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Research article

Investigating preferences and price sensitivity of incentive-based recycling of household waste in emerging megacities

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ABSTRACT

While the pay-as-you-throw approach is widely adopted, some emerging megacities have successfully implemented incentive-based schemes to encourage residents to participate in waste recycling. A common incentive is rewarding residents based on the value of recyclables (e.g., monetary incentives or accumulated points used for gift exchange). However, monetary incentives are subject to fluctuations in recycling market prices, which may further influence residents' recycling behavior. To evaluate whether such price fluctuations will affect residents' willingness to participate in household waste recycling in emerging megacities, it is crucial to examine residents' sensitivity to the price of recyclables. In this study, we investigated residents' preferences for different incentives and residents' price sensitivity of incentive-based recycling of household waste by building models on preference heterogeneity analysis and price sensitivity measurement (PSM). Analysis results based on first-hand data from two emerging megacities yield several findings. First, residents exhibit a stronger preference for monetary incentives and practical items (e.g., daily necessities and groceries). Second, preferences for reward types vary across emerging megacities (e.g., different preferences shown for entertainment products and subsidies incentives), implying that a one-size-fits-all incentive scheme is not effective among cities. Third, fluctuations in the pricing of recyclables do influence the willingness to participate in recycling. However, it is essential to ensure the price adjustments do not devalue the perceived worth of recyclables. The quantitative analysis suggests that megacities like Shanghai and Chengdu should not reduce the price by over 21.15 % and 13.74 %, respectively. These new findings could provide policy-relevant insights to stakeholders in the household waste recycling industry of emerging megacities.

1. Introduction

As a result of rapid population and economic growth, urbanization and industrialization have led to changes in consumption patterns and population behavior. Waste generation has grown rapidly, posing great challenges to sustainable city management (Lu et al., 2024). According to The World Bank (2018), the global waste volume will reach 2.59 billion tons in 2030 and 3.4 billion tons in 2050. Open dumps, sanitary landfills, and incineration are three primary methods of waste disposal (Xiao et al., 2023), posing serious risks to social and public health and endangering the city ecosystem (Gutberlet and Bramryd, 2025). Practical solutions are needed to mitigate such threats (Ayodele et al., 2018; Zoumpoulis et al., 2024). The European Commission (2015) emphasized the importance of waste reuse and recycling, aiming to effectively utilize resources through comprehensive recycling systems. With the rapid growth in waste production, recycling is of great significance in addressing the increasingly serious threat posed by waste (Yu and Du, 2020). Local policy adjustments are critical to achieving environmental goals (Cerqua et al., 2024). Various incentive measures have been developed to reduce waste generation and promote the recycling and

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utilization of waste (Olatayo et al., 2023), especially in developing countries. Wang et al. (2020) found that incentives or penalties can increase the probability of recycling participation among collectors and recyclers. In many advanced megacities in Europe, the pay-as-you-throw (PAYT) scheme that charges households based on the amount of waste is widely adopted (Valente, 2023). While the PAYT scheme has been successfully implemented in advanced economies, its effectiveness in emerging megacities remains limited due to socio-economic constraints such as lower household incomes, lack of enforcement capacity, and lower environmental awareness (Zhou et al., 2021). For example, in the early days, the PAYT scheme in most Chinese cities introduced indirect charges by combining garbage disposal fees with electricity or utility charges (Welivita et al., 2015). Zhang et al. (2022a) demonstrated that the PAYT scheme can effectively motivate residents to reduce waste production. However, it would be difficult to promote these systems in urban environments with high population density and high frequency of collection and transportation. Even in megacities like Beijing, where its PAYT scheme adopts differential pricing between sorted and mixed waste, the public acceptance rate of such policies remains below 50 % (Zhang et al., 2023).

Incentive-based recycling programs, which employ positive reinforcement rather than penalties, have gained traction as an alternative strategy in some emerging megacities. Incentives can encourage residents to participate in household recycling and strongly influence the types and proportions of recyclables collected (Shan et al., 2020). Wang et al. (2021) proposed that both non-monetary and monetary incentives significantly enhance residents' willingness to participate in recycling. Matter et al. (2015) put forward a model of economic incentives in Dhaka, Bangladesh, which achieved moderate success. Studies have shown that providing sufficient monetary incentives can effectively encourage residents to engage in recycling programs (Ng and Wang, 2017). Meanwhile, Saulītis et al. (2024) demonstrated that monetary interventions can promote pro-environmental behavior, but it is not a decisive strategy on its own. Moreover, due to the intrinsic driving effect of prosocial behavior, excessive monetary incentives may inhibit endogenous prosocial behavior, such as volunteering for waste recycling (Wollbrant et al., 2022). Therefore, in practical application scenarios, more investigation should be conducted to explore suitable incentive levels and implementation methods of incentives to balance the recycling demand and recycling intention of residents with different characteristics. Shanghai implemented an incentive-based recycling policy in 2019 (Yang et al., 2022). The results show that in addition to monetary incentives, exchanging point-based rewards (e.g., gift exchanges) can encourage residents to participate in waste segregation and recycling activities (Govindan et al., 2022). It is necessary to explore the incentive model combining multiple approaches rather than a single economic incentive (Yang et al., 2025), but there is a paucity of existing literature focusing on comprehensive studies on different incentives (such as random prizes, daily necessities, parking coupons, and cash). For these reasons, this study investigated the preferences of respondents with diverse backgrounds for various incentives before discussing the price sensitivity of incentive-based recycling of household waste.

Among various incentives, monetary incentives and their pricing have become an important focus (Ji et al., 2023). Optimizing the pricing of recyclables has the potential to boost residents' enthusiasm and enhance their participation in recycling programs. Pricing has been partially studied and shown to stimulate residents' participation in recycling behavior (Valente, 2023). In different cities, residents have varying perceptions of the price associated with household waste recycling. Factors such as average income and education levels in different cities affect the implementation effectiveness of recycling policies. For example, Bai and Lin (2022) pointed out that in addition to individual characteristics, factors such as knowledge level and degree of publicity promote the willingness to pay for waste segregation. Moreover, capital formation, exports, and urban household consumption were considered the main factors driving solid waste recycling (Huang et al., 2020). For incentive prices related to recycling, policymakers should also consider the heterogeneity of cities (Valente and Bueno, 2019). Therefore, it is crucial to investigate the sensitivity of residents with different social backgrounds to changes in the price of recyclables. The impact of fluctuating prices on residents' recycling willingness and their sensitivity to price changes can be employed to provide insights into designing effective recycling pricing policies.

Investigating residents' sensitivity to the price of recyclables in emerging megacities presents several challenges. First, emerging megacities are undergoing rapid development, but their urban infrastructure and waste management systems are still evolving, and incentive-based recycling management remains in the exploratory phase (Yang et al., 2022; Zhou et al., 2022). Second, residents' low willingness and awareness of recycling make resource recycling inefficient, especially under a poor recycling operation management system (Xiao et al., 2018; Zheng et al., 2024). Third, there is a lack of quantitative analysis on the price sensitivity of monetary incentives, and no well-established framework exists to systematically examine the impact of incentive measures or price fluctuations on residents' recycling willingness. To tackle these challenges and fill the research gaps, this study compares the similarities and differences in residents' recycling attitudes in different emerging megacities under incentive-based recycling policies. Furthermore, residents' price sensitivity regarding incentive-based recycling in different emerging megacities was investigated by building a Price Sensitivity Measurement (PSM) model. Compared with other classical price sensitivity analysis models, such as the Gabor-Granger technique (Gabor and Granger, 1966; Gabor et al., 1970), the Logit model (McFadden, 1974) and Conjoint Analysis (Green and Rao, 1971), the PSM model is capable of identifying consumers' psychological thresholds for pricing, thereby offering a more intuitive and interpretable framework for understanding acceptable price ranges. (Erdmann et al., 2023). The major contributions of this study are summarized as follows:

A. Residents' preferences for recycling incentives were quantitatively investigated. We identified which incentives are more attractive to residents and investigated whether residents from different emerging megacities with various demographics (i.e., ages, education levels, and income levels) have varying preferences.
B. The PSM model was built to quantitatively measure residents' sensitivity to the price of recyclables, which determines a reasonable range for price fluctuations and assists recycling companies in setting reasonable prices for household recyclables.
C. Real-world data from two emerging megacities, namely Shanghai and Chengdu, were collected to examine the regional variations in the effectiveness of incentive-based recycling programs under different recycling policies, offering policy recommendations for governments and recycling companies.

The structure of the article is as follows. Section 2 reviews the related works. Section 3 presents methods. Section 4 analyzes and discusses the results. Section 5 concludes this study.

2. Literature review

2.1. Waste pricing and recycling incentives

Along with urbanization, economic expansion, and residents' rising living standards, the amount of household waste increased dramatically (Chioatto et al., 2023). How to effectively incentivize recycling has become an urgent problem for city development. A series of solutions have been proposed to address this problem worldwide. Various strategies and methods, such as implementing waste collection fees, establishing mandatory regulations, and developing internet-based recycling systems, have been proposed to address the issue of low recycling rates (Gu et al., 2019; Valente, 2023). Many municipalities in the United

States have adopted unit-based pricing as a means of reducing municipal waste generation (Huang et al., 2011). The European Union believes that government regulations, taxes, and funding schemes play a significant role in waste recycling (Malinauskaite et al., 2017). Ng and Wang (2017) found that waste recycling incentive schemes, which rely on individual household incentives and ensure adequate incentive levels and accessibility, are more conducive to associated challenges. However, these strategies in developed megacities may not yield the same results in emerging megacities. Although policy incentives and social norms have a significant impact on residents' segregation behavior (Meng et al., 2024), the effectiveness of these policies depends on institutional maturity, public awareness, and economic conditions. In emerging megacities, recycling infrastructures are underdeveloped, and financial incentives and gifts play a significant role in shaping residents' behavior. For example, empirical analysis of the "new policy" in Shanghai suggested that the incentive system of converting "green points" into cash effectively encourages and promotes residents' participation in waste segregation and recycling activities (Govindan et al., 2022).

Currently, public environmental awareness is weak, and the recycling regulatory framework remains underdeveloped in some emerging megacities, making incentive-based recycling a viable option for these cities (Gu et al., 2019; Liu and Zhang, 2018; Wang et al., 2018). Considering residents' living habits, the absence of immediate rewards for recycling often leads to reduced participation (Zhou et al., 2021). Many forms of rewards can be used for waste recycling incentives, including monetary incentives, sweepstakes, discount coupons and taxes (Wang et al., 2021). However, although economic incentives can improve recycling levels, they may not necessarily lead to an increase in the recycling behavior of the general population (Ling and Xu, 2021). The existing system's supply of recycling services does not match residents' demand, and adjusting the pricing of recyclables according to certain standards can effectively address the imbalance between waste supply and demand (Zhou et al., 2021). As such, establishing reasonable pricing models for recycled household waste is crucial.

Most existing models have been primarily designed from the recyclers' perspective. To respond to economic changes each month, Hsu and Kuo (2019) proposed a floating pricing mechanism by conducting surveys to gather information on recycling, such as the amount of waste, the cost of waste recycling, and the prices of secondary materials. He et al. (2020) established a waste-pricing model between enterprises for different supply-demand relationships. In the recycling process, businesses can reduce recycling costs through market price adjustment mechanisms to achieve sustainable recycling and profit growth (Di Matteo and Guadagno, 2024). The existing research focused on costs but largely overlooked how price fluctuations might influence consumer enthusiasm for recycling. Additionally, rewards and performance improvements have varying effects on incentivizing the behavior of different stakeholders (Zhu et al., 2023). To genuinely foster a culture of recycling among residents, it is essential to explore and understand their price sensitivity concerning recyclables.

Meanwhile, the current pricing system of the recycling market is lagging and unitary. Within the market's incentive-driven recycling systems, companies have established their pricing strategies, leading to a stagnation in recyclable waste pricing (Zhou et al., 2021). The fixed price may not meet customers' willingness to recycle their waste. Since the recycling promotion effect of the incentive measures on residents' recycling behavior changes over time, incentives should be dynamically adjusted, such as modifying the price of recyclables, to continuously encourage residents' participation (Yang et al., 2022; Zhao et al., 2025). However, due to factors such as a limited understanding of population preferences regarding the maximum range of acceptable price changes, dynamic pricing for recyclables over time remains challenging in the industry (Schlosser et al., 2021). This necessitates the investigation of preferences and price sensitivity of incentive-based recycling of household recyclable waste, especially in emerging megacities.

2.2. Data analysis of price sensitivity

Most emerging megacities struggle with underdeveloped recycling systems and operational inefficiencies, where the allocation of resources for waste collection does not consistently align with the demand for recyclable waste collection, leading to dynamic price adjustments (Zhou et al., 2021). The analysis of price sensitivity plays a key role in making recycling strategies (Chen et al., 2024). Residents' sensitivity to the price of recyclables affects the efficiency of recycling. Tang et al. (2021) found that customer price sensitivity affects supply and demand. Ma et al. (2016) studied the sensitivity between the price of direct recycling payment and the environmental awareness of consumers. They found that high environmental awareness and price sensitivity contribute to increasing the recycling volume of enterprises. Existing research generally employs numerical experiments for sensitivity analysis to determine the price sensitivity of household recycling. Yu et al. (2019) analyzed the sensitivity of selling prices through numerical experiments and concluded that when the demand price sensitivity parameters are reduced, the sales price can be appropriately increased. Through numerical experiments, Schlosser et al. (2021) found that when the price of recyclables is low, demand tends to increase, while the profit margin decreases.

However, for the price sensitivity analysis of household waste recycling in the context of emerging megacities, general numerical experimental analysis methods have limitations. For example, there are multiple influencing factors, such as population characteristics, waste categories, and time ranges, affecting price sensitivity, and it is difficult for numerical experimental methods to analyze these factors comprehensively (Chen et al., 2017). Liu et al. (2016) conducted a sensitivity analysis on multi-channel pricing for waste electronic devices, focusing on the proportion of waste electronic device refurbishment. However, this method provided only a theoretical model for single pricing. An analysis of the price sensitivity of incentive-based recycling of household waste can be incorporated into such theoretical models for further pricing settings in practical applications in emerging megacities.

Among the various price sensitivity analysis models, the Gabor–-Granger method is easy to operate, but it does not emphasize the psychological price effect (Wedel and Leeflang, 1998). Although the joint analysis model and the Logit model perform well in behavioral modeling (Jedidi and Zhang, 2002; Zhao et al., 2020), they mostly infer price effects indirectly through consumers' choice behavior. It is difficult to directly capture the psychological price thresholds (Han et al., 2001). The PSM model is easy to operate and intuitive to interpret, which can not only identify the price acceptance range but also deduce the psychological optimal price point and price conflict interval (Erdmann et al., 2023). This makes it more suitable for rapidly evaluating the design of incentive policies in the early stage. For example, Dong et al. (2020) built a PSM model to measure the price preference for pure electric vehicles in urban households. Lan et al. (2020) employed the PSM model to estimate the willingness of different households or individuals to pay for better air quality. Asensio et al. (2024) used the PSM model to assess the impact of housing policies on energy efficiency in low- and middle-income communities. Such a model not only identifies the optimal price but also provides a reasonable price range (Cho and Kim, 2016).

Despite the widespread application of the PSM model in various domains, especially since Zhang et al. (2022b) employed it to control for self-selection bias when investigating the impact of payment methods on willingness to pay, the adoption of PSM models for analyzing price sensitivity in incentive-based recycling remains limited. This gap presents an opportunity for further exploration and application of PSM in understanding and optimizing recycling pricing strategies. To address this gap, this study examines the price sensitivity of residents' recycling behaviors in emerging megacities. By developing an integrated analysis framework, we aim to provide actionable insights for policymakers and recycling companies to enhance participation through adaptable incentive mechanisms.

3. Methods

3.1. Analysis framework

An integrated analysis framework for incentive-based recycling and residents' price sensitivity to recyclables is shown in Fig. 1. The framework covers the entire analysis process, including a pre-investigation through a formal questionnaire on residents' attitudes toward incentive-based recycling and their reactions to the price of recyclables changes, as well as the data analysis of the methods. This study analyzes the data collected to answer the following questions.

A. What is the attitude of residents in emerging megacities toward incentive-based recycling and dynamic pricing of recyclables?
B. Do specific groups of residents favor monetary incentives? Beyond monetary incentives, what types of incentives are favored by different demographic groups within emerging megacities?
C. Are residents sensitive to changes in the price of recyclables? If so, what is a reasonable range for such price fluctuations?

3.2. Data collection and processing

The questionnaire design process and related details are provided in Supporting *Information A* and Supporting *Information B*, respectively. The pre-survey was conducted, and its results were used to test the consistency and reliability of the questionnaire. The *Cronbach's* α coefficient (Bland and Altman, 1997) was employed to test for reliability, ensuring the internal consistency of the questionnaire. The Kaiser-Meyer-Olkin (*KMO*) coefficient and Bartlett's Sphericity test (Ugulu, 2015) were used to assess whether the collected data were suitable for further data analysis.

In formal investigations, the variance (s^2) of the pre-survey and design effect are used to estimate the required sample size, to reach the required level of statistical power under multi-stage sampling (Donner et al., 1981):

$$n = \frac{\left(\mu_{1-\alpha/2}\right)^2 \frac{s^2}{d^2}}{1 + \frac{1}{N - \left(\mu_{1-\alpha/2}\right)^2 \frac{s^2}{d^2}} \left(\left(\mu_{1-\alpha/2}\right)^2 \frac{s^2}{d^2} - 1 \right)} \quad (1)$$

where N is the number of total households in the targeted city; μ is the cumulative distribution function value for a given confidence level. For example, if μ is 1.96, this corresponds to a 95 % confidence level (i.e., $\alpha = 0.05$); d is the limit of error (i.e., the margin of error allowed in the estimate), which is usually set as $\pm$ 5 % (i.e., $d = 0.05$).

The design effect coefficient q is used to adjust for the increase in variance caused by factors like stratification, clustering, or unequal weighting in the sampling process:

$$q = 1 + \rho\,(M - 1) \quad (2)$$

where ρ is the correlation coefficient between sample units, which is used to measure the characteristics of intra-group homogeneity, and M is the sample group size. Finally, the sample size needed is equal to n multiplied by q.

After determining the sample size, multi-stage sampling was conducted using the sampling method proposed by Rai (2020). To ensure the representativeness of the samples, a proportional allocation was applied in the first stage based on population size to cover various districts in a megacity (Sohil et al., 2022). In the second stage, communities were randomly selected to be the secondary sampling unit. In the third stage, community residents were selected by voluntary sampling. In addition, the demographic distribution (e.g., gender, age, and education level) of the responses received was compared with official census statistics to verify the representativeness of the samples. Similar to the pre-survey, data obtained from formal surveys also must pass the reliability and validity tests, ensuring that the data are suitable for further

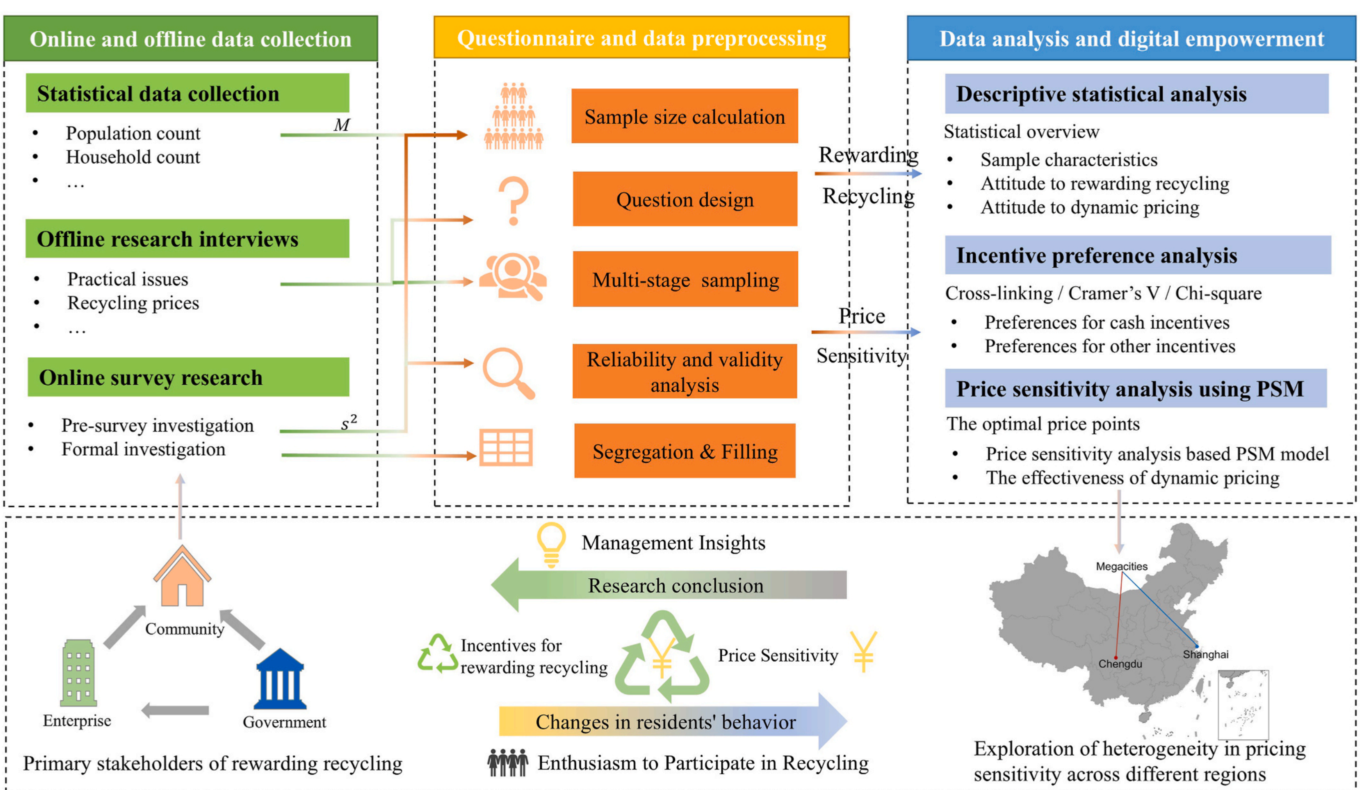

Fig. 1. The integrated analysis framework of residents' preferences and price sensitivity for incentive-based recycling.

statistical analysis.

3.3. Data analysis

3.3.1. Descriptive statistics

This section focuses on descriptive statistical analysis of the residents' attitudes toward incentive-based recycling and dynamic pricing of recyclables. The questionnaire results are plotted and analyzed based on the distribution of respondent characteristics, residents' behavior toward household waste segregation and recycling, sample differences across cities, and residents' willingness to segregate and recycle waste.

The survey's targeted demographic details, such as gender, age, and educational background of the respondents, have been employed to validate the representativeness of the sample distribution. The survey and analysis of urban residents' attitudes toward incentive-based recycling and household waste segregation were carried out, mainly including preferences for different forms of incentive-based recycling, attitude toward incentive-based recycling, and their willingness to participate. Jia et al. (2023) proposed that factors such as attitude and perceived behavioral control would influence residents' willingness to recycle, while Govindan et al. (2022) have also demonstrated significant relationships between these factors and residents' willingness to participate in waste segregation and recycling. The relevant charts are drawn to illustrate the effect of incentives on waste recycling. After charting the terrain of attitudes toward incentive-based waste recycling, the attitudes of residents toward the pricing fluctuation of monetary incentive-based recycling were further investigated. This includes the effect of price change on residents' participation in household waste recycling and their attitudes toward dynamic recycling pricing.

3.3.2. Preference heterogeneity analysis

By investigating these discrepancies alongside other socio-economic factors, it is possible to implement more targeted interventions aimed at improving the performance of recycling systems (Firmansyah et al., 2024). The degree of residents' preference for different types of rewards is illustrated using the data to analyze whether significant differences exist between residents' preferences for monetary incentives and other incentive types (e.g., consumption coupons, practical items, spiritual awards, entertainment products, and subsidies). Besides, we also investigated whether there are significant differences in the preferences for the same incentive method among different groups with varying characteristics (such as age and education level).

The cross-tabulation method (Byrne and O'Regan, 2014) is used to summarize the distribution of incentive preferences across these subgroups under different categories, such as ages and income levels. Hypotheses are made based on the analysis results of the cross-tabulation tables. For statistical testing, the chi-square (χ^2) test of independence is applied to assess whether the observed distribution of rankings differs significantly from the expected distribution under the null hypothesis. For example, after showing the distribution of incentive preferences among residents of different ages in a cross-tabulation, to test whether there are significant differences among various age stages of respondents regarding the preference ranking of monetary rewards, the hypotheses are set as.

H_0. There is no statistically significant difference in the ranking of monetary incentives across age groups.

H_1. There is a statistically significant difference in the ranking of monetary incentives across age groups.

The chi-square test statistic is calculated as:

$$\chi^2 = \sum_{i=1}^{k} \frac{(A_i - E_i)^2}{E_i} = \sum_{i=1}^{k} \frac{(A_i - np_i)^2}{np_i} \quad (i = 1, 2, 3\cdots, k) \tag{3}$$

where A_i denotes the number of observed frequencies of the i-th category, referring to the number of occurrences recorded in the sample for that category. E_i is the expected frequency, which represents the theoretically expected count under the null hypothesis and is computed as $E_i = np_i$, where n is the total sample size, and p_i is the theoretical probability of the i-th category occurring. The parameter k indicates the total number of categories into which the data is classified.

A significance level of 0.05 is used. If $P < 0.05$, the null hypothesis is rejected, indicating a statistically significant difference between groups. All statistical analyses are performed using the SPSSPRO online software (https://www.spsspro.com/). The related test results enable us to identify population subgroups that exhibit differentiated preferences for recycling incentives, which is useful for designing tailored incentive schemes.

3.3.3. Price sensitivity analysis via PSM modeling

The PSM modeling is based on two assumptions. First, individuals can identify price points that they subjectively consider "too low," "acceptable", and "too high". Second, optimal pricing can be informed by the distribution of these perceptions across individuals. Unlike traditional price-demand models, the PSM model built in this study does not estimate price elasticity but rather identifies psychological tipping points that reflect recycling participation intention. In this study, the PSM model is built to analyze residents' sensitivity to recyclable prices and to obtain a reasonable range for price fluctuations. The specific steps of the modeling are as follows.

Step 1: Data collection

In this step, by asking a respondent four questions about a product or service, the data obtained can be processed to derive different target prices. To assess the overall sensitivity of residents to changes in the price of recyclables, a price list is created by referencing the prices at local recycling points in the city, providing respondents with an intuitive price reference. Additionally, the fluctuating ratio of the price of recyclables is determined based on the historical market prices of local recyclables from the most recent year, resulting in a gradient table of price fluctuations. Four options are set for each gradient price, as shown in Table 1.

Step 2: Data processing

For the collected data, firstly, invalid responses (e.g., inconsistent ordering of prices) are excluded. Subsequently, preprocessing steps such as data imputation are conducted (for example, residents who believe that 'Price 2' (at a higher price level) is cheap, will also believe the lower price 'Price 1' (at a lower price level) is cheap, and vice versa). After summarizing all the attitudes to a series of increasing price levels (i.e., gradient pricing) from each valid respondent, we can obtain the distribution of the number of respondents holding the four distinct attitudes

Table 1
Attitude options for the current gradient price.

Option	Attitude
Type A	The price of recyclables is so low that it is not worth selling to the recycling site.
Type B	The price of recyclables is low but still acceptable, and the respondent is willing to sell to the recycling site.
Type C	The price of recyclables is high, and the respondent is willing to sell to the recycling site.
Type D	The price of recyclables is very high, making it naturally willing to sell to the recycling site.

Note: Based on one questionnaire received, when the price of recyclables decreases by 20.00 %, the respondent's attitude is Type A. When the price of recyclables decreases by 10.00 %, the attitude is Type B. When the price of recyclables increases by 30.00 %, the attitude is Type C. When the price of recyclables increases by 50.00 %, the attitude is Type D.

listed in Table 1 across different price levels. This is regarded as price-consciousness. More details are shown in Table S1 (Supporting *Information C*), which illustrates the link between price levels and perception categories, along with the aggregation method. For each kind of consciousness, its cumulative distribution can be calculated from Table S1 and S2 (Supporting *Information C*). Table S2 shows the cumulative percentage of respondents with each consciousness at 'Price level *j*'.

Step 3: Key point calculation

When the cumulative distributions of each kind of consciousness are plotted in a line graph, the two 'cheap' lines cross the two 'high' lines. And the four intersections are the key price points of the PSM model.

A. **Point of marginal cheapness (PMC):** PMC is the intersection of "too cheap" and "relatively expensive", which means that at this point, the proportion of respondents who think it is too cheap and relatively expensive is the same. If the price is below this tipping point, it is "too cheap".
B. **Indifference price point (IPP)**: IPP is the intersection of "relatively cheap" and "relatively expensive", which is the price that respondents find ambiguous.
C. **Point of marginal expensiveness (PME):** PME is the intersection of "relatively cheap" and "too high". If the price is above this tipping point, it is considered "too high", and respondents generally perceive the price as higher than the value of the product itself.
D. **Optimal Price Point (OPP):** OPP is the intersection of "too cheap" and "too high". It is considered the best price point because it balances high price and product value.

The price range between PMC and PME falls within an acceptable range. The OPP, rather than the IPP, is generally considered the best price point.

4. Case study

4.1. Case statement

In the two emerging megacities, Shanghai stands out as a pioneer city for waste segregation and recycling in China (Zhou et al., 2021). Chengdu, although less developed than Shanghai, is gradually implementing waste segregation and recycling initiatives (Miao, 2021). Shanghai, a coastal megacity leading in waste segregation and recycling policy advocacy, has gradually demonstrated strong waste management capabilities, being consistent with its urban positioning under recent policy frameworks. As an emerging megacity in the inland region of China, Chengdu has been actively pursuing the "Park City" development concept (Wu et al., 2024). However, in comparison to Shanghai, Chengdu initiated urban waste segregation and recycling management later, and the overall societal implementation remains relatively low. Shanghai and Chengdu have been selected to represent the regional differences between China's coastal and inland areas, allowing for an analysis of the effectiveness of waste recycling policies in varying geographical, economic, and cultural contexts. Such a comparison demonstrates the efficacy of the modeling approach and provides potential managerial insights that can be applied to other emerging megacities. To support this comparison, Table 2 presents key demographic and waste-related statistics in Chengdu and Shanghai. These statistics help contextualize the two megacities' recycling environments, including population scale, density, number of households, land area, and waste generation volume. This data provides background information for analyzing residents' recycling behaviors and their price sensitivities.

Table 2
Demographic and waste statistics in Chengdu and Shanghai.

Comparison dimension	Chengdu[a]	Shanghai[b]
Resident population (10^3)	21268.0	24758.9
Population density (inhabitants/km^2)	1483.6	3905.0
Number of households (10^3)	5843.4	5730.5
Land area (km^2)	14335.0	6340.5
Waste generation[c] (10^6 tons)	6.86[d]	11.29

Notes: Data are from the year 2022, which aligns with the incentive-based recycling system in operation.
[a] Chengdu Municipal Statistics Bureau.
[b] Shanghai Municipal Statistics Bureau.
[c] Only household waste is included.
[d] Chengdu Municipal Management Committee.

4.2. Pre-survey analysis

Surveys were conducted in both Shanghai and Chengdu to explore the dynamics of monetary incentive-based recycling. In the pre-survey, 157 valid responses were collected. In the formal investigation, over 1,000 questionnaires were distributed, with 645 valid responses collected. The *Cronbach's α* coefficient is employed to test the internal consistency of the questionnaire's 17 scale items in the two emerging megacities, Shanghai and Chengdu. The *Cronbach's α* values are calculated as 0.837 and 0.884, respectively, indicating high reliability and internal consistency. The *KMO* coefficient and *Bartlett's test of Sphericity* are employed to test the validity of data from Shanghai and Chengdu for analysis. The *KMO* values of the questionnaires from the two emerging megacities are 0.893 and 0.773, respectively, and the significance levels of *Bartlett's test of Sphericity* are both less than 0.001, indicating the data have good structural validity and are suitable for factor analysis.

4.3. Results and discussion

4.3.1. Results of data statistics

A total of 645 valid questionnaires (307 samples from Chengdu and 338 samples from Shanghai) were collected after the pre-survey, and basic information such as gender, age, and education level of respondents was also collected. The demographic characteristics of the respondents were compared with census data from Shanghai and Chengdu. The sample structure shows close alignment with the official distributions, suggesting that the collected samples are representative. The sample characteristics are summarized in Table S3 and illustrated through a series of pie charts in Fig. S2 (Supporting *Information D)*. These representations cover key demographic dimensions — including gender, age, education level, and household income per capita — providing an intuitive overview of the sample composition.

(1) Preference toward incentive-based recycling

Regarding the preference related to incentive-based recycling, questions include respondents' willingness to participate in incentive-based recycling, preferences for different types of incentives, and reasons for not participating in incentive-based recycling.

A. **Willingness to participate in incentive-based recycling.** Most respondents in both Chengdu (86.32 %) and Shanghai (84.02 %) expressed willingness to participate in incentive-based recycling and receive compensation. Notably, a higher percentage of Shanghai respondents (12.43 %) indicated their unwillingness to participate, compared to Chengdu (4.23 %). A part of the population remained undecided, with 9.45 % in Chengdu and a mere 3.55 % in Shanghai. Overall, Chengdu respondents were more willing to participate in incentive-based recycling.
B. **Preferred incentives for incentive-based recycling.** Fig. 2 shows the ranking results of respondents' preferences for different types of

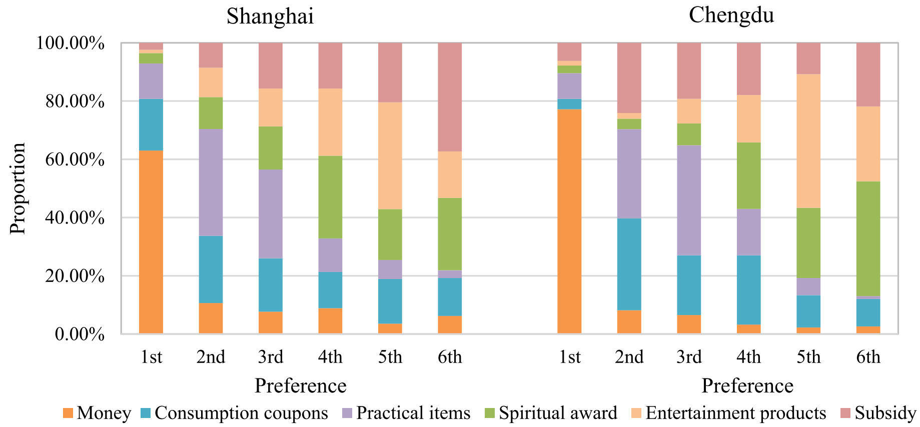

Fig. 2. The comparison of respondents' preference ranking for incentive mechanisms. Note: The corresponding incentive ranking question (i.e., Question 5 in the questionnaire) is given in *Supporting Information B*.

incentives, including "money", "consumption coupons" (e.g., supermarket vouchers), "practical items" (e.g., groceries and stationery), "spiritual awards" (e.g., green energy in the Ant Forest (Zhang et al., 2020)), "entertainment products" (e.g., concert and cinema tickets), and "subsidy" (e.g., utility subsidy and parking allowance). In Fig. 2, the orange segment of the 1st bar represents the percentage of respondents who selected "money" as the most attractive incentive. Most respondents regarded "money" as the most attractive incentive, with a higher percentage of Chengdu respondents (77.20 %) ranking it first compared to Shanghai respondents (63.02 %). The purple part is mainly distributed in the 2nd and 3rd bars, which means most respondents ranked "practical items" as the second or the third attractive incentive. More respondents in Shanghai ranked "practical items" second (36.69 % in Shanghai and 30.62 % in Chengdu), while more Chengdu respondents ranked it as the third (30.47 % in Shanghai and 37.79 % in Chengdu). Both respondents in Shanghai (36.69 %) and Chengdu (45.93 %) intended to rank "entertainment products" as the fifth most attractive incentive. As seen for the 6th bar, respondents from Shanghai intended to rank "subsidy" as the least attractive incentive (37.28 %), while Chengdu's respondents intended to rank "spiritual awards" as the last (39.41 %). In addition, even though "consumption coupons" is predominantly ranked second among respondents from the two emerging megacities, it is evident that more respondents in Shanghai ranked it first than those in Chengdu.

C. **Reasons for not participating in incentive-based recycling.** Fig. 3 shows the reasons for respondents not participating in recycling. A majority (68.49 % in Chengdu and 63.64 % in Shanghai) cited the absence of convenient incentive-based recycling channels as a deterrent. The second most common reason in both megacities is inadequate public awareness, though more pronounced in Chengdu

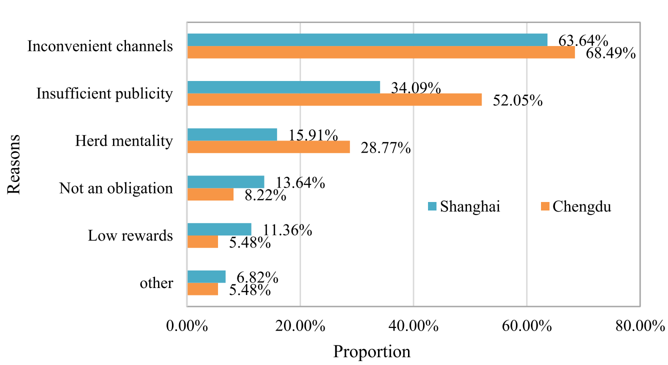

Fig. 3. The reasons for not participating in incentive-based recycling.

(52.05 %) compared to Shanghai (34.09 %). Overall, the presence of accessible incentive-based recycling channels emerges as a vital determinant of respondents' decisions to engage in such incentive-based programs. As noted by Struk (2017) and Zhou et al. (2021), the ease of participation significantly influences recycling behavior. Moreover, the level of community awareness and publicity about incentive-based recycling in Shanghai is higher than that in Chengdu, where further improvement is still needed.

(2) Attitude toward dynamic pricing of monetary incentive-based recycling

A similar method is used to analyze the attitudes of respondents in Chengdu and Shanghai toward the dynamic pricing of monetary incentive-based recycling.

A. The incentive effect of monetary reward on waste recycling. Fig. 4 shows the distribution of respondents' intentions toward recycling based on monetary incentives. In both megacities, most respondents expressed a positive inclination toward recycling, whether or not monetary incentives were involved (both over 60.00 %). This indicates that respondents naturally have a positive attitude toward waste recycling. As noted by Gilli et al. (2018), intrinsic motivation is strongly associated with recycling behavior, and residents actively participate in recycling even in the absence of external incentives.

Some residents would participate in recycling if they could get a reward. Shanghai respondents (33.14 %) showed higher enthusiasm for recycling than Chengdu respondents (22.80 %). Among a smaller proportion of respondents, the amount of remuneration still influenced their willingness to participate in waste recycling, with a higher proportion among Chengdu respondents (13.36 %) than Shanghai respondents (5.03 %). This phenomenon suggests that the willingness to recycle among Shanghai respondents is less sensitive to the value of the incentive. On the one hand, as policies become institutionalized over

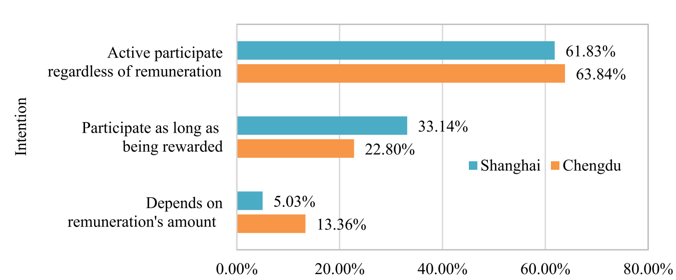

Fig. 4. Distribution of respondents' recycling intention with a monetary incentive.

time, the effectiveness of incentives may gradually reduce, and daily "habit" is becoming the primary driver of sustained recycling behavior (Li et al., 2021). On the other hand, residents in regions with different economic development levels exhibit varying degrees of environmental awareness (Yu, 2014). Considering regional differences in the policy implementation duration and socioeconomic development, pricing and incentive policies should be tailored to local contexts and implemented with precision.

B. Views toward dynamic pricing of recyclable waste. Fig. 5(a) shows the distribution of respondents' views on conducting dynamic pricing for recycling. Respondents from Chengdu and Shanghai who supported dynamic pricing account for 92.83 % and 82.25 % respectively, indicating the feasibility of implementing dynamic pricing in both megacities. Fig. 5(b) shows that among respondents with the Type I view (who thought dynamic pricing was necessary), some found frequent price adjustments unacceptable, with a higher proportion in Chengdu (31.23 %) than in Shanghai (16.55 %). This suggests a nuanced view toward dynamic pricing: balancing the potential financial benefits against the desire for pricing stability, which means residents expect the benefits of dynamic pricing, but they do not like the hassle of high-frequency price adjustments.

4.3.2. Results of preference heterogeneity analysis

(1) Cross-tabulation analysis results

Through cross-tabulation analysis, the ranking proportion of monetary incentives among different age groups is depicted in Fig. 6. In both Shanghai and Chengdu, respondents tended to exhibit similar preferences for monetary incentives within each city. In Shanghai, most residents under 60 either ranked monetary incentives as 1st or 2nd, while in Chengdu, more than 70.00 % of respondents in each age group ranked monetary incentives as 1st. However, there are significant differences in ranking results among different cities. For example, fewer residents from Shanghai ranked monetary as 1st (at least 50.00 %) than those in Chengdu (at least 70.00 %). Therefore, it is assumed that the age of respondents does not significantly influence the preference ranking for monetary incentives, whereas the region (city) does significantly affect it. The hypothesis testing results related to these assumptions are given as follows.

(2) Hypothesis testing results

As for the difference among respondents' age groups regarding the preference for monetary incentives in Shanghai, the calculated chi-square value is 22.2 ($P = 0.864 \gg 0.05$), with no evidence to reject the null hypothesis (H_0). This suggests that the differences in age-related monetary incentive preferences in Shanghai are not statistically significant. As for Chengdu, the calculated chi-square value is 27.2 ($P = 0.613 \gg 0.05$), thus the null hypothesis (H_0) cannot be rejected, indicating a similar finding with Shanghai.

Similarly, differences between various types of incentives and represent characteristics (age, region, education level, and family income) are analyzed and tested. Then we have the following findings.

A. **Ages:** Beyond the monetary incentives, in Shanghai, the preferences of respondents for "subsidy" vary significantly across different age groups, with the 30–49 age group showing a stronger preference. In Chengdu, there are significant differences in the preference for "spiritual awards" or "entertainment products" among different age groups, with younger individuals showing a greater preference. Age has no significant effect on the preference for other types of incentives in either city.
B. **Regions:** Regarding the comparison between Shanghai and Chengdu, respondents' preferences for incentives including "money", "practical items", "spiritual awards", "entertainment products", and "subsidy" are significantly different in the two cities. However, there is no significant difference between the two emerging megacities in the residents' preferences for "consumption coupons".
C. **Education level:** There are significant differences in respondents' preferences for "spiritual awards" and "subsidy" among different education groups in Shanghai. There are significant differences in respondents' preferences for "spiritual awards" and "consumption coupons" among different education groups in Chengdu. The education levels have no significant effects on the preferences for other types of incentives in either city.
D. **Family incomes:** There are significant differences in respondents' preferences for "money", "spiritual awards", and "subsidy" among different family income groups in Shanghai. There are significant differences in respondents' preferences for "money", "practical items", "subsidy", and "consumption coupons" among different family income groups in Chengdu. Family incomes have no significant effect on preference for other types of incentives in either city.

These findings contribute to a deeper understanding of how incentive preferences vary across demographic and regional dimensions in emerging megacities. The results show that respondents in Shanghai and Chengdu exhibit significant differences in incentives preferences compared to factors such as age and education levels. This may be attributed to the greater influence of differences in policy implementation and infrastructure provisions between megacities on household recycling behavior, relative to individual demographic characteristics (Halvorsen, 2012; Kinnaman, 2006). These results highlight the need for policymakers to develop context-specific incentive mechanisms that take into account the varying levels of infrastructure and behavioral

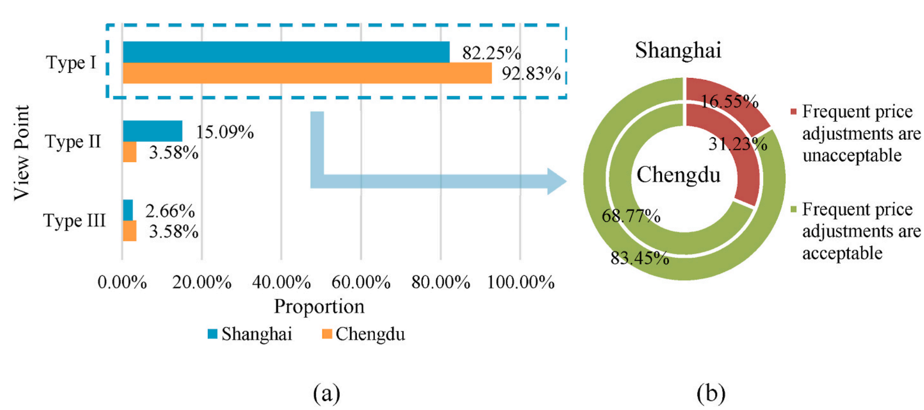

Fig. 5. Views toward dynamic pricing of recyclable waste. Note: (a) Whether it is necessary to conduct dynamic pricing (Type I: Necessary; Type II: Not necessary; Type III: I have no idea). (b) Among Type I, whether frequent pricing adjustments are acceptable.

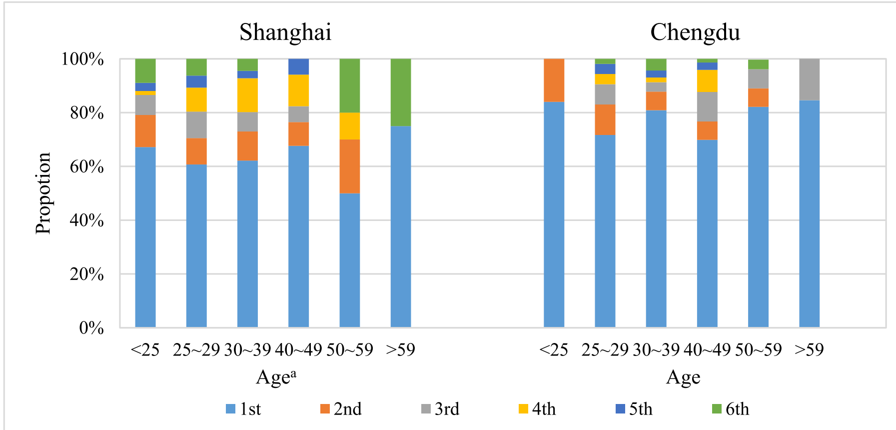

Fig. 6. The ranking proportion of monetary incentives among different age groups. Note: [a] a young group (aged 29 and below), a young-adult group (aged 30–39), a middle-aged group (aged 40–49), a senior group (aged 50 and above). The corresponding incentive ranking question (i.e., Question 5 in the questionnaire) is shown in *Supporting Information B*.

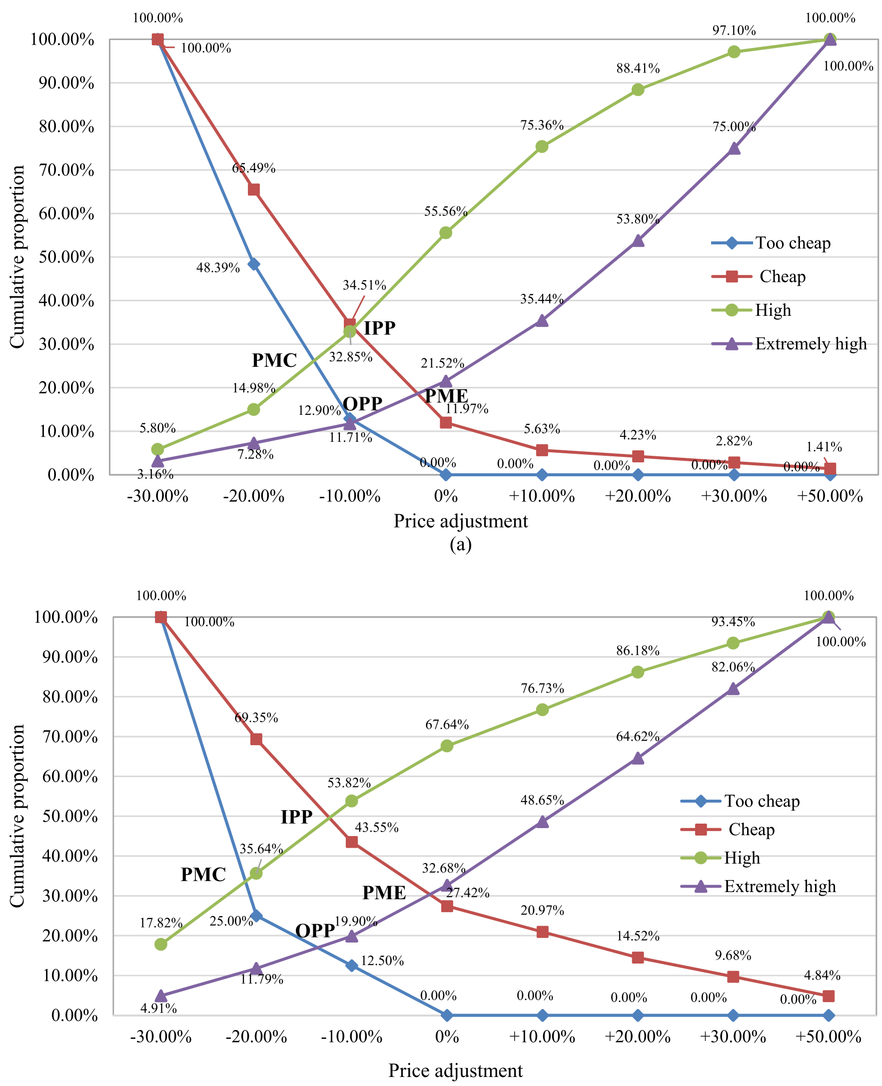

Fig. 7. Consciousness cumulative percentage line chart. (a) Chengdu and (b) Shanghai.

characteristics of residents across different megacities.

4.3.3. Results of price sensitivity analysis

The line charts shown in Fig. 7 are based on the “consciousness cumulative percentage table”, as described in Section 3.3.3. The horizontal coordinate in Fig. 7 represents the price changes, while the vertical coordinate represents the cumulative proportion of respondents. The intersection points in the chart represent the four recommended price points. In Fig. 7, with the increase in prices, the cumulative percentage of respondents who think the price of recyclables is ‘high’ or ‘extremely high’ increases; as prices fall, the cumulative percentage of respondents who find recyclables ‘cheap’ or ‘too cheap’ increases.

For the two emerging megacities, when the price of recyclables reaches the ‘original price’, no respondent thinks the price is ‘too cheap’. However, when the price increases by 50.00 %, there are still 1.41 % and 4.84 % of respondents who think the price is low in Chengdu and Shanghai, respectively. When the price of recyclables decreases by 30.00 %, there are 5.80 % and 17.82 % of respondents who think the price is ‘high’, and 3.16 % and 4.91 % of them regard it as ‘extremely high’ for the two emerging megacities. When the price increases by 30.00 %, most respondents (97.10 % and 93.45 %) think the price is ‘high’, and 75.00 % and 82.06 % of respondents think the price is ‘extremely high’ in Chengdu and Shanghai, respectively.

Fig. 8 shows the overlap of the four recommended price points for recyclables in Shanghai and Chengdu calculated by the PSM model. In general, respondents in Shanghai can accept a wider price range for recyclables than those in Chengdu. In Chengdu, when the price drops by more than 13.74 % (judged by the PMC), respondents feel that the price is too low and choose not to sell recyclables to a recycling company. In other words, a drop of 13.74 % is the largest price adjustment that respondents in Chengdu can accept. A price drop of 9.63 % is the indifferent price (judged by the IPP), at which point the proportion of respondents who feel that the price is relatively high is equal to the proportion of respondents who feel that the price is relatively low (both account for 33.68 %). A price drop of 8.90 % marks the OPP, at which point respondents feel that the price will not be too cheap or too high. In Shanghai, the price of recyclables decline of 21.15 % is the lowest price acceptable to respondents (judged by the PMC), and when the price drop is greater than 21.15 %, respondents in Shanghai feel that the price is too low, so they choose not to sell the recyclables. A price drop of 12.34 % marks an IPP, at which the proportion of respondents who feel that the price is relatively high is equal to the proportion of respondents who feel that the price is relatively low (both account for 49.57 %). If the recyclable price is higher than the new price (i.e., the one reduced by 1.82 % based on the existing price), respondents in Shanghai will feel the price is still high (judged by the PME). However, offering a higher recycling price reduces the interests of businesses and is difficult to achieve by recycling companies. A price drop of 13.59 % makes the OPP, at which respondents feel the price will not be too cheap or too high.

Compared with previous PSM-based studies in green behavior contexts—such as air-quality valuation or electric-vehicle pricing (Dong et al., 2020)—we find similar optimal price-point estimation patterns. However, the acceptable price range observed in our study is narrower, particularly in Chengdu, suggesting that in the settings of low-value recyclables, residents demonstrate heightened price sensitivity (Messina et al., 2023; Li et al., 2024). Furthermore, the findings are consistent with the study by Lu and Wang (2022), which highlighted price as a key factor influencing public support for recycling policies. These results reinforce the notion that pricing remains an effective mechanism for motivating recycling participation in emerging megacities.

5. Conclusions and policy recommendations

This study investigated respondents’ attitudes, preferences, and price sensitivity for incentive-based recycling in two emerging megacities. The key quantitative findings based on the investigation of real-world cases from Shanghai and Chengdu offer several managerial insights and policy recommendations regarding incentive-based household waste recycling:

Firstly, over 80.00 % of the respondents in the two megacities support incentive-based recycling. Although Chengdu implemented the waste segregation and recycling policy several years later than Shanghai, respondents’ recycling willingness is equal to or even higher than that in Shanghai. It is recommended that other emerging megacities that have not yet fully implemented waste segregation actively initiate pilot programs for incentive-based recycling. Simultaneously, supportive mechanisms—such as public awareness campaigns and

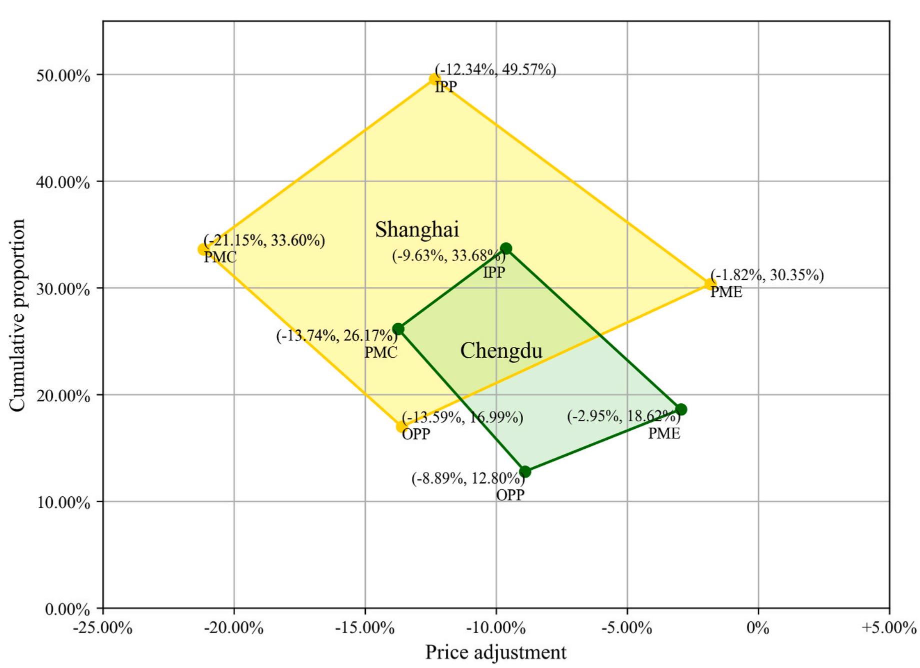

Fig. 8. Price range identification for Shanghai and Chengdu based on PSM modeling.

policy training systems—should be established to enhance public understanding and encourage participation.

Secondly, the two most popular types of recycling incentives are “money” and “practical items” among the respondents in both emerging megacities. When designing incentive mechanisms, a combined “cash + goods” model can be adopted, allowing residents to choose their preferred reward type. This flexible approach is likely to improve participation rates and maintain long-term engagement.

Thirdly, respondents with different demographic characteristics have various preferences for incentives. For example, the value of remuneration affects respondents’ participation rate in recycling, and its impact on Chengdu respondents is greater than that of Shanghai respondents. Young respondents in Chengdu show a preference for “entertainment products” and “spiritual awards”, whereas those aged 30–49 in Shanghai are more inclined toward “subsidy”. Governments or recycling operators should implement incentive strategies based on a combined “age + region” framework. For example, entertainment-related rewards or cultural points could be introduced for the younger population in Chengdu, while additional living subsidies could be offered to middle-aged groups in Shanghai to enhance the responsiveness and engagement of different demographic segments.

Fourthly, although the majority of respondents (82.25 % in Shanghai and 92.83 % in Chengdu) support dynamic pricing of recyclables, some individuals are sensitive to frequent price changes. For example, 16.55 % of supporters in Shanghai and 31.23 % of supporters in Chengdu cannot accept frequent price adjustments. It is thus recommended to limit the frequency of price adjustments, for instance, no more than three times per month, and to announce changes in advance to improve transparency and manage public expectations. In addition, dynamic pricing can be optimized in alignment with holidays or seasonal variations to help stabilize recycling volumes.

Fifthly, the analysis of the price sensitivity of incentive-based recycling of household waste suggests that a price reduction of approximately 13.74 % marks the lowest acceptable threshold for Chengdu respondents and a 21.15 % reduction for Shanghai. Optimal pricing points have been identified at approximately 8.89 % reduction for Chengdu and 13.59 % reduction for Shanghai. Accordingly, it is recommended that megacities conduct pilot surveys before the policy implementation, which can assess residents’ price sensitivity and use this information to establish a rational “price fluctuation range” for household waste recycling.

The study investigated the group behavior of respondents participating in recycling and their price sensitivity to recyclables. In the future, it will be useful to consider developing dynamic pricing strategies for each specific category of recyclables. To achieve such a goal, substantial real-world recycling data are needed. With the increasing adoption of smart recycling devices and new information technologies across various emerging megacities, the accessibility of large-scale recycling data is likely to improve. A similar approach could be applied to other cities for comparison, providing better mapping and insights into how socioeconomic and demographic variables influence behavior and responses to incentive recycling.

CRediT authorship contribution statement

Wenjing Xu: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Xueqian Lyu:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Yu Chen:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation. **Jieyu Zhou:** Writing – review & editing, Validation, Supervision, Formal analysis, Conceptualization. **Shuyi Sun:** Writing – review & editing, Validation, Formal analysis. **Yee Van Fan:** Writing – review & editing, Funding acquisition, Formal analysis. **Huijuan Dong:** Writing – review & editing, Formal analysis. **Peng Jiang:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2025.126595.

Data availability

Data will be made available on request.

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