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ANALYSIS OF PACKAGING RECYCLING PATTERNS USING MATHEMATICAL MODELING

Análisis de patrones de reciclaje de empaques con modelación matemática

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Key words: Express packaging, recycling, mathematical modeling, optimization.

ABSTRACT

With the rapid development of online shopping platforms, China's express industry has embraced explosive growth, but, at the same time, numerous significant social problems also occur. Regarding the problems, how to deal with the large number of packaging from express delivery has become a growing concern for governments, e-commerce platforms, express enterprises, and ordinary consumers. Abandoned express packaging increases the cost of express enterprises and aggravates the environmental burden. Therefore, based on previous research, this paper tried to establish two recycling models and analyze their benefits through mathematical model deduction. By comparing the results, this paper aimed to set up a model to maximize express enterprises' revenue from recycling packaging. According to the results, regardless of the governmental subsidies, the revenue from recycling packaging was bound up with the environmental awareness of residents and the recycling price. Through the comprehensive analysis, the author hopes that the results could provide express enterprises with the option of the best recycling model in different contexts and help governments formulate more appropriate recycling policies.

Palabras clave: embalaje exprés, reciclaje, modelación matemática, optimización.

RESUMEN

Con el rápido desarrollo de las plataformas de compras en línea, la industria de los envíos exprés de China ha alcanzado un crecimiento explosivo pero, al mismo tiempo, también ocurren numerosos problemas sociales significativos. En cuanto a los problemas, cómo hacer frente a la gran cantidad de envases de la entrega exprés se ha convertido en una creciente preocupación para los gobiernos, las plataformas de comercio electrónico, las empresas y los consumidores comunes. El embalaje exprés abandonado aumenta el costo de las empresas de correo urgente y agrava la carga ambiental. Por lo tanto, con base en investigaciones anteriores, este trabajo trató de establecer dos patrones de reciclaje y analizar sus beneficios a través de la deducción de modelos matemáticos. Al comparar los resultados, este documento tuvo como objetivo establecer un patrón para maximizar los ingresos de las empresas de mensajería rápida procedentes del

reciclaje de empaques. Según los resultados, independientemente de los subsidios gubernamentales, los ingresos procedentes del reciclaje de empaques están ligados a la conciencia ambiental de los residentes y al precio del reciclaje. A través del análisis exhaustivo, el autor espera que los resultados puedan proporcionar a las empresas la opción del mejor patrón de reciclaje en diferentes contextos y ayudar a los gobiernos a formular políticas de reciclaje más apropiadas.

INTRODUCTION

With the rapid development of online shopping platforms, the business volume of China's express delivery industry has grown rapidly (Hayashi et al. 2014). In the first half of 2020, the express enterprises across China have a total business volume of 33.88 billion pieces, a year-on-year increase of 22.1%, according to the State Post Office. However, the explosive growth of China's express industry has also caused many significant social problems, among which, how to deal with the large number of express packaging has become a growing concern for governments, e-commerce platforms, express enterprises and ordinary consumers (Chen 2016).

Since 2015, the State Post Office has issued the Report on the Development Status and Trends of China's Green Express Packaging Industry. The report provides statistics on the annual consumption of materials by express companies and the development status and trends of packaging recycling (Yu et al. 2020a). In this report, packaging in the domestic express industry is divided into seven categories: express waybills, woven bags, plastic bags, envelopes, packing boxes (corrugated box), tapes and internal buffers (fillers) (Yu et al. 2020b). According to the 2018 statistics, the total usage of woven bags reached about 5.3 billion, plastic bags about 24.5 billion, envelopes about 5.7 billion, boxes about 14.3 billion and tapes about 430 million. In terms of the used express packaging, except for clear regulations on the storage and recycling (destruction) of the express waybills, other types of express packaging are mainly recycled without clear provisions.

Recycling can reduce the packaging waste to some extent, but express packaging differs from ordinary waste in that it can be reused without secondary processing and only need simple processing (Gu et al. 2017). It is a waste of express packaging, if it is only recycled as ordinary garbage. How to effectively recycle packaging and put it into use quickly can not only reduce packaging costs for express enterprises, but also greatly reduce the waste of raw materials and mitigate the environmental pollution (Gu et al. 2019, Liang et al. 2020, Zhang 2020).

As the direct users of express packaging, express enterprises can recycle and reuse their packaging in the most effective manner. To mobilize the express enterprises to recycle their packaging, first of all, express enterprises need to have a clear idea about the costs and income from recycling packaging. Therefore, based on previous research, this paper attempts to establish two recycling models and reach a consensus based on mathematical model deduction. By comparing the results, this paper aims to figure out a model that can maximize the express enterprises' income from recycling packaging. This should be able to provide auxiliary support for the design mechanism of the express enterprises in the future.

LITERATURE REVIEW

Related research in policy formulation

A few scholars have studied the express packaging recycling based on qualitative methods (Ferdinand et al. 2013), which involves policy formulation and experience learning.

From the perspective of legislation, Liu (2018) analyzed the necessity of legislation in encouraging enterprises and the public to actively participate in express packaging recycling. The author argues that the legislation requires both incentives and punishments as well as a combination of special and penetration laws. According to Bening et al. (2021), regulatory barriers are interrelated with other barriers in the value chain. The author found interrelationships between economic, technical, and regulatory barriers through a study on flexible packaging recycling. Hua et al. (2021) argued that community-based trust relationships would affect residents' willingness to recycle packaging. This author suggested that the local governments should enhance communication among residents to increase their trust.

Influencing factors of recycling

Cai et al. (2021) assessed the willingness to pay for express packaging recycling. They found that the residents in Guangdong had little knowledge about

the package recycling, in terms of both the situation and policies. The authors indicated that the lack of knowledge and publicity was closely bound up with the low recycling rate. Yang et al. (2021) developed a tripartite game model to analyze the impact of consumers' willingness to recycle packaging and found that the advertisement and subsidy policy could positively affect the recycling willingness.

Some scholars had also conducted research on the methods and strategies of packaging recycling. Zhang et al. (2017) reviewed relevant information and conducted a field survey on foreign express packaging recycling, and designed a complex system for express packaging recycling, in which all links need to be coordinated to optimize the system under macro control. The authors also concluded that the most effective solution to this problem is to control it at the source. Zhu (2019) put forward the concept of shared express packaging based on the concept of sharing economy. The author designed a set of paths to realize shared express packaging. From material selection to the final stage of technology application, the environmentally friendly and shared packaging should be fully taken into consideration (Yang et al. 2020).

As can be seen, few scholars have studied e-commerce and express industries, which are emerging industries that have not been around for a long time. Therefore, this paper also reviews the research on recycling in other industries.

Recycling of other commodities

Li and Zhu (2017) optimized the design of the trade-in mechanism for the home appliance market. They analyzed the optimal decision of firms under different conditions of policy, consumer characteristics, and product sales from the perspective of sellers. Tian et al. (2020) concluded that the current recycling treatment of household appliances is inappropriate. They studied the optimal recycling strategy by establishing a system dynamics model. Chen and Yang (2018) studied the recycling model of electronic equipment waste in colleges and designed a model of self-recycling by consumers using principal-agent theory. The author first divided college teachers into different categories, then established a model of recycling costs and income, and designed different scenarios to calculate the path with the highest revenue from the recycling.

Different from home appliances, used clothing and other wastes, the recycling of express packaging is characterized by larger recycling volume, controllable recycling time, and simple recycling methods. Therefore, after considering the recycling experience of other industries and the characteristics of express packaging itself, this paper studies a path that can maximize the revenue of recycling packaging for express companies by building a mathematical model.

INTRODUCTION OF THE RECYCLING MODEL

There are two recycling models in this paper (as shown in **figure 1** and **figure 2**). The first model is the direct recycling and reuse by express enterprises. This recycling is almost voluntary. The express enterprises set up recycling bins and the customers deliver packaging to the recycling bins by themselves when it is necessary.

The second model is recycling by the collection depot (as a third-party). The express enterprises purchased the recycled packaging from the collection depot. The collection depots go to pick up the packaging door-to-door regularly, which is a paid service. However, in this case, the customer needs to preserve packaging at home for a period of time.

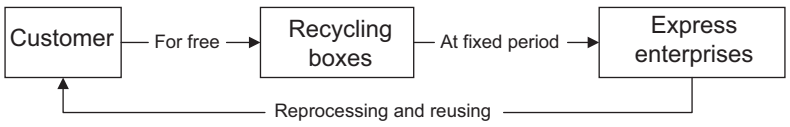

Fig. I. The model of recycling by express enterprises.

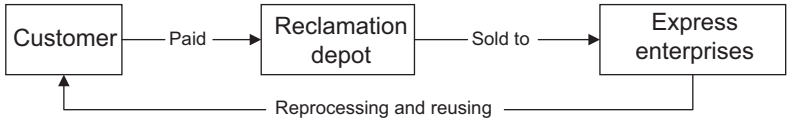

Fig. 2. The model of recycling by collection depots.

Problem modeling

First, the model must be built based on the following assumptions:

1) The express packaging can be directly recycled by the express enterprises, or be recycled by collection depots and resold to the express enterprises.
2) Recycled express packaging is considered to be identical to the new packaging in terms of function.
3) In order to simplify the model, the model in this study do not consider the wear and depreciation of express packaging.
4) Customers, express enterprises and collection depots are all rational people.

Then, the model parameters and the definitions of each variable were determined:

P_α : Cost of producing new packaging
P_β : Unit cost of recycle packaging from customers by collection depot
P_χ : Unit cost of the packaging recovered by the express enterprises from collection depot
C_N : Unit cost of producing new packaging by recycled materials
Δ : Unit cost saving of packaging, $\Delta = P_\alpha - C_N$
Q_R : The amount of packaging directly recycled by express enterprises
Q_A : The amount of packaging recycled by collection depot
S_A : The amount of recycling bins set up by express enterprises
C_S : The unit cost of recycling bins
h : Environmental awareness of local residents as a parameter
C_R : The other cost of packaging recycling of express enterprises
C_A : The other cost of packaging recycling of collection depot

The amount of packaging directly recycled by express enterprises were calculated as follows:

$$Q_R = hS_A$$

It is assumed that the amount of packaging directly recycled by express enterprises was only related to the environmental awareness of local residents and the number of recycling bins. The stronger the residents' environmental awareness, the more they are willing to deliver the packaging to the recycling bins. The more recycling boxes, the more convenient the delivery will be.

The amount of packaging recycled by the collection depot:

$$Q_A = hP_b$$

It is assumed that the amount of packaging recycled by collection depot was only related to the environmental awareness of local residents and the recycling price. The higher the recycling price and the stronger the residents' environmental awareness, the higher the willingness of customers to keep the packaging.

Other costs of packaging recycling of express enterprises were calculated as follows:

$$C_R = bQ_R^2 = b(hS_A)^2 \qquad b > 0$$

The higher the recycling amount, the higher the costs for express enterprises. In this equation, b represents the cost coefficient of express enterprises.

Other packaging recycling costs for collection depot:

$$C_A = kQ_A^2 = k(hP_\beta)^2 \qquad k > 0$$

The higher the recycling volume, the higher the cost of the collection depot. In this equation, k means the cost coefficient of collection depot.

Moreover, for the convenience of calculation, we assumed $P_c = mP_b \quad m > 1$.

Regardless of government subsidies and other invisible income from recycling packaging, the income that express enterprises gained from recycling packaging in the first model:

$$U_R = (P_\alpha - C_N)Q_R - S_A C_S - C_R = \Delta \cdot hS_A - S_A C_S - b(hS_A)^2$$

$$\frac{\partial U_R}{\partial S_A} = \Delta \cdot h - C_S - 2bh^2 \times S_A = 0$$

$$S_A^* = \frac{\Delta \cdot h - C_S}{2bh^2}$$

Meanwhile, $\frac{\partial U_R^2}{\partial^2 S_A} = -2bh^2 < 0$

Hence, after substituting the optimal solution into the model, the optimal solution for the first model became as follows:

$$U_{R\max} = \Delta \cdot hS_A^* - S_A^* C_S - b(hS_A^*)^2 = \frac{(\Delta \cdot h - C_S)^2}{4bh^2}$$

Similarly, the express enterprises' income from recycling packaging in the second model could be calculated in the following equation:

$$U_A = (P_\alpha - C_N)Q_A - P_\chi Q_A - C_A = \Delta \cdot hP_\beta - mhP_\beta^2 - k(hP_\beta)^2$$

$$\frac{\partial U_a}{\partial P_\beta} = \Delta \cdot h - 2mhP_\beta - 2kh^2 P_\beta = 0$$

$$P_\beta^* = \frac{\Delta}{2(m+kh)}$$

Meanwhile, $\frac{\partial U_A^2}{\partial^2 P_\beta} = -2h(m+kh) < 0$.

Hence, by substituting the optimal solution into the model, the optimal solution of the second model became:

$$U_{A\max} = \Delta \cdot hP_\beta^* - mhP_\beta^{*2} - kh^2 P_\beta^{*2} = \frac{\Delta^2 \cdot h}{4(m+kh)}$$

It is clear from the optimal solution that the income of express enterprises came from the unit cost saved from the packaging and the environmental awareness of local residents. When the packaging was recycled directly by express enterprises, the unit cost of recycling bins also determined the income.

CONTRAST ANALYSIS

According to the equation of $U_{A\max}$ and $U_{R\max}$, the differences between these optimal profit functions can be deduced as follows:

$$U_{R\max} - U_{A\max} = \frac{(\Delta \cdot h - C_S)^2}{4bh^2} - \frac{\Delta^2 \cdot h}{4(m+kh)} = \frac{\Delta \cdot h - C_S}{2} S_A^* - \frac{\Delta \cdot h}{2} P_\beta^*$$

It is easy to verify the following two inferences:

(1) If $S_A^* > \frac{1}{1-\frac{C_S}{\Delta \cdot h}} P_\beta^*$, then $U_{R\max} > U_{A\max}$.
(2) Otherwise, if $S_A^* < \frac{1}{1-\frac{C_S}{\Delta \cdot h}} P_\beta^*$, then $U_{R\max} < U_{A\max}$.

This means that if $S_A^* > \frac{1}{1-\frac{C_S}{\Delta \cdot h}} P_\beta^*$, express enterprises could gain more benefits from the direct recycling packaging. In this case, express enterprises should set up more recycling bins, so as to make it easier for local residents to deliver their packaging. If $S_A^* < \frac{1}{1-\frac{C_S}{\Delta \cdot h}} P_\beta^*$, express enterprises could benefit more from recycling the packaging from collection depots. In this circumstance, express enterprises should negotiate and reach an optimal recycling price with collection depots.

In order to compare the advantages and disadvantages of these two models, we set up a function $F(S_A, P_b)$:

$$F(S_A, P_\beta) = U_R - U_A = -bh^2 S_A^{\,2} + (\Delta \cdot h - C_S)S_A + h(m+kh)P_\beta^2 - \Delta \cdot hP_\beta$$

Let $F(S_A, P_b) > 0$, then $U_R > U_A$. Thus:

$$-bh^2 S_A^{\,2} + (\Delta \cdot h - C_S)S_A > -h(m+kh)P_\beta^2 + \Delta \cdot hP_\beta$$

$$\therefore S_A < \sqrt{\frac{(m+kh)}{bh}P_\beta^2 - \frac{\Delta}{bh}P_\beta + \frac{(\Delta \cdot h - C_S)^2}{4b^2h^4}} + \frac{\Delta \cdot h - C_S}{2bh^2}$$

Let $G(P_b)$ denote $\sqrt{\frac{(m+kh)}{bh}P_\beta^2 - \frac{\Delta}{bh}P_\beta + \frac{(\Delta \cdot h - C_S)^2}{4b^2h^4}} + \frac{\Delta \cdot h - C_S}{2bh^2}$. Thus when $S_A < G(P_b)$, $U_R > U_A$. Otherwise, when $S_A > G(P_b)$, $U_R < U_A$.

As shown in **figure 3**, the two recycling models were demarcated by $G(P_\beta)$. In the upper left part, express enterprises benefit more by recycling packaging from collection depots rather than customers' recycling behavior. The input factors included unit cost of recycling packaging from customers by collection depot and other costs for collection depots to recycle the packaging. In the bottom right corner, express enterprises gain more benefit by recycling packaging directly from customers rather than from collection depots. The input factors included the unit cost of recycling bins and other costs of packaging recycling for express enterprises.

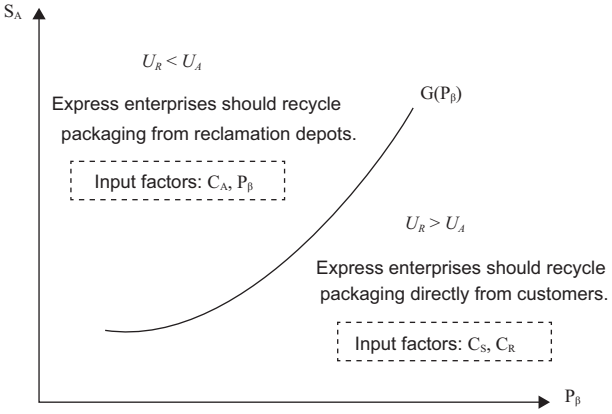

Fig. 3. Contrastive analysis of the two models.

Mathematical proof

In order to further demonstrate the profitability of the two recycling models, the calculation example is analyzed by assuming parameter values. According to the express industry's statistical index and the express

employee salary index in the official website of the National Bureau of Statistics, it was assumed that: $a = 1$; $b = 0.01$; $k = 0.01$. According to the social research and online data query, the remaining parameters are as follows:

$\Delta = 50$Yuan/kg; $S_A = 50$; $C_S =$ 500Yuan; $P_\beta = 0.5$Yuan/kg; $m = 1.1$

According to Xiong and Liang (2014), the environmental awareness of local residents h should range from 10 to 100. This paper selected 10, 20, 30...100 as representatives, and the calculation results are shown in **table I**.

TABLE I. EFFECTS OF DIFFERENT RECYCLING AWARENESS ON TWO MODELS.

h	$G(P_\beta)$	U_R	U_A
10	0.00	-2500	247
20	124.01	15000	493.5
30	110.37	27500	739.5
40	93.09	35000	985
50	79.38	37500	1230
60	68.85	35000	1474.5
70	60.65	27500	1718.5
80	54.12	15000	1962
90	48.83	-2500	2205
100	44.45	-25000	2447.5

As shown in **table I**, as h increased, the function value of $G(P_\beta)$ became smaller, which meant that the curve of $G(P_\beta)$ will shift to the bottom right with the increase of environmental awareness.

Meanwhile, with the increasing environmental awareness of local residents, the income in the first model (recycled by express enterprises) increased and then decreased, while the income in the second model (recycled by collection depots) continued to increase.

In the first pattern, express enterprises could not gain benefit from recycling packaging when the environmental awareness was quite low. However, in the beginning, the income of express companies increased as environmental awareness grew. With the enhancing environmental awareness, the residents became more willing to take the packaging to the recycling bins for free, even if they are some distance away from the recycling bins. After reaching a threshold of around 50 (mid-value), the income began to decrease. The reason probably lay in the amount of recycling bins. As the volume of recycling increased, the demand for recycling bins was increasing, which would aggravate the financial burden of express enterprises.

In the second model, express enterprises could benefit from recycling packaging even when the environmental awareness was rather low. This is because it lacks investment in the early stage. The collection depots are deemed as a third party for express enterprises. In this model, express enterprises just need to pay for the recycled materials. The income increases slowly with the increasing environmental awareness, most of which were much lower than the first model. However, there will be no losses from it.

In conclusion, the key for express enterprises is to raise the environmental awareness among local residents and reduce investment. It depends on two aspects. Express enterprises should strive to reduce unit cost of recycling bins and leverage every opportunity to promote the importance of recycling. On the other hand, local governments should also spare no efforts to promote circular economy. Moreover, if the local governments provide a certain subsidy for recycling bins, express enterprises can obtain more benefits from recycling, which will encourage express enterprises to invest more resources in recycling, thus forming a virtuous circle.

CONCLUSION

The rapid development of e-commerce and online retail industry has facilitated people's daily life and empowered the economy to flourish. However, many significant social problems have appeared. For example, how to deal with the large amount of express packaging has become a growing concern for governments, e-commerce platforms, express enterprises and consumers.

Therefore, this paper compared two recycling models. According to the results, without considering government subsidies, the income from recycling packaging was up to environmental awareness of local residents and the recycling price. By building a critical function, we found the dividing line between the two models. This can help companies to choose the appropriate model when they need to recycle the packaging.

In order to further demonstrate the profitability of the two recycling models, a calculation example is analyzed by assuming parameter values. The results showed that, with the increasing environmental awareness of local residents, the income in the first model (recycled by express enterprises) first increased and

then decreased, while the income in the second model (recycled by collection depots) continuously increased. In general, the benefits of direct recycling are greater than recycling from collection depots. However, if residents' environmental awareness can further be improved, recycling from a third party can bring about more sustainable benefits. Moreover, if government can subsidize the recycling bins, the benefits of direct recycling can be more substantial.

Although this paper has provided the most considerable findings to the greatest extent possible, there are still some aspects that have not been considered. In the future studies, the model should also take into consideration the government subsidies, enterprise image promotion and other invisible income, as well as the environmental awareness of urban residents in different areas.

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