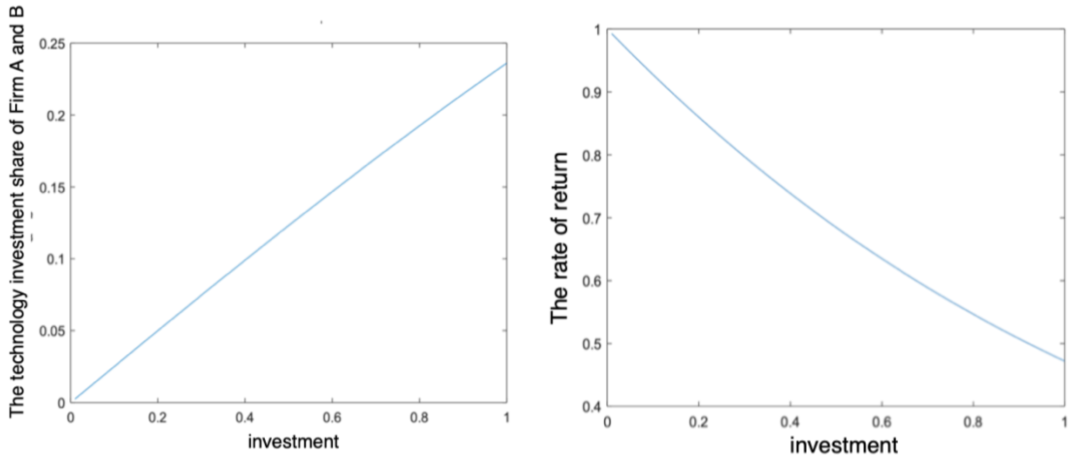

Figure 3. The relationship of available investment fund with the (a) share of technology investment and (b) rate of return.

If there is only one bike at a certain location, the consumer can only choose that bike to ride. If there is no bike at a particular location, there will be no chance for a consumer to take this firm's bike even though the firm's technological level is higher. Therefore, it is of the utmost importance that each firm increase the total number of bikes available to the market. When the size of the available funding is relatively small, most of the investment will be devoted to increasing the quantity of bikes (Proposition 1).

PROPOSITION 2

In the symmetric equilibrium in which two firms have the same amount of investment funding available at the beginning:

a) *When the size of the available investment fund increases, both firms will slightly increase their share of technology investment; and*

b) *the maximum share of the technology investment is less than one-quarter.*

Proof.

We can take the derivative of the share of the technology investment in equilibrium (a^*) with respect to the size of investment fund (i) and get

$$\frac{\partial a^*}{\partial i} = \frac{2\sqrt{i^2+4}-4}{i^2\sqrt{i^2+4}} > 0.$$

This means that a^* is an increasing function of i.

Moreover, we have assumed before that $j = \frac{I_j}{sC} < 1$ and, because a^* is an increasing function of i,

$$a^* < \frac{\sqrt{i^2+4}-2}{i} = \sqrt{5}-2 \approx 0.236 < 0.25.$$

Q.E.D.

When bike-sharing firms get a larger amount of investment, the importance of improving the technology of bikes increases accordingly. Therefore, the proportion of technology investment will increase.

Nevertheless, the ratio of technology investment to the scale of the total investment increases very slowly. Also, in equilibrium, the ratio of technology investment (i) is insignificant compared with quantity investment $(1-i)$ even if the two firms receive an extremely large investment. Note that $i = 1$ means that if the firm uses all its investment to increase quantity, it can reach a distribution density of 1. In other words, the investment received by a firm at this time can finance the production of enough bikes (with no technological value added) to cover the whole market. However, even under such an extreme condition, the ratio of the technology investment to the total investment is still lower than $0.25 (a = b = 0.2361)$. It is for this reason that bike-sharing firms will tend to refuse to spend most of their investment on technological improvement. This is true although a very large quantity of shared bikes and the various problems that often come with them (for example, bikes parked in roadways and the deposition of wasted bikes) have inconvenienced people and there have already been strong social and public appeals concerning these issues.

PROPOSITION 3

In the symmetric equilibrium in which two firms have the same amount of investment funds available, the rate of return on investment in such an equilibrium decreases as the scale of investment increases.

Proof.

We can take the derivative of the investment return in equilibrium with respect to the overall investment and get

$$\frac{\partial r^*/i}{\partial i} < 0.$$

Q.E.D.

In this symmetric equilibrium, a larger amount of available funding is associated with a lower rate of return. This is consistent with the principle of a return rate's decreasing with scale. In this model, the marginal profit associated with an additional bike will decline as the number of existing bikes increases, while improving the technological level of bikes will become relatively more profitable, as suggested by Proposition 2. The transition to technological improvement, however, cannot reverse the aggregate trend of a return rate's decreasing with scale, as demonstrated by Proposition 3; this reveals why some shared-bike companies lack the motivation to improve their bikes' technology.

3.2 Equilibrium with an unequal endowment

We now consider the scenario in which Firm 1 and Firm 2 receive different amount of outside investment ($i_1/i_2 = k > 1$) and there is an assumption that Firm 1 receives a larger investment fund. In turn, this produces an asymmetric equilibrium.

In this case, the best responses of the two firms to each other would be

$$\begin{cases} a = -\frac{b}{k} + \frac{\sqrt{bi(1-b)(b+k)}}{k^{3/2}}, \\ b = -ak + \sqrt{kai(1-a)(ak+1)}. \end{cases} \tag{2-11}$$

However, it is difficult to solve Equation 2-11 in such a way as to achieve a closed-form solution. Therefore, we mainly present our simulation results and calibrations in this subsection.

3.2.1 Situations with a fixed k and a fixed i

We start with the situation in which k and i are fixed.

RESULT 1

In the asymmetric equilibrium in which two firms have different amounts of investment funding,

(1) The firm with a greater investment will spend a relatively small share of its funding on improving technology and it will have a lower technological level.

(2) The firm with a greater investment will achieve a higher rate of return on investment.

Simulation. Set $k = 2$, $i = 0.1$.

We can calibrate the values of k and i based on actual data from the Chinese bike-sharing industry. In practice, the initial investment received by the first two competing bike-sharing firms in this market (prior to Round B) is about 2:1 and the small value of i reflects the fact that the market is huge and neither firm has enough capital to put bikes at all those locations.

According to (2-9), the two firms' revenue would be

$$\begin{cases} r_1 = 0.1(1-a)\left(1 - \dfrac{0.1b(1-b)}{2(2a+b)}\right); \\ r_2 = 0.05(1-b)\left(1 - \dfrac{0.2a(1-a)}{2a+b}\right). \end{cases}$$

From (2-11), the two firms' best responses to each other would be

$$\begin{cases} a = -\dfrac{b}{2} + \dfrac{\sqrt{0.1b(1-b)(b+2)}}{2\sqrt{2}}; \\ b = -2a + \sqrt{0.2a(1-a)(2a+1)}. \end{cases}$$

In equilibrium, the ratios of technology investment to the total investment received for each firm can be solved as:

$$\begin{cases} a^* = 0.012336; \\ b^* = 0.0252968. \end{cases}$$

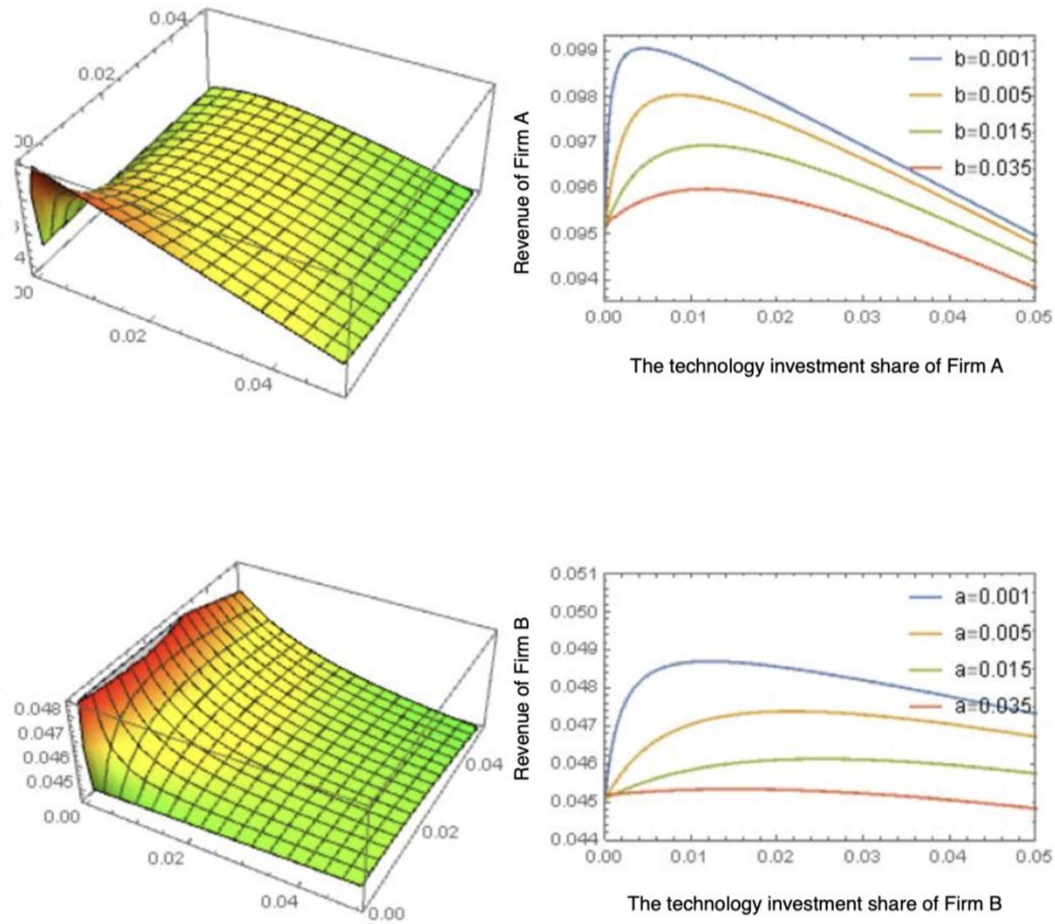

Figure 3.2. The proportional relationship between revenue and technology investment for the two firms receiving different amounts of investment ($i = 0.1$, $k = 2$)

According to the simulation above, the relative ratio of the two firms' technological level and rate of return on investment in equilibrium would be

$$\frac{{t_1}^*}{{t_2}^*} = \frac{a^* i_1}{b^* i_2} = \frac{ka^*}{b^*} = 0.975301 < 1;$$

$$\frac{r_1^*}{i_1} \Big/ \frac{r_2^*}{i_2} = r_1^*/kr_2^* = 1.07929 > 1.$$

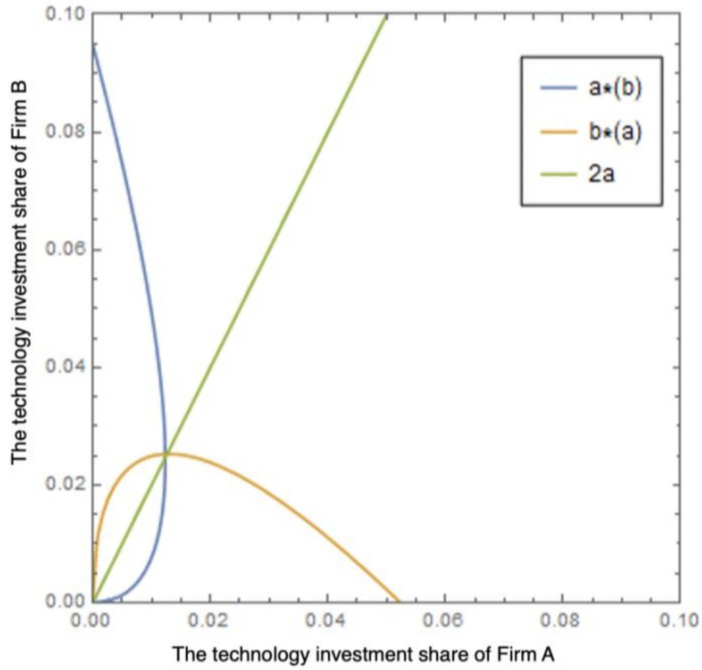

Figure 3.3. The best reaction curve for the ratio of technology investment for the two firms, which receive different amounts of investment ($i = 0.1$, $k = 2$)

To check the robustness of our result, we calculated the two firms' relative technological level and investment return in equilibrium when given different sets of $\{i, k\}$. The results presented in Table 3.1 show that $t_1^*/t_2^* < 1$ while $(r_1^*/i_1)/(r_2^*/i_2) > 1$, if $k > 1$, which is consistent with these results.

Table 3.1. Two firms' relative technological level and investment return with different levels of *i and k*

$\boldsymbol{t_1^*/t_2^*}$	*k*=1	*k*=2	*k*=3	*k*=4	*k*=5
i=0.01	1	0.997503	0.996672	0.996257	0.996008
i=0.1	1	0.975297	0.967209	0.963192	0.960790
i=0.5	1	0.881080	0.845701	0.828759	0.818826
$\boldsymbol{\frac{r_1^*}{i_1} \Big/ \frac{r_2^*}{i_2}}$	*k*=1	*k*=2	*k*=3	*k*=4	*k*=5

i=0.01	1	1.00376	1.00502	1.00565	1.00603
i=0.1	1	1.03896	1.05216	1.05880	1.06279
i=0.5	1	1.23056	1.31260	1.35443	1.37976

According to this model, when the two firms receive different amounts of investment, the one with the larger scale of investment ($k>1$; thus Firm 1) would have a lower share of technology investment to total investment and a lower absolute amount of technology investment. This firm will also end up with a correspondingly lower technological level. This is because the firm receiving the smaller amount of investment is aware of its unfavorable position during the "matching" step. That is, even if that firm spends all its investment funding on increasing its quantity of bikes, it will not increase the probability of being selected and crowding out the opponent's product. Therefore, it would be unwise to adopt an aggressive quantity-oriented strategy for the firm with less investment. Instead, it would tend to attract potential consumers at the selection stage with a higher technological level. This is the logic by which the firm receiving a smaller amount of investment will adopt a more aggressive technology-oriented strategy in comparison with the firm receiving more investment.

With that said, though the firm with less investment will tend to attempt to attract potential consumers at the selection step, the matching step (which happens prior to the selection step) has a more significant influence on the firm's revenue. Therefore, in terms of the rate of return on investment, the firm with less investment has no advantage against its opponent. Hence, to attract more investment, the company will increase its quantity and keep its technology share low, which might lead to oversupply.

3.2.2 Situations with fixed k, changing i

We can consider cases in which k is fixed and i changes.

<u>RESULT 2</u>

In an asymmetric equilibrium in which two firms have different amounts of investment funding and the relative ratio between their investments remains constant, *(1) The firm with more available funds tends to perform at a lower technological level, and the technological level difference is further enlarged as more capital flow into the industry.*

(2) The firm with more available funds tends to achieve a higher rate of return, and this difference is further enlarged as more capital flows into the industry.

Simulation. We can set $k = 2$ and change i within the interval of $(0,1)$.

The value of k is chosen for the same reason we have discussed previously, and we can set i in the range of 0 to 1 since this interval can cover most cases in practice—even extreme ones. A value of i close to 0 represents an untapped market, while a value of i close to 1 implies that even the less invested firm can cover the whole market with its bikes if it spends all its funds on improving quantity.

The following figure shows how the two firms' technological level and the rate of return on investment in equilibrium will change in relation to their overall scale of investment (i):

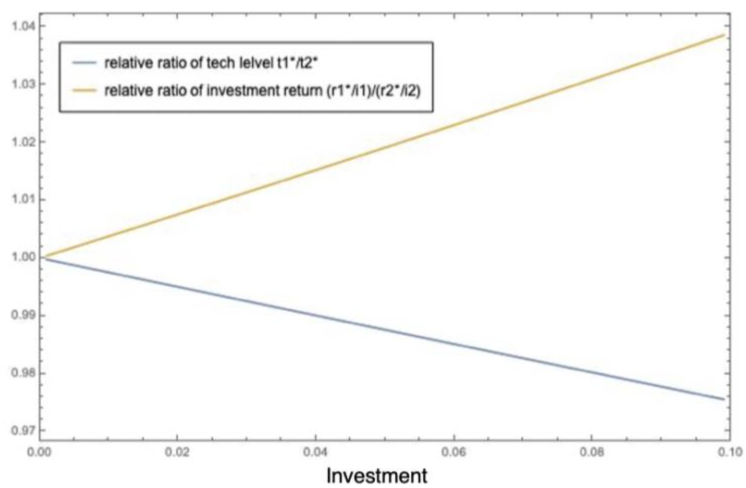

Figure 3.4 The relationship between the relative ratio of two firms' technological level and the rate of return on investment in equilibrium, and the scale of investment i when $k = 2$

When both firms receive a small scale of investment, the less invested one would be able to dominate the selection step with a higher technological level despite its disadvantage during the matching step. However, its disadvantage in the matching step would be more significant as the absolute investment scale grows, which motivates the firm with less investment to salvage the situation by using an even more aggressive technology-oriented strategy. The gap in technological level between the two firms is thus further widened. However, although this strategy is the optimal choice for the less invested firm, it fails to attract a sufficient investment return and becomes less effective as the industrial investment scale grows. As we can see in Figure 3.4, the gap between the two firms' rate of return on investment is further widened.

According to this model, when the overall scale of investment is small, even though one firm has an investment several times larger than the other, their rates of return on investment are almost the same. This suggests that, taking into consideration various real-life factors (for example, market uncertainty and the fact that different investors would tend to invest in different companies within the same industry), the receiver of the smaller amount at the beginning is quite capable of getting financial support from investors and even having a chance to turn the tables in terms of the scale of its investment received. The early stage of the bike-sharing industry is indeed full of opportunities.

However, when the overall scale of investment is large, the investment return would be significantly influenced by the difference between their own relative scales of investment. At this time, we would find some extremely advanced bikes on the market. However, the firm with this type of bike will probably be quickly knocked out of the market due to its unsatisfying performance in terms of its investment return—if a mature bike-sharing industry would calmly and efficiently eliminate the firm that receives relatively less investment.

3.2.3 Situations with a changing k and fixed i

We can consider the case in which i is fixed and k changes.

Result 3

In the asymmetric equilibrium in which two firms have different amounts of investment funding available, one has a constant scale of investment and the other's investment varies:

(1) The firm with more available funds tends to perform at a lower technological level, and the technological level difference is further enlarged as the disparity in investment received by the two firms grows.

(2) The firm with more available funds tends to achieve a higher rate of return, and such difference is further enlarged as the disparity in investment received by the two firms grows.

Simulation. We can set $i = 0.1$ and change k within the interval of $(1, 5)$.

The value of i is chosen for the same reason we have discussed previously and the range of k from 1 to 5 would be sufficient to enable a clear view of the trend.

As Figure 3.5 shows, with some fluctuation, the relative ratio of the two firms' technological level and the rate of return on investment in equilibrium would change as their ratio of investment received (k) increases:

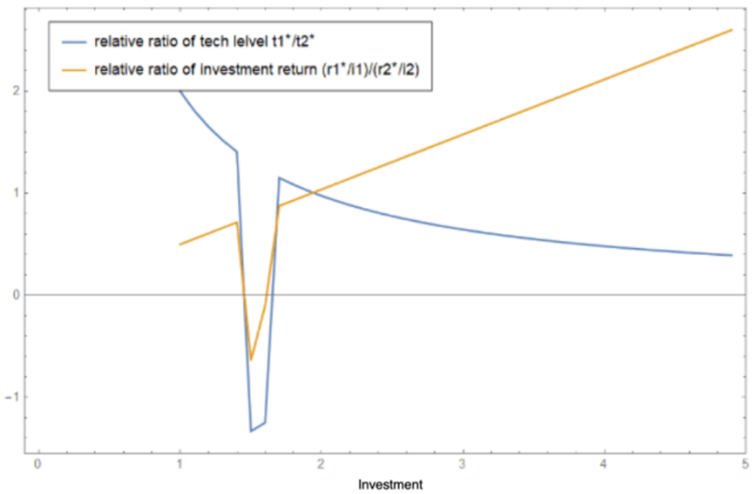

Figure 3.5. Relationship between the relative ratio of the two firms' technological level and their rate of return on investment, and their ratio of investment received k, when $i = 0.1$

In general, the ratio of the two firms' technological level and investment return rate increases as the disparity in funding received is increased. When there is significant disparity in terms of investment, the less invested firm would be more motivated to attract potential consumers with an aggressive technological strategy, while it still falls behind in the competition for a higher investment return rate.

However, we can see that this trend is not consistent. When the value of i changes from 1 to 2, the relative ratio of technology level and investment return experiences significant fluctuation in which they both drop rapidly to a negative value and then recover to the original trajectory.

The two bike-sharing firms must achieve a relatively higher rate of return on investment than their opponent to obtain further investment. However, this requires a large scale of investment obtained beforehand. In other words, a large scale of investment received in the earlier stage leads to a greater possibility of obtaining further investment and a lower possibility of capital chain rupture in the future.

For investors in bike-sharing firms, if they want a relatively high rate of return on investment, they should give their money to the more invested firm. In fact, if investors continue to support Firm 1 and keep its scale of investment received greater than that for Firm 2, Firm 1 will be able to reward its investors with a relatively higher rate of return on investment than Firm 2. This means that investors don't even need to have information about the firm's profitability when making investment decisions; they only need to identify the company with a larger amount of financing. The rationality of investing in one rather than the other would then be self-reinforcing. In fact, this situation for investors is like a game of kingmakers, in which investors can only prove the correctness of their decision by choosing one alternative and funding it without too much consideration given to budgeting.

From this point of view, bike-sharing firms will struggle to obtain more investment than their opponents, while investors will reasonably invest as much as they can. The reason behind the enormous capital influx into this industry is not, as suggested by behavioral economics, such as bounded rationality or irrational investment in consequence; instead, it is exactly the opposite. Firms and investors act rationally and self-certification of the soundness of investment is further demonstrated as the amount of investment increases. This explains the logic behind the capital influx in the bike-sharing industry to a certain extent and offers a major reason why this industry developed at such a remarkably high speed.

4. Case studies and empirical evidence

China's bike-sharing industry has so far experienced three stages of development. In 2007, China introduced a government-controlled public bike system, and bike docking under the management of each city began to appear. In 2010, Yonon Technology Company was founded, and private enterprises started to participate in the business of docking bikes. Around 2015, Ofo and Mobike were founded, and the dockless bike-sharing services provided by private enterprises using internet of things technology sprang up. Since then, the development of China's dockless bike-sharing industry has experienced significant acceleration, in terms of both the number of firms (and the types of bikes) on the market and the rapidly growing number of consumers. In 2017, however, several shared-bike firms went bankrupt and left the market. The bike-sharing firms that closed in 2017 include Wukong Bike (June); 3Vbike (June); Xiaoming Bike (July); Dingding Bike (August); Kuqi Bike (September); and Bluegogo (November). Although two firms with a combined market share of 93% (Ofo with 52% and Mobike with 41%) maintained their leading positions, negative news about them (for example, that the firms could not obtain continuous funding, that they would compete for market share through the environmentally unfriendly "sea of bikes" tactic without improving technology, etc.) spread significantly. The inherent reasons for these phenomena are worth studying.

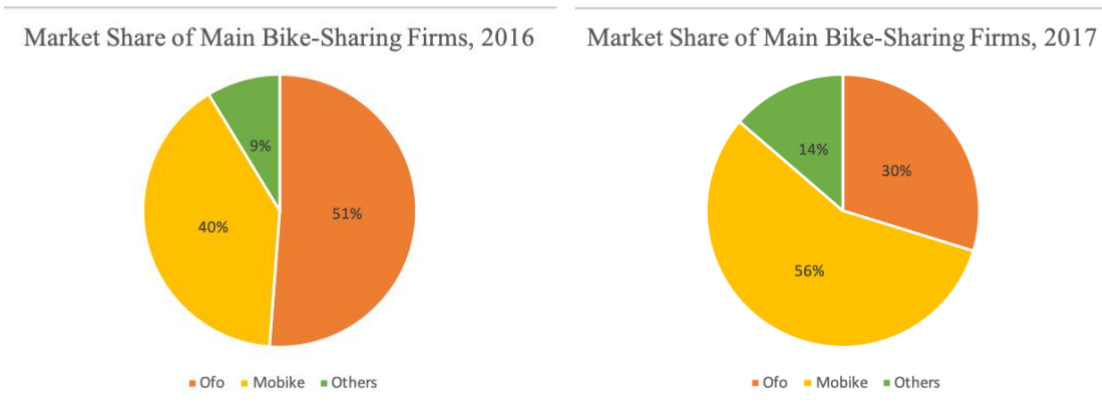

Figure 3.6 Market share of the main bike-sharing firms in 2016 and 2017. Source: iimedia.cn

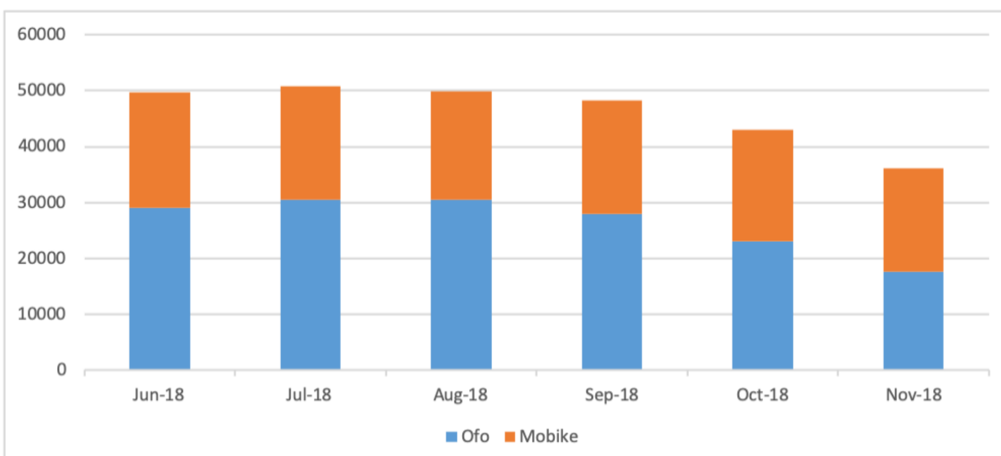

Figure 3.7 Daily active users of the main bike-sharing apps in the second half of 2018. Source: iimedia.cn

In this section, we examine some representative cases in China's bike-sharing industry and analyze their development based on our model. By combining theory and practice, we can better confirm the real-life significance of our model's conclusion and gain a better understanding of bike-sharing as a newly emerging aspect of the sharing economy.

4.1 Ofo and Mobike

As pioneers of China's dockless bike-sharing industry, Ofo and Mobike were the top two firms in the industry (Ma et al., 2019) until Ofo's bankruptcy in December 2018. Although there are many more than these two firms in China's dockless bike-sharing market, the remaining firms cannot compare with these two in terms of either entry time or market share. For this reason, the game between Ofo and Mobike can be captured by our model.

Founded in December 2014, Ofo focused on providing bikes on university campuses and did not enter the market until it launched in Beijing in October 2016. Mobike was founded in January 2015 and officially started its dockless bike-sharing business in Shanghai in April 2016. As we can see in the following table, since each is specific to one city, it is reasonable to consider the two companies as entering the market at the same time.

Table 4.1 Time at which Ofo and Mobike entered their main cities

	Ofo	**Mobike**
Shanghai	2016/10	2016/04
Beijing	2016/10	2016/08
Guangzhou	2016/11	2016/09
Shenzhen	2016/11	2016/10
Chengdu	2016/12	2016/11
Xiamen	2016/12	2016/12

For Ofo bikes, the riding fee is 1 RMB per 60 minutes, the average riding distance is within approximately 2 kilometers, and riding 1 kilometer takes around 10 minutes[8]. For Mobike, the riding fee is 1 RMB per 30 minutes, the average riding distance is around 2 kilometers, and it takes

[8] The lowest average single-use distance of Ofo bike riders from different age groups is 1.47 km (1980s birth cohort), and the highest is 1.65 km (1960s birth cohort). The lowest riding speed is 94.1m per minute (1970s birth cohort) and the highest is 99.1m per minute (1960s birth cohort). Source: Data from Ofo.

about 8 minutes to ride one kilometer.[9] Most of the consumers of these two firms ride for under 30 minutes, so the two firms can be considered to have established the unified single-use price in the market.

Prior to Round B, Ofo received about twice as much investment as Mobike, and this difference in investment scale at the initial stage is why the two firms made different strategic choices. According to **Result 1** of our model, the more invested firm would spend a relatively small percentage of its funds on improving technology and would have a lower technological level. Ofo, with a larger scale of investment, adopted a quantity-oriented strategy while Mobike, with a relatively small scale of investment, chose a more technology-oriented strategy.

Table 4.2 Financing history of Ofo and Mobike[10]

Ofo			**Mobike**		
2015/03	Angel Round	¥ 1 million	2015/03	Angel Round	¥ 1.46 million
2015/12	pre-A	¥ 9 million	2015/10	A	$ 3 million
2016/04	A	¥ 25 million	2016/08	B	$ tens of millions
2016/09	B	$ tens of millions	2016/08	B+	$ tens of millions
2016/09	B+	$ tens of millions	2016/09	C	$ 100 million
2016/10	C	$ 130 million	2016/10	C+	$ 55 million
2017/03	D	$ 450 million	2017/01	D	$ 215 million
2017/04	D+	$ hundreds of millions	2017/01	Strategic Investment	$ hundreds of millions
2017/07	E	$ 700 million	2017/06	E	$ 600 million

[9] The minimum single-use distance of Mobike riders from different cities is 1.8 km (Shanghai), and the maximum is 2.8 km (Haikou). The highest riding speed is 6.2 minutes for 1 km (Jinan) and the lowest is 9.3 minutes for 1 km (Changsha). Source: Data from Mobike.

[10] Source: ITJUZI.

2018/03	Strategic Investment	¥ 1.77 billion	2017/11	Strategic Investment	Not Revealed
2018/03	Strategic Investment	$ 866 million	2018/01	Strategic Investment	$ 1 billion
2018/03	Strategic Investment	$ 866 million			
About ¥ 18.1 billion in total			About ¥ 17.2 billion in total		

The data show that Mobike was not immediately knocked out of market, even though it received relatively little investment at the initial stage. According to **Result 2** of the model, the more invested firm's rate of return on investment, compared with its opponent's, is higher than 1 and increases as they both obtain more investment funding. Therefore, at the initial stage, when the overall scale of investment is small in absolute terms, even though the investment received by Ofo was twice that of Mobike, the gap between their investment return rate was not significant. Based on such a strategic consideration (investing in different enterprises in the same industry along with other investors), investors would naturally assume that Mobike might have potential value despite its slightly lower rate of return on investment and therefore would be worthy of investment.

Furthermore, Mobike received more investment than Ofo in subsequent Rounds B, C, and D despite attaining a smaller investment during the initial stage and the continuing narrowing of the gap between the two companies' investment scale. This was because investors in Mobike were motivated to help the firm achieve a higher investment return rate by providing further investment to prove the correctness of their initial decisions. As the gap in investment scale shrank, the difference in quantity and technology between the two firms also narrowed. According to BigData-Research and qianzhan, Ofo's cumulative number of bikes was 150% higher than Mobike's in March 2017. And in May 2017, Ofo had 36% more bikes than Mobike. Moreover, though Mobike was once well known for not prioritizing advanced technology, the firm also introduced smart locks and a GPS system in 2017, which indicates that the disparity in the two firms' technological level was no longer very great. This phenomenon corresponds very well with our **Result 3**: The ratio of the more invested firm's technological level to its competitor's is lower than 1 and decreases as the disparity in their investment scale grows—or, looking at this another way, the gap would be narrowed as the disparity in their investment scale disappears.

Table 4.3 Cumulative number of Ofo and Mobike bikes/10,000

	Ofo	**Mobike**
2016/12	80	50
2017/03	250	100
2017/05	500	365

During the bankruptcy wave for bike-sharing firms in the second half of 2017, Ofo and Mobike still occupied leading positions in the industry with extremely high market shares. However, this did not mean that Ofo and Mobike could rest easily. In 2018, Ofo and Mobike canceled low-price promotions (such as riding a bike with a fixed fee of 1 RMB per month). There was then more speculation that Ofo and Mobike's capital chains were about to break. The converging scales of investment led Ofo and Mobike to be considered firms that received equal funding. Thus, the capital crisis for both can be explained by **Proposition 1** of our model: The rate of return on investment in equilibrium decreases as the scale of investment increases. In a case in which a huge scale of investment was obtained, the two firms could maintain the original investment rate of return and the capital crisis was thus inevitable.

The two firm's demise is consistent with our model's prediction. In 2018, Mobike was purchased by Meituan and then ended its existence as an independent firm. At the end of 2018, Ofo started to have difficulty returning its users' deposit and later went bankrupt.

4.2. Bluegogo

Founded in November 2016, Bluegogo chose Shenzhen as its starting point in the dockless bike-sharing industry. Bluegogo received Round A financing of 400 million RMB in January 2017 and was known as the most easy-riding shared bike because of its ergonomic design. However, Bluegogo's good performance did not last long; it failed in its Round B financing plan and stopped operating in November 2017.

Unlike Mobike, which was once at a disadvantage in terms of its investment scale yet managed to catch up with its competitor, Bluegogo was never able to turn the tables. The reason is that when Bluegogo entered the market, the overall scale of investment was much larger than what it was when Mobike entered. Mobike entered with an investment of 1.46 million RMB, while Bluegogo obtained 400 million RMB (and is still less funded compared with other early comers in the industry). This indicates that the bike-sharing market has experienced rapid expansion. Just as **Result 2** and **Result 3** suggest, when the disparity between two firms' available investment scale is large and their overall investment level is high, their difference in technological level and investment return will be increased. Compared with the bikes of other firms, the kind of bike released by Bluegogo is far superior in terms of comfort level, which resulted from the fact that an aggressive technological strategy was its optimal choice. Nevertheless, when Bluegogo made that choice, it should have realized that as the firm with the most easy-riding bike, it would suffer a crushing defeat in terms of its investment return rate and inevitably be knocked out of the market soon after.

5. Conclusion

In this paper, in addition to the traditional consumer-to-consumer sharing economy (Acquier et al., 2017; Murillo et al., 2017), we present a novel game-theoretic model to explore the mechanism behind some unique phenomena regarding profit versus sustainability in the business-to-consumer bike-sharing industry. In this matching game, each bike-sharing firm chooses its optimal competitive strategy and aims to match more consumers with its own bikes. Each firm has two dimensions of instruments with which to compete in this specific matching game: make investments to increase the quantity of bikes (i.e., accessibility to consumers) and make investments to increase the quality of bikes (i.e., the technological level). When firms increase quantity, more consumers will have access to its bikes while consumers' utility reduces. By improving quality, consumers' utility gets higher (compared with using its competitor's bike) while the number of bikes reduces. The optimal strategy for a bike-sharing firm in equilibrium will be a trade-off between the quantity and quality of its bikes since it has limited available investment funds. Given its higher quality, consumers are more likely to use its bike when its competitor's bike is also in the same location, but the total number of its bikes decreases—and with larger quantity, there will be more locations in which only this firm's bike is available, and thereby consumers can only choose it.

When the two firms receive unequal amount of outside investment, the results show that the firm with more investments attaches relatively less importance to quality but has a higher rate of return on its investment. The firm with higher quality is more likely to be knocked out of the market. These theoretical results are generally supported by the case studies and empirical evidence presented in Section 4.

China's dockless bike-sharing industry has moved into a new stage: The main firms in the industry have started to develop electric bikes and have launched them in some mid-sized cities. It is widely agreed that this new type of electric bike will become the focus of another round of competition and the trade-offs between the quantity and quality of these new bikes can also be an important aspect for competitors to consider. Beyond the bike-sharing industry, the idea of quantity-quality trade-offs can also be applied to some newly emerging businesses, such community-group buying, which allows a group of residents within the same apartment compound to get discounts by buying as a group. The trade-off between attracting customers and keeping them loyal is worth discussing across multiple fields, and this trend can be seen as ongoing.

Therefore, we put forward some new and useful managerial insights. First, from the perspective of market competition, the government should impose a policy that strictly limits the number of shared-bike providers in one city to avoid both monopoly and excessive competition. Second, from the perspective of externality, sharing platforms require self-supervision and taking corresponding social responsibility. Therefore, the government should charge a tax to internalize the cost of negative externalities for oversupplied platforms. Third, from the perspective of technology improvement, the government should give subsidies to platforms to encourage technological progress. For example, Meituan Bike won the "2021 Leading Scientific and Technological Achievement" award with its industry-leading intelligent parking management technology.

The framework developed in this research can be applied to analyze more industries with similar characteristics. Two strategies can be chosen to improve the success rate of matching in this type of game. One dimension of the matching strategy can be thought of as raising the direct matching probability, which is exemplified by raising the quantity of bikes in the case of bike-sharing. The other dimension of matching can be thought of as increasing matching efficiency, which is exemplified by improving the technological level of bikes. A matching competition with these two dimensions of strategies under a budget constraint can deliver useful predictions for relevant markets.

Acknowledgements:

Xie acknowledges the financial support from the National Natural Science Foundation of China (Grant No. 71973075, 71973076). Zhang acknowledges the financial support from the National Science Foundation of the US (Grant No. 1928278) and Michigan State University Asian Studies Center.

References

Alvisi, M., & Carbonara, E. (2020). Cocktails done right: Price competition and welfare when substitutes become complements. *Journal of Economics*, 1-38.

Berry, S., Levinsohn, J. and Pakes, A., 1995. Automobile prices in market equilibrium. *Econometrica*, 841-890.

Berry, S., Levinsohn, J. and Pakes, A., 2004. Differentiated products demand systems from a combination of micro and macro data: The new car market. *Journal of Political Economy*, 112(1), 68-105.

Bieliński, T., Kwapisz, A., & Ważna, A. (2019). Bike-sharing systems in Poland. *Sustainability*, 11(9), 2458.

BigData Research. (2017, February 8). 2016 China Shared Bike Market Research Report. Retrieved October 18, 2022, from http://www.bigdata-research.cn/content/201702/383.html

BigData Research. (2017, May 16). Research Report on China's Shared Bike Market in the First Quarter of 2017. Retrieved October 18, 2022, from http://www.bigdata-research.cn/content/201705/455.html

China Academy of Information and Communications Technology. (2019) China bike-sharing industry report. http://www.caict.ac.cn/kxyj/qwfb/ztbg/201804/t20180426_158533.htm.

China Shared Bike Market Research Report in 2016. Retrieved October 18, 2022, from http://www.bigdata-research.cn/content/201702/383.html

China Shared Bike Market Research Report in the First Quarter of 2017. Retrieved October 18, 2022, from http://www.bigdata-research.cn/content/201705/455.html

Cheng, Y. L., & Peng, S. K. (2012). Quality and quantity competition in a multiproduct duopoly. *Southern Economic Journal*, 79(1), 180-202.

Cohen, P., Hahn, R., Hall, J., Levitt, S., & Metcalfe, R. (2016). Using big data to estimate consumer surplus: The case of Uber (No. w22627). National Bureau of Economic Research.

DeMaio, P. (2009). Bike-sharing: History, impacts, models of provision, and future. *Journal of Public Transportation*, 12(4), 3.

Dixit, A. (1979). Quality and quantity competition. *Review of Economic Studies*, *46*(4), 587-599.

Erzhile. (2019). Where did abandoned sharing bikes go? Last accessed: October 9, 2022. https://www.sohu.com/a/329293332_655347.

Eren, E., & Uz, V. E. (2020). A review on bike-sharing: The factors affecting bike-sharing demand. *Sustainable Cities and Society*, 54, 101882.

Faghih-Imani, A., Hampshire, R., Marla, L., & Eluru, N. (2017). An empirical analysis of bike sharing usage and rebalancing: Evidence from Barcelona and Seville. *Transportation Research Part A: Policy and Practice*, 97, 177-191.

Freund, D., Henderson, S. G., & Shmoys, D. B. (2019). Bike sharing. In *Sharing Economy* (pp. 435-459). Springer, Cham.

Gal-Or, E. (1983). Quality and quantity competition. *Bell Journal of Economics*, 590-600.

Guo, P., Lin, X.Z., Huang, Y., Tu, S.M., Bai, X.M., & Yang, Y.W., et al. (2017). Bike sharing: Collaborative governance in Internet technology and public services. *Journal of Public Management* (03), 6-15+159.

Jiemian. (2019). Bike-sharing 4 years, and many bikes were wasted. Last accessed: October 9, 2022. https://www.jiemian.com/article/3328106.html.

Ma, G.Q., & Wei, M.K. (2017). Dilemma and strategy of China's bike-sharing market in "Internet +" Era. *Industrial Economy* (12).

Ma, J.H., Cao, W.Q., Xu, W.M., Zhu, X.X., & Shao, C.X. (2018). Analysis of bike-sharing market under four-sided game perspective. *Science and Technology & Innovation*, No.97(01), 33-36.

Ma, Y., Rong, K., Luo, Y., Wang, Y., Mangalagiu, D., & Thornton, T. F. (2019). Value co-creation for sustainable consumption and production in the sharing economy in China. *Journal of Cleaner Production,* 208, 1148-1158.

Macioszek, E., Świerk, P., & Kurek, A. (2020). The bike-sharing system as an element of enhancing sustainable mobility—A case study based on a city in Poland. *Sustainability*, 12(8), 3285.

Meng, L., & Tang, H.K. (2017). Deepening data sharing, advance smart operation: Multi-scene analysis of shared bike big data smart operation. *China Telecommunications Trade* (11), 69-71.

Parente, R. C., Geleilate, J. M. G., & Rong, K. (2018). The sharing economy globalization phenomenon: A research agenda. *Journal of International Management*, *24*(1), 52-64.

Pelechrinis, K., Zacharias, C., Kokkodis, M., & Lappas, T. (2017). Economic impact and policy implications from urban shared transportation: The case of Pittsburgh's shared bike system. *PLOS ONE*, 12(8), e0184092.

Qianzhan Industry Research Institute. (2017, May 24). Over 10 million shared bicycles. Retrieved October 18, 2022, from https://bg.qianzhan.com/report/detail/459/170524-1deb391e.html

Qiu, C. Q. (2016). Is shared bike really a form of sharing economy? *Modern Business* (35), 190-191.

Qiu, L. Y., & He, L. Y. (2018). Bike sharing and the economy, the environment, and health-related externalities. *Sustainability*, 10(4), 1145.

Rong, K., & Wang, Y. (2017) Sharing economy 2.0: Born sharing [EB/OL]. *Harvard Business Review*. http://www.hbrchina.org/2017-09-04/5486.html.

Rong, K., Xiao, F., & Wang, Y. (2019). Redundancy in the sharing economy. *Resources, Conservation and Recycling*, *151*, 104455.

Shen, Y., Zhang, X., & Zhao, J. (2018). Understanding the usage of dockless bike sharing in Singapore. *International Journal of Sustainable Transportation*, 12(9), 686-700.

Si, H., Shi, J. G., Wu, G., Chen, J., & Zhao, X. (2019). Mapping the bike sharing research published from 2010 to 2018: A scientometric review. *Journal of Cleaner Production*, 213, 415-427.

Siilu. (2022) BigData Research and The Paper.

Soriguera, F., & Jiménez-Meroño, E. (2020). A continuous approximation model for the optimal design of public bike-sharing systems. *Sustainable Cities and Society*, 52, 101826.

Song, Z.Y., & Zhang, X.B. (2017). Research on urban sharing bicycle marketing strategy based on SWOT Analysis: Take Ofo sharing bikes for example. *Management & Technology of SME* (12), 43-44.

Statista. (2022). Bike-sharing—China: Statista market forecast. https://www.statista.com/outlook/mmo/shared-mobility/shared-rides/bike-sharing/china#revenue. Last accessed: October 14, 2022.

That's Magazine Online. (2022). Three shared bike brands still rolling in China. Last accessed: October 14, 2022, https://www.thatsmags.com/beijing/post/31720/three-shared-bike-brands-still-rolling-in-china.

The State Information Center of China. (2019). Annual report of China's sharing economy. http://www.sic.gov.cn/News/568/8873.htm.

Wang, J. G. (2017). An analysis of profit model of bike-sharing in Internet sharing economy. *China Journal of Commerce* (11), 147.

Wang, J.Y. (2017). Bike-sharing: Status quo, profit model and prospects—Using Ofo and Mobike as examples. *Forum of Leadership Science* (7).

Wang, X., Hou, W. J., & Zhao, J. Y. (2017). An analysis of business model of sharing economy based on O2O perspective: Taking Ofo as an example. *Market Modernization* (8), 28-29.

Wang, Y., & Wu, D. (2017). Discussion on mechanism and tendency of price competition in bike sharing market: Based on game model. *Price: Theory & Practice* (11), 66-69.

Wen, J. (2019). Where did abandoned sharing bikes go? 4,000 little yellow bikes got new lives in Myanmar. https://www.thepaper.cn/newsDetail_forward_3789403. Last accessed: October 9, 2022.

Xie, D. (2018). A rational rush theory of financing innovations. Mimeo.

Yang, H., Huo, J., Bao, Y., Li, X., Yang, L., & Cherry, C. R. (2021). Impact of e-scooter sharing on bike sharing in Chicago. *Transportation Research Part A: Policy and Practice*, 154, 23-36.

Zhang, L., Zhang, J., Duan, Z. Y., & Bryde, D. (2015). Sustainable bike-sharing systems: characteristics and commonalities across cases in urban China. *Journal of Cleaner Production*, 97, 124-133.

Zhang, Z. X., & Wu, W. (2017). Status quo, problem, and advice on development strategy of bike-sharing. *Modern Business* (15), 162-163.