



Cost–benefit analysis of reusable takeaway food containers usage: a case on campus in China

Ruijuan Li¹ · Yuanchun Zhou² · Hongyan Su³ · Qi Wang¹ · Hua Wang¹

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Abstract

Promoting the use of reusable takeaway food container (RTFC) in takeaway industry is an effective way to reduce the negative environmental impacts caused by single-use plastic containers. This study intended to figure out the barriers to the new business model deployment through evaluating the economic costs and benefits of RTFC from a stakeholder's perspective. Taking the pilot RTFC project at a university in Guangdong province as a case, we established a holistic cost and benefit analysis framework from a stakeholder's perspective. Both the costs and benefits with and without a market price of each stakeholder were evaluated using market price method and contingent valuation method. The analysis result shows that while shifting to reusable takeaway food container, the costs and benefits of all the main stakeholders changed. The net benefit of consumers is positive about 360 thousand yuan during 2020–2025, while the platform company, the university and the restaurants gain negative net benefits ranging from –20 to –470 thousand yuan under current operation situation, which may hinder the sustainable development of this new business model. However, the sensitivity analysis shows that all the stakeholders could gain a positive net benefit by adjusting the rental price, cleaning price and packaging price, as well as optimizing the location of recycling cabinets.

Keywords Reusable takeaway food container · Cost–benefit analysis · Net benefit · Stakeholder · Sensitivity analysis

Introduction

Mass use of single-use plastic products has been a worldwide problem and induced serious environmental, social, and economic problems (United Nations Environment Programme 2019). Takeaway food package is one of the main sources of single-use plastics (Gallego-Schmid et al. 2019; Li et al. 2021). In 2020, the takeaway food industry of China generated 1.6 million tons of plastic waste, accounting for 3% of all waste plastic in municipal solid waste (Zhang and

Wen 2022). What's more, the demand for takeaway foods has been increasing, for example, online orders in China have surged during the COVID-19 pandemic (Guo et al. 2021; Liu et al. 2021). In order to tackle the plastic pollution problem, China has set up a goal to cut the use of non-degradable single-use plastic tableware for takeaway in cities by 30% by the end of 2025 compared to 2020 to reduce plastic waste (National Development and Reform Commission and Ministry of Ecology and Environment 2020).

Reusable takeaway food container (RTFC), generating less pollution during lifetime, is an environment friendly alternative compared with single-use ones for its lower environmental impacts. Gallego-Schmid et al. (2019) compared the environmental impact of aluminium, polypropylene and extruded polystyrene to reusable polypropylene containers, and found that reusable takeaway polypropylene containers have the lowest environmental impacts if they are reused 3–39 times. Zhou et al. (2020) found that sharing tableware, including reusable container, spoon, etc., could balance out most of the environment impacts of single-use alternatives except dioxin emission after being reused 2–43 times. In recent years, pilot programs for RTFC usage have

Responsible Editor: Philippe Garrigues

✉ Yuanchun Zhou
zhouych11@163.com

¹ School of Environment & Natural Resources, Renmin University of China, Beijing 100872, China

² Green Economy Development Institute, School of Economics, Nanjing University of Finance and Economics, Nanjing 210023, China

³ School of Applied Economics, Renmin University of China, Beijing 100872, China

been initiated in several cities around the world (Chen et al. 2020; Dundon 2021; Korea Bizwire 2021) and on campus in China (Chen 2020). The RTFC used on campus in China could balance out the main environmental impacts of single-use alternatives after being used 7 times (Plastic Free China 2022). However, reusable takeaway food containers are not convenient as single-use ones, because consumers have to return it back. Then restaurants or a third party has to collect the used containers, then clean, disinfect and deliver the containers for their use in the next recycle (Chen et al. 2020), which means consumers, restaurants and the third service providers are all involved in the reverse logistics (Chen et al. 2020; Zhang et al. 2021). The business model shift from single-use to reusable depends on the decision of related stakeholders, whose costs and benefits change plays an important role for their decisions (Bulgurcu et al. 2010). Hence, it is necessary to conduct a holistic cost–benefit analysis (CBA) to evaluate whether RTFC is economically beneficial or not for different stakeholders.

CBA has a long history. At the earlier stage, only costs and benefits that had direct market price were valued, many environmental impacts without market prices were ignored in CBA (Pearce 1998). Later, preference-based methods (such as contingent valuation, choice experiment, hedonic pricing, or averting expenditure) are used to assess people's willingness to pay for better environmental goods or services, which had promoted the use of CBA for environmental impact analysis involved in related projects and policies assessment (Asian Development Bank 2017; Atkinson et al. 2018).

Previous literatures shows that CBA from stakeholder's perspective could identify the distribution of the costs and benefits among stakeholders and help to understand the barriers of a policy or an investment project. Some literatures focused on the financial costs and benefits of stakeholders. Liu et al. (2022) estimated the financial internal rate of return of core stakeholders in the waste photovoltaic module recycling project, found an unequal benefit distribution among stakeholders which affects their investment motivation and efficiency. Franzò et al. (2019) applied it to the Italian White Certificates scheme, and found the scheme led to several positive impacts for almost all stakeholders involved and a major economic loss for energy utilities, which offered interesting insights and implications for policymakers. Chen et al. (2017) conducted a CBA of a hydropower development project from stakeholder's perspective, found farmers' net income decreased while that of other stakeholders increased, which may hinder the sustainable development of hydropower projects. Some researches evaluated stakeholders' costs and benefits with and without market price which presented a more holistic evaluation. Ren et al. (2019) evaluated the multi-benefits of a distributed energy system of multi-stakeholders using market price and contingent valuation

method (CVM) and figured out that second benefit trade-off may be required to ensure the satisfied profit return for each stakeholder. Chabba et al. (2022) designed an equity-weighted, risk-based CBA of an ecosystem-based disaster risk reduction investment and figured out broader sustainability outcomes beyond monetary gain must be considered.

The researches related to RTFCs so far focus predominantly on environmental impacts (Gallego-Schmid et al. 2019; Zhou et al. 2020), influential factors on choice (Dorn and Stöckli 2018) and service model (Chen et al. 2020). Little literature has evaluated and monetized the costs and benefits of RTFC project, especially for all stakeholders. This paper aims to address this gap through identifying and monetizing the costs and benefits of RTFC usage from stakeholder's perspective. It is helpful to understand the barriers of the promotion of this new business model. The remainder of the paper is structured as follows. The "Methods" section introduces the main stakeholders of the case project and their relationship, then illustrates a detailed costs and benefits matrix and along with estimation methods. The "Surveys and data" section gives a brief introduction of the surveys and data. The "Results analysis" section presents the estimation results and sensitivity analysis results. Finally, the "Conclusions and discussions" section provides conclusions with a focus on the ways to promote the sustainable development of the RTFC business model.

Methods

Main stakeholders identification

As mentioned in the "Introduction" section, the biggest difference between RTFC and the single-use counterpart is that the former should be returned by the consumer and collected, cleaned, disinfected and delivered back to the next business circle. There may be different business models for the loop of the RTFCs and different stakeholders involved (Chen et al. 2020). In order to make practical analysis, we selected the RTFC project at Shunde campus of Southern Medical University in Guangdong Province of China as a case.

In 2018, the university began to cooperate with the platform company, ShuangTi, who provides delivery service for the restaurants and the consumers in the university. The consumers could order foods from restaurants through an application (APP) developed by the platform company, then the platform company delivers the foods to the self-pickup cabinet designated by consumers in the order. Initially, all the restaurants packaged the takeaway foods using single-use containers, as described in Fig. 1(a). Since June 2020, the project began to provide RTFCs (Plastic Free China 2022), which is the first pilot

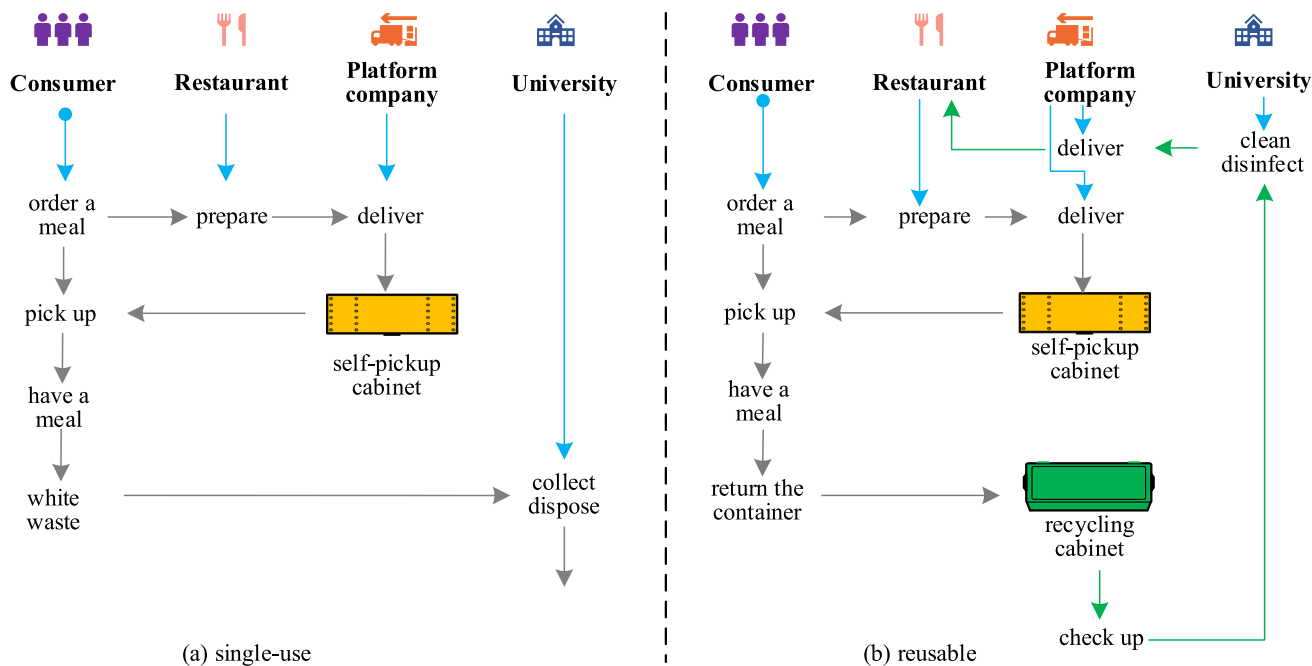


Fig. 1 Single-use takeaway food container model (a) and reusable-takeaway food container model (b)

project in China. The restaurants on campus could rent RTFCs from the platform company and provide them to consumers. The consumers have to return the RTFCs to the recycling cabinets on campus after meal in 2–3 days. The platform company collects containers in recycling cabinets and sends them to the canteen of the university for cleaning and disinfecting, then delivers the clean containers to the restaurants for the next loop, as described in Fig. 1(b). The main stakeholders of the case project include the platform company, the university, the restaurants and the consumers, who play different roles, bear some costs and gain some benefits from the project.

Costs and benefits matrix

In this paper, we aim to evaluate whether it is beneficial or not to substitute the single-use takeaway food containers with reusable ones from the perspective of multi-stakeholders. Therefore, the single-use takeaway food container model is set as a reference, and the costs and benefits under the RTFC model are estimated as changes relative to the reference. The shared costs and benefits under both situations are not evaluated in this study. According to this principle, the main stakeholders’ costs and benefits are described in Table 1.

Table 1 Main stakeholder’s costs and benefits matrix

Project stage	Stakeholder	Model	Costs	Benefits
Preparation	Platform company	Reusable	R&D cost	
Operation	Platform company	Reusable	Equipment cost, RTFC cost, collection and delivery cost, cleaning fee	RTFC rent revenue, equipment disposal revenue, RTFC disposal revenue
	University	Reusable	RTFC cleaning cost	Cleaning revenue paid by the platform company
		Single-use	Waste collection and disposal cost of SUTFC	WWDF paid by restaurants or consumers
	Restaurants	Reusable	cost of renting RTFC	Packaging revenue of RTFC
		Single-use	SUTFC cost, WWDF	Packaging revenue of SUTFC
	Consumers	Reusable	packaging fee of RTFC time cost of returning RTFC	Satisfaction from the advantages of RTFC
		Single-use	Packaging fee of SUTFC	
Completion	Platform company	Reusable		Scrap value of waste equipment and RTFC

The shared costs and benefits of the two models are not included in this table; SUTFC, single-use takeaway food containers; WWDF, white waste disposal fee

The project includes the preparation stage, operation stage and completion stage. At the preparation stage, the platform company invests in research and development (R&D) of the RTFCs and related software and equipment. The R&D cost may be gradually recovered from this pilot project and other projects. At the operation stage, all the four stakeholders are involved in the project. At the completion stage, the platform company disposes the residual RTFCs and equipment and gains some benefits. The costs and benefits at operational stage are critical for the sustainable development of the pilot project. Therefore, we mainly focus on the costs and benefits of each stakeholder at the operation stage in the following sections.

For monetizing the costs and benefits, both market and non-market price methods are used in this study. The market price method is used to estimate the costs and benefits of the platform company, the university and the restaurants as well as consumers' packaging fee. CVM is adopted to monetize consumers' time cost and net benefits.

Cost change

Compared with the single-use takeaway food container model, the changes of cost for each stakeholder under the RTFC model are defined as follows:

- (1) The platform company's cost change is estimated as costs for purchasing RTFCs and equipment, labor cost and cleaning cost.

$$C_{p,t} = C_{r,t} + C_{e,t} + C_{l,t} + P_{c,t} Q_t \tag{1}$$

where $C_{p,t}$ is the cost change of the platform company, $C_{r,t}$ is the container cost, $C_{e,t}$ is the equipment cost, $C_{l,t}$ is the labor cost for the management of the RTFC project in year t , $P_{c,t}$ is the cleaning price and Q_t is the total quantity of RTFC circulation in year t .

- (2) The university's cost change is estimated as the RTFC cleaning cost minus the avoided waste collection and disposal cost. The cleaning cost includes the water, electricity, cleaning products and labor costs occurred in the containers' cleaning process. The waste collection and disposal cost includes labor cost and consumable material cost for waste collection and disposal.

$$C_{u,t} = (AC_{c,t} - AC_{w,t}) Q_t \tag{2}$$

where $C_{u,t}$ is the cost change of the university in year t , $AC_{c,t}$ is the average cleaning cost of RTFCs, $AC_{w,t}$ is the average white waste collection and disposal cost in year t .

- (3) The restaurants' cost change is estimated as the rental cost for RTFCs minus the avoided single-use takeaway food container cost and the white waste disposal fee

levied by the university. Some restaurants added the white waste disposal fee to the order, which was paid by the consumers instead.

$$C_{r,t} = (P_{r,t} - P_{s,t}) Q_t \tag{3}$$

where $C_{r,t}$ is the cost change of restaurants in year t , $P_{r,t}$ is the rental price of the RTFC, $P_{s,t}$ is the average price of single-use takeaway food containers including white waste disposal fee.

- (4) The consumers' cost change is estimated as packaging fee and time cost under the RTFC model minus the avoided packaging fee for single-use takeaway food containers. The packaging fees are set by restaurants. If restaurants added the white waste disposal fee to the order, it will be paid by consumers. There's no market price. of time cost. We conducted a questionnaire and used the multi-boundary discrete choice elicitation strategy to measure the value of time cost. See Appendix 1 for the questionnaire and Appendix 2 for the estimation method.

$$C_{c,t} = (F_{r,t} + T_{r,t} - F_{s,t}) Q_t \tag{4}$$

where $C_{c,t}$ is the cost change of consumers in year t , $F_{r,t}$ is the average packaging fee of RTFCs, $T_{r,t}$ is the average time cost of returning RTFCs per time, $F_{s,t}$ is the average packaging fee of single-use takeaway food containers including white waste disposal fee.

Benefit change

Similarly, each stakeholder' benefit change under the RTFC model is defined as follows:

- (1) The platform company's benefit change is estimated as rent revenue paid by the restaurants and scrap value from the disposal of waste equipment and RTFCs reaching their service life.

$$B_{p,t} = P_{r,t} Q_t + R_{e,t} + R_{r,t} \tag{5}$$

where $B_{p,t}$ is the benefit change of the platform company, $R_{e,t}$ is the scrap value from the disposal of waste equipment, and $R_{r,t}$ is the scrap value from the disposal of waste RTFCs in year t .

- (2) The university's incremental benefits were estimated as the cleaning revenue paid by the platform company minus the avoided white waste disposal fee.

$$B_{u,t} = (P_{c,t} - F_w) Q_t \tag{6}$$

where $B_{u,t}$ is the benefit change of the university in year t , F_w is the white waste disposal fee.

- (3) The restaurants' benefit change is estimated as packaging revenue from RTFCs minus the avoided packaging revenue from single-use takeaway food containers.

$$B_{r,t} = (F_{r,t} - PP_{s,t}) Q_t \quad (7)$$

where $B_{r,t}$ is the benefit change of the restaurants in year t , the packaging price of RTFCs is equal to the packaging fee $F_{r,t}$, and $PP_{s,t}$ is the average packaging price of single-use takeaway food containers. It should be noted that $PP_{s,t}$ is not equal to $F_{s,t}$ which includes the white waste disposal fee paid by consumers.

- (4) The consumers' benefit change is estimated as their satisfaction with the advantages of RTFCs, which equals to consumers' net benefit plus cost change.

$$B_{c,t} = ANB_{c,t} Q_t + C_{c,t} \quad (8)$$

where $B_{c,t}$ is the benefit change of the consumers in year t , $ANB_{c,t}$ is the average net benefit of consumers choosing RTFC.

Net benefits

All the costs and benefits are presented on an annual basis in Chinese yuan for the year 2019 when the R&D cost of this project occurred. Based on the estimation of costs and benefits as described above, we estimated the net benefit of the platform company, the university and the restaurants using Eq. (9):

$$NB = \sum_t \frac{(B_t - C_t)}{(1+r)^{t-2019}} \quad (9)$$

where NB is the net benefit for a specific stakeholder in a target period, B_t is the benefit change in year t , C_t is the cost change in year t , and r is the discount rate. All the costs and benefits occurring after 2019 are discounted to 2019 values using a discount rate of 4.35%, the same as the benchmark interest rate of central bank loans (The People's Bank of China 2015). To test the sensitivity of estimation results to the choice of the discount rate, we also use another two discount rates following previous literature, 8% (Zhou et al. 2019) and 12% (Cropper et al. 2019), for sensitivity analysis.

In terms of the net benefit of consumers, we estimated it using a payment card elicitation strategy through survey. The estimation method is presented in Appendix 3.

If the net benefit of a specific stakeholder is positive, it means that switching from single-use takeaway food container model to RTFC model could make the stakeholder better off.

Surveys and data

The platform company provided the data related to its and the university's costs and benefits (Plastic Free China 2022). The survey on restaurants was conducted through face-to-face questionnaires. The data related to consumers were obtained through online questionnaires using WJX.cn in December 2021. All the respondents were students from Shunde campus of Southern Medical University.

The manager or whom knew well of the takeaway food containers from the restaurants were asked to provide information on the cost for purchasing single-use takeaway food containers and their attitudes towards RTFCs. Forty-two restaurants, about 74% of the total restaurants in the university, participated in the survey. The packaging prices were marked on the order bill which were collected through checking the menu of each restaurant one by one on the ordering APP. Then, 13 restaurants at the campus provide both single-use takeaway food containers and reusable ones for consumers, the other restaurants provide only single-use food containers. The restaurants rent RTFCs from the platform company at a universal price.

Consumers were asked about their experiences of using RTFCs, and their attitudes toward the pros and cons of RTFCs compared with single-use takeaway. Then the value of time cost was measured by the multi-boundary discrete choice elicitation strategy. In the last part of the questionnaires, the respondents were asked to make a choice about the net benefit of the RTFCs from a series of price options given out in the form of intervals. Options in interval format could help the respondents to reduce cognitive pressure (Su and Wang 2019). Before making a choice, the respondents were asked to consider the pros and cons of the RTFC, as well as its influence on them and their surroundings (Appendix 1). Three hundred-sixteen valid questionnaires were collected.

For monetizing the costs and benefits, we made main assumptions as follows:

- (1) The usable life of RTFC is 2 years and the equipment has an expected life of 3–5 years. During the operation stage, about 75% of the RTFCs are replaced every 2 years, and the equipment are replaced at the end of their usable life. Therefore, an assessment period from 2020 to 2025 was chosen which could cover the lifetime of equipment and the 14th 5-year plan period (2021–2025) in China.
- (2) The daily quantity of RTFC circulation was 500 sets, which was the average takeaway food orders packaged by reusable containers each day, accounting for 30% of the total orders. The pilot project was in operation for 150 days in 2020 and 270 days in 2021–2025.

- (3) The average cost of single-use takeaway food containers including the white waste disposal fee ($P_{s,t}$) was 0.99 yuan, ranging from 0.66 to 1.32; the average packaging price (fee) of RTFC ($F_{r,t}$) was 0.77 yuan per container, ranging from 0.53 to 1.01; and the average packaging price of single-use takeaway food container ($PP_{s,t}$) was about 1.04 yuan per container, ranging from 0.58 to 1.50.
- (4) For the consumers, the average packaging fee of single-use takeaway food containers was 1.36 yuan per container, ranging from 0.8 to 1.92. The average time cost of returning RTFCs ($T_{r,t}$) was 1.45 yuan per time, ranging from 0.42 to 2.48. The estimation method for the time cost of returning RTFCs is shown in the Appendix 2.

Considering the variance of these factors, we used the average unit price to calculate the costs and benefits and further conduct a sensitivity analysis.

Results analysis

Cost change of each stakeholder

Taking single-use takeaway food containers as a reference, we estimated the cost changes of the main stakeholders, as described in Fig. 2. The cost that occurs in the reusable model is assigned a positive value, and the cost that occurs in the single-use model is assigned a negative value. The cost change is the difference between the cost in the reusable mode and the cost in the single-use model, which may be positive or negative.

For the platform company, its cost change ($C_{p,t}$) is positive. The cost for purchasing equipment and RTFCs, and

labor account for about 80–90% of the total incremental cost. The cleaning fee accounts for a relatively small part, about 12%. The annual average incremental cost of the platform company is about 165 thousand yuan, and it is higher when the equipment or RTFCs reach usable life and cost for purchasing new equipment or RTFCs occurs, just like in 2022, 2024 and 2025.

For the university, it provides a cleaning service for the platform company, which costs about 20 thousand yuan annually. And it could reduce its expenditure on white waste collection and disposal under the RTFC model, more than 40 thousand yuan per year. Overall, the university’s cost change ($C_{u,t}$) is negative, which means the university’s cost could decrease by about 50% through shifting to the RTFC model.

For the restaurants, its cost change ($C_{r,t}$) is negative, which means the rent for RTFCs is lower than the average price of single-use takeaway food containers including the white waste disposal fee. Therefore, their cost decreases under the RTFC model.

For the consumers, the packaging fee with RTFCs is lower, but the cost change ($C_{c,t}$) for consumers is positive. It is because the time cost for returning RTFCs increases the total cost for consumers. Overall, compared with the single-use takeaway container model, the costs of the platform company and the consumers increased, and the costs of the university and restaurants decreased under the RTFC model. The total costs of the four stakeholders increased about 1296 thousand yuan during 2020–2025 because the new costs were higher than the avoided costs.

Benefit change of each stakeholder

In addition to the change in costs, the estimation result shows that benefits of each stakeholder also changed when shifting to the RTFC model, as shown in Fig. 3.

Fig. 2 Annual costs change of main stakeholders (thousand yuan)

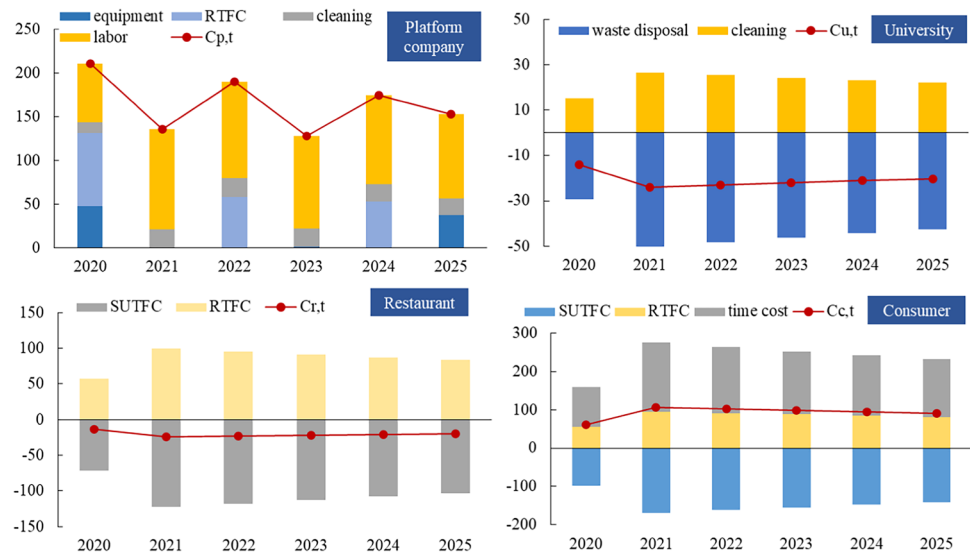
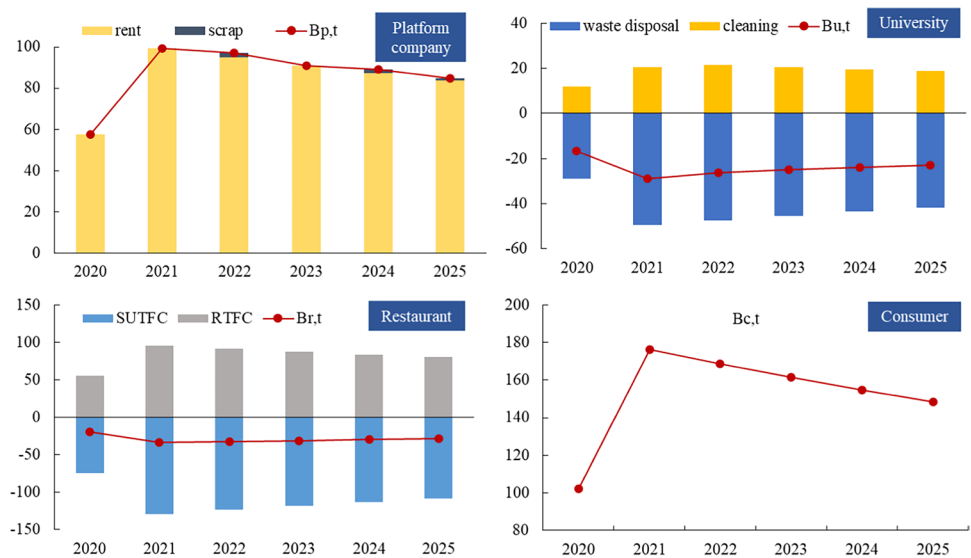


Fig. 3 Annual benefits change of main stakeholders (thousand yuan)



For the platform company, its benefit change ($B_{p,t}$) almost comes from the rent revenue paid by the restaurants, with a little from the scrap value of waste equipment and waste containers. During 2020–2025, the platform company could gain benefit of about 90 thousand yuan annually. The rent revenue depends on the rental price and the order quantity of the RTFCs.

For the university, the benefit change ($B_{u,t}$) is negative. That is, its benefit from the cleaning fee paid by the platform company is lower than the benefit from the white waste disposal fee paid by restaurants and consumers.

For the restaurants, its benefit change ($B_{r,t}$) is also negative. The revenue from the packaging fee of RTFCs is lower than that of single-use ones.

For the consumers, the benefit change ($B_{c,t}$) is positive. Consumers’ incremental benefit is mainly from their satisfaction with the advantages of RTFCs. The survey result of consumers shows that the respondents think the top three advantages of RTFCs are reducing waste generation, saving resources, and better thermal insulation performance, accounting for 78, 60 and 23%, respectively. The first two advantages can bring benefit to society, and better thermal insulation performance can bring benefit to consumers themselves.

Overall, following the assumptions, the platform company and the consumers could gain incremental benefits from the RTFC project, while the university and the restaurants lost part of their revenue. The total benefits of the four stakeholders increased about 1110 thousand yuan during 2020–2025.

Distribution of the net benefits

The net benefit of stakeholders may affect their motivation to participate in the project and the promotion of this

business model. The above results show that both the costs and the benefits of each stakeholder have changed shifting to the RTFC model. The costs and benefits of the platform company and consumers increased, while the costs and benefits of the university and restaurants decreased. Following, we estimate the net benefit of each stakeholder. The result shows that under current assumptions, the platform company, the university, and the restaurants gain negative net benefits during 2020–2025, about -470, -20 and -50 thousand yuan, respectively. The consumers could gain a positive net benefit, about 360 thousand yuan during 2020–2025 (Fig. 4). Therefore, it is not profitable to switch from single-use takeaway food containers to reusable ones for the platform company, the university, and restaurants.

Although the RTFC project could help to reduce waste generation and bring environmental benefit to society, if the

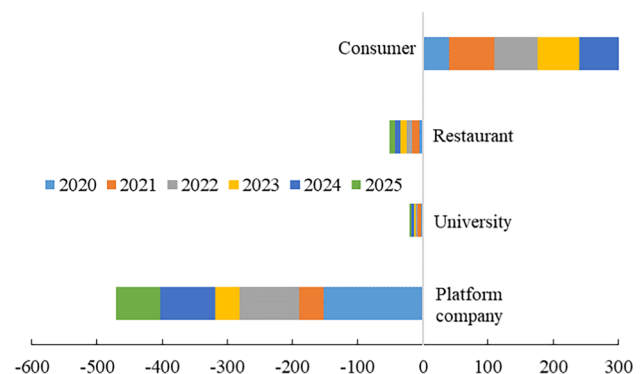


Fig. 4 Net benefits of main stakeholders during 2020–2025 (thousand yuan)

negative net benefits are not aligned with the stakeholders' goals, it tends to hinder the promotion of this business model.

Sensitivity analysis

A positive net benefit is necessary to increase stakeholders' motivation to participate in the RTFC project. In this subsection, sensitivity analyses are implemented to investigate the influence of key factors on the distribution of net benefits between stakeholders and find ways toward positive net benefits for all stakeholders.

The total quantity of RTFC circulation (Q_t) influences the cleaning cost, the rent revenue of the platform company, as well as the costs and benefits of other stakeholders. The rental price ($P_{r,t}$) influences the benefit of the platform company and the cost of the restaurants. The cleaning fee ($P_{c,t}$) influences the cost of the platform company and the benefit of the university. The packaging fee ($F_{r,t}$) influences the benefit of the restaurants and the cost of the consumers. The time cost of returning RTFCs ($T_{r,t}$) influences the cost of consumers. In addition, the discount rate has an impact on the net benefit of each stakeholder, especially the platform company whose costs for equipment and containers occur closer to the present time than its benefits. Therefore, we tested the uncertainty of these factors' influence on main stakeholders' net benefits through sensitivity analysis.

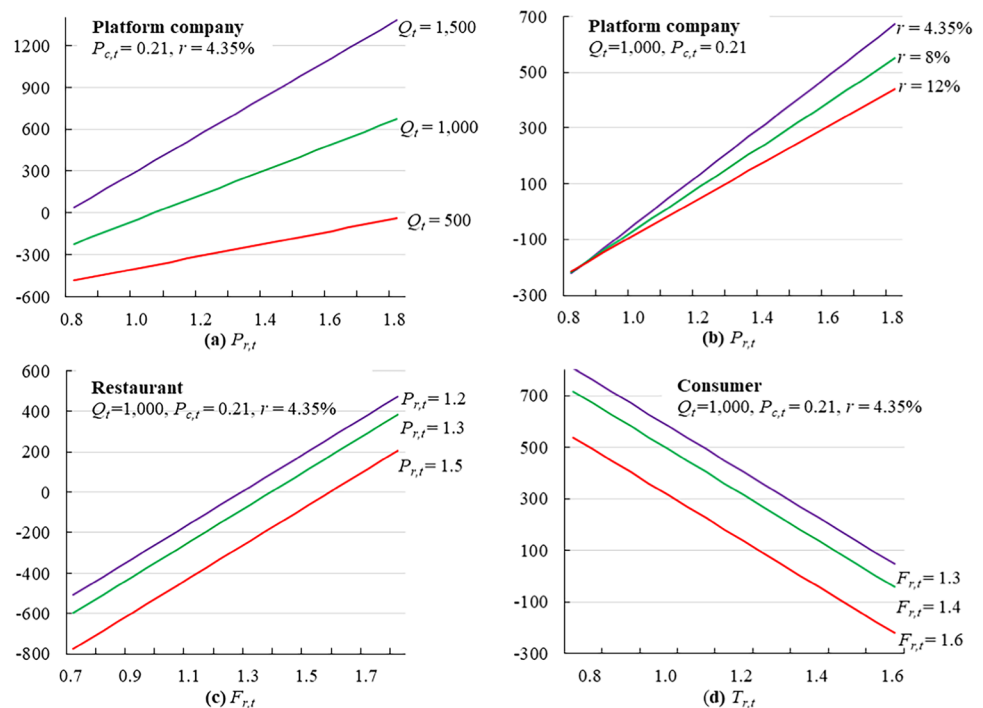
Because the university doesn't aim to pursue profit in the RTFC project, we assume that its cleaning revenue

paid by the platform company equals its cleaning cost, $P_{c,t} = AC_{c,t} = 0.21$ yuan per container. Then we tested the impacts of Q_t , $P_{r,t}$, $F_{r,t}$, $T_{r,t}$ and r on the net benefits of the platform company, restaurants and consumers during 2020–2025 as described in Fig. 5. As the costs and benefits in 2020–2021 have occurred before this study, we assume that changes in key factors in the sensitivity analysis only affect the costs and benefits in 2022–2025.

The results show that the platform company could gain a positive net benefit during 2020–2025 when Q_t reaches 1000 per day (60% of the total orders) and the rental price increases to about 1.1 yuan per container, and gain a net benefit of 400 thousand yuan at a rental price of 1.5 yuan. If Q_t reaches 1500 per day, the platform company could gain a positive net benefit at the current rental price of 0.8 yuan and gain a net benefit of 980 thousand yuan at a rental price of 1.5 yuan (Fig. 5(a)). However, if the discount rate of 8 or 12% is adopted, the platform company needs a higher rental price to gain a positive net benefit (Fig. 5(b)). It also shows that the platform company couldn't recover the R&D cost in a short period in the pilot project and has to recover the platform company through the deployment of this business model.

For the restaurants, compared with the single-use take-away food container, they could gain a positive net benefit through increasing the packaging fee of RTFC. Assuming that Q_t is 1000 and the rental price is 1.2 yuan, the restaurants could gain a positive net benefit at a packaging fee of about 1.3 yuan, which is lower than the average single-use

Fig. 5 The influence of key factors on stakeholders' net benefits (thousand yuan)



packaging fee of 1.36 yuan. In other words, if the restaurants set a packaging fee 0.1 yuan higher than the container rental price, they could gain a positive net benefit (Fig. 5(c)). Therefore, it is necessary to reserve a profit space for the restaurants, allowing them to set the packaging fee.

With the increasing of the packaging fee, consumers' net benefit would decrease. With other parameters unchanged ($Q_t = 1000$, $P_{c,t} = 0.21$, $r = 4.35\%$ and $T_{r,t} = 1.45$), consumers' net benefit would be keeping positive until the packaging fee increases to about 1.5 yuan. On the other hand, reducing the time cost could increase the net benefit of consumers and keep it being positive even at a higher packaging fee (Fig. 5(d)).

Conclusions and discussions

Replacing single-use takeaway food containers with reusable ones is a promising solution to reduce waste generation in takeaway food industry. In this study, we compared the costs, benefits and net benefits of main stakeholders under RTFC model with that under the single-use takeaway food container model, which aimed to figure out the potential barriers that hinders the deployment of the RTFC model.

We find that the costs and benefits of the platform company and the consumers increased, while the costs and benefits of the university and restaurants decreased under the RTFC model. The consumers' net benefit during 2020–2025 is positive, while the platform company, the university and the restaurants are negative, which may discourage the motivation of the platform company, the university and the restaurants to join the RTFC project. However, the sensitivity analysis result shows that main stakeholders could all gain positive net benefits through price adjustment and optimized management.

Some active measures could help to improve the deployment of this new business model. Firstly, increase the cleaning price to compensate the cleaning cost of the university; secondly, the university continues to levy the white waste disposal fee which could encourage the restaurants and consumers to choose RTFCs; thirdly, increase the rental price and packaging price to achieve positive net benefits for the platform company, restaurants, which is critical for the sustainable development of the RTFC project. Fourthly, reduce consumer's time cost for returning RTFCs through optimizing the location of the recycling cabinets, which could increase the net benefit of consumers.

In addition to the above measures, the involvement of local governments may provide incentives to the deployment of this new business model. After the issue of “*Opinions on further strengthening plastic*

pollution” by National Development and Reform Commission and Ministry of Ecology and Environment in 2020, some local governments have developed action plan to tackle plastic pollution and included the reduction of single-use plastic takeaway food container in the plan (Beijing Municipal Commission of Development and Reform and Beijing Municipal Ecology and Environmental Bureau 2020; Guangdong Provincial Development and Reform Commission and Department of Ecology and Environment of Guangdong Province 2022). The local governments encourage takeaway food platforms to reduce the usage of single-use plastic containers and require related agencies to strengthen supervision and information disclosure of the usage of single-use plastic products. The involvement of local governments would accelerate the deployment of this new business model.

Although we have established a relatively holistic CBA framework of the RTFC project, there are still some uncertainties and factors hardly measured. The platform company may obtain good reputations from the RTFC project which may bring it some social benefits. With the scaling up of the project at other campus, the marginal cost of the platform company may decrease. Therefore, the net benefit of the platform company may be underestimated. Besides, the benefit of consumers may be underestimated, because it includes not only individual benefit but also social benefits for the positive externality of pollution reduction. Last but not the least, regional heterogeneity in socioeconomic development, population size, and geographical location results in large differences in the regional takeaway packaging waste generation in China (Li et al. 2022). Hence, much more local evaluation work was needed to do provide more accurate information for decision-making.

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Data Availability The data are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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