Recycling of Durable Goods: Modeling and Experiments

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1 Introduction

This paper describes a way in which durable goods can be recycled.

A producer of recyclable goods faces an optimal pricing problem that is considerably complicated and difficult to solve mathematically. In a recycling market, a producer must make a decision about price and durability. For example, the producer must set numerous parameters, among which are: new unit price, used unit price, recycled unit price, durability of new units, and durability of recycled units. The producer can not find a profit-maximizing price in such circumstances. Moreover, several optimal prices are derived through a combination of production costs and recycling costs.

Many studies have specifically addressed durable goods. For example, Swan considered the question of optimal durability [9, 10]. Much of the literature published the 1970s regarding durable goods theory focused on the generality of Swan's results. Coase argued that a durable goods monopolist faces a problem of time inconsistency [3]. Many studies of durable goods theory in the 1980s focused on Coase's insights. Recently, many studies have considered more realistic models of durable goods. Numerous authors have argued about the role of leasing [8], monopolized aftermarkets for their own products [1, 2], and upgrade processes, which are common in the software industry [4]. On the other hand, Reynolds conducted experiments with regard to durable goods theory and explained deviations from equilibrium using a version of bounded rationality [11]. However, studies that consider recycling problems as durable goods' problems are very few.

We have produced a model in which a monopolist produces new units of a durable good and sells them at Price P, while collecting (purchasing) some of the used units it produced in the previous period at Price Q to sell as recycled goods at Price R. Mathematical analysis shows that the set of prices (P, Q, R) that maximizes the monopolist's profit changes in a complicated fashion according to available technology and consumer preferences. In addition we undertook a series of experiments with human subjects to verify that people would behave as the model suggests.

This paper is organized as follows. Section 2 explains our model, in which durable goods are recycled. Section 3 analyzes the model mathematically and derives its equilibria. Subsequently in Section 4 we describe experimental design and conduct experiments. Finally, we conclude this study in Section 5.

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2 The Model

2.1 Overview

A monopolistic producer, consumers and dismantlers exist in the market; the model is considered as an n period model.

A monopolist produces new units of a durable good and sells them at Price P, while collecting (purchasing) some of the used units it produced in the previous period at price Q to sell as recycled goods at price R. Monopolistic producers can produce a new unit of the durable good at a certain marginal cost $c(v, \alpha)$. The good can be used for two periods, but its quality decreases from v (the quality of a new unit) to $\alpha < v$ (the quality of a used unit) after its one-period usage. The producer can collect a unit to make a recycled unit whose quality is β ($\alpha < \beta < v$), with a certain marginal cost $d(\beta, \alpha)$.

A consumer with the utility parameter θ extracts θq of utility from one-period usage of a unit whose quality is q. The utility parameter θ of consumers is distributed uniformly between 0 and 1.

An overview of our model is shown in Fig. 1.

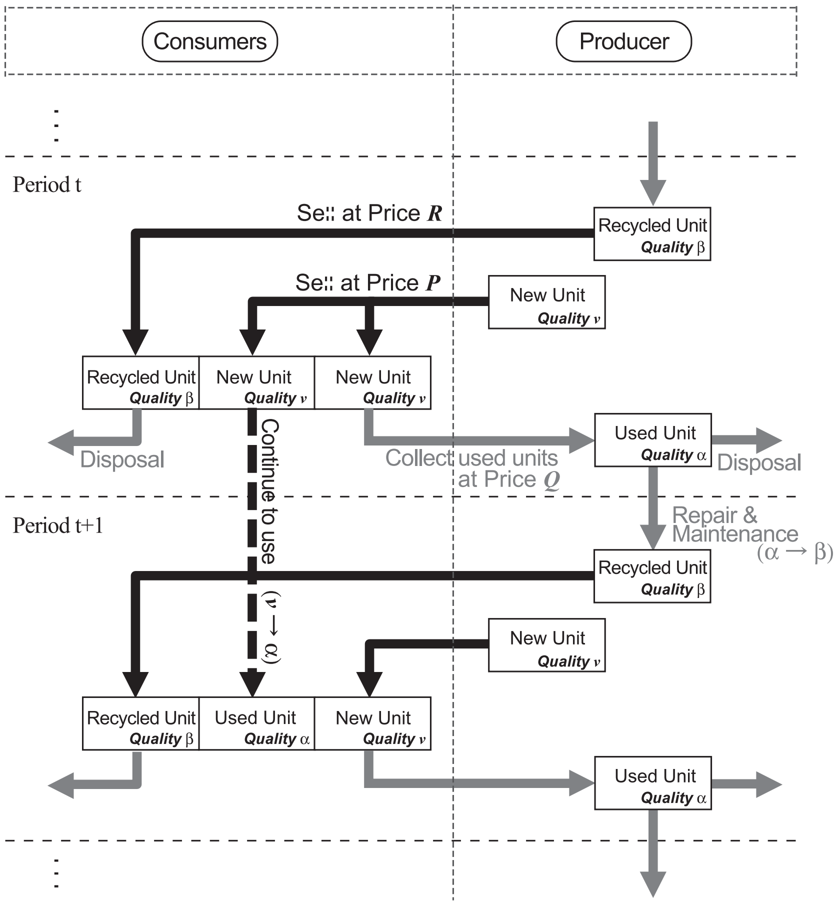

Fig. 1: Overview of our model

2.2 Consumers

A unit mass of consumers who live forever (no new consumers are born). Consumers' preferences are as follows: consumers demand a maximum of one unit at any date; a consumer of type θ who consumes a good with quality q obtains utility $u(\theta, q)$

$$u(\theta, q) = \theta q, \tag{1}$$

whereas a consumer purchasing a good at price p obtains surplus $V(\theta, q, p)$

$$V(\theta, q, p) = \theta q - p. \tag{2}$$

We assume that θ is distributed uniformly in $[0, 1]$

If a consumer purchases a new unit of the durable good, the surplus is

$$\theta v - P. \tag{3}$$

If a consumer purchases a recycled unit, the surplus is

$$\theta\beta - R. \tag{4}$$

On the other hand, if a consumer purchases neither a new unit nor a recycled unit and uses the used unit that was purchased in a preceding period, then the payment is zero. In such a case, the surplus is calculated as

$$\theta\alpha - 0. \tag{5}$$

2.3 Producer

The producer is a monopolist, selling new units at price P, collecting (purchases) some of the used units which were produced in past period, and subsequently selling them at price R as recycled units that have been repaired. The producer incurs a production cost $c(v, \alpha)$ in producing a new unit with quality v and incurs a recycling cost $d(\beta, \alpha)$ in producing a recycled unit with quality β.

Because the goods can be used for two periods, used units that the producer can accept at price Q are units after one period of usage only. Used-up units that have been used for two periods are collected by the producer at price S. The producer asks dismantlers S to dispose of them at price S.

The producer has market power and chooses prices P, Q, R to maximize profit.

2.4 Dismantlers

Dismantlers always accept used-up units at price S from the producer. For simplicity, we assume that S is an exogenous parameter. [1]

Hereafter, we focus on the producer's and consumers' respective behaviors. We simplify the dismantlers' behavior.

[1] The producer only collects used-up units at price S and enlists dismantlers to dispose of them at price S. We assume that the producer incurs no costs that are related to this disposal process. Therefore, the producer obtains no profit or loss in this process: the producer gets S and pays S.

3 Mathematical analysis

3.1 Formulation

We consider the long-run equilibrium in steady state.

In equilibrium, a consumer chooses one of the following consumption patterns according to utility parameters, price, and quality of each unit:

Pattern 1. a consumer purchases a new unit and sells the used unit in every period
$$V_1(\theta) = -P + v\theta + \delta(Q - P + v\theta) + \delta^2 Q,$$

Pattern 2. a consumer purchases a new unit and continues to use it (purchases a new unit every two periods)
$$V_2(\theta) = -P + v\theta + \delta\alpha\theta - \delta^2 S,$$

Pattern 3. a consumer purchases a recycled unit in every period
$$V_3(\theta) = -R + \beta\theta + \delta(-S - R + \beta\theta) - \delta^2 S,$$

Pattern 4. a consumer purchases no unit in any period
$$V_4(\theta) = 0,$$

where δ is a discount factor and V_i $(i = 1, 2, 3, 4)$ is the consumers' surplus in each pattern.

We assume that the quantity of Pattern 1 is x, the quantity of Pattern 2 is y, and the quantity of Pattern 3 is z. Then, we classify consumers according to preference parameter θ:

(i) $v + \delta\alpha > (1 + \delta)\beta$
$\Theta(x) < \theta \rightarrow$ Pattern 1
$\Theta(x + y) < \theta < \Theta(x) \rightarrow$ Pattern 2
$\Theta(x + y + z) < \theta < \Theta(x + y) \rightarrow$ Pattern 3
$\theta < \Theta(x + y + z) \rightarrow$ Pattern 4

(ii) $v + \delta\alpha < (1 + \delta)\beta$
$\Theta(x) < \theta \rightarrow$ Pattern 1
$\Theta(x + z) < \theta < \Theta(x) \rightarrow$ Pattern 2
$\Theta(x + y + z) < \theta < \Theta(x + z) \rightarrow$ Pattern 3
$\theta < \Theta(x + y + z) \rightarrow$ Pattern 4

Therein, we denote as $\Theta(x)$ that type for which $1 - F(\Theta(z)) \equiv x.F(\theta)$ is the cumulative distribution function. Consequently, $\Theta(x)$ is a type such that there is a mass x of consumers with higher valuation.

The producer's profit Π is represented as

$$\Pi = (P - c)(x + \frac{y}{2}) + (R - d)z - Qx, \tag{6}$$

where the following constraints exist for prices and quantities:

(i) $v + \delta\alpha > (1 + \delta)\beta$

$$P = \Theta(x + y)\{v + \delta\alpha - (1 + \delta)\beta\} + (1 + \delta)R + \delta S \tag{7}$$
$$Q = \frac{1}{1 + \delta}\{P - \Theta(x)(v - \alpha) - \delta S\} \tag{8}$$
$$R = \Theta(x + y + z)\beta - \delta S \tag{9}$$

(ii) $v + \delta\alpha < (1+\delta)\beta$

$$P = \Theta(x+y+z)(v+\delta\alpha) - \delta^2 S \tag{10}$$

$$Q = \frac{1}{\delta}\{P - R - \Theta(x)(v-\beta) - \delta S\} \tag{11}$$

$$R = \frac{1}{1+\delta}[P - \Theta(x+z)\{v+\delta\alpha-(1+\delta)\beta\} - \delta S] \tag{12}$$

In equilibrium, the producer chooses price P, Q, R to maximize profit Π.

3.2 Equilibrium

Let us see the equilibrium to solve the maximizing problem. We assume that $\delta = 1$ and $S = 0$. We obtain the following solutions, which depend on production cost c, recycling cost d and quality v, α, β.

(i)$v + \alpha > 2\beta$

(a) $c > c_9, c < c_8, c < c_6 \rightarrow$ see "Region A-(i)",
(b) $c > c_6, c < c_3, c < c_4 \rightarrow$ see "Region B-(i)",
(c) $c > c_8, c < c_7 \rightarrow$ see "Region C",
(d) $c > c_3, c > c_7, c < c_1 \rightarrow$ see "Region D",
(e) $c < c_5, c < c_9 \rightarrow$ see "Region E",
(f) $c > c_4, c < c_5, c < c_2 \rightarrow$ see "Region F",
(g) $c > c_1, c > c_2 \rightarrow$ see "Region G",

(ii)$v + \alpha < 2\beta$

(a) $c > c_8, c < c_9, c < c_{11} \rightarrow$ see "Region A-(ii)",
(b) $c > c_{11}, c < c_{10}, d < d_1 \rightarrow$ see "Region B-(ii)",
(c) $c > c_9, c < c_7 \rightarrow$ see "Region C",
(d) $c > c_{10}, c > c_7, c < c_1 \rightarrow$ see "Region D",
(e) $c < c_5, c < c_8 \rightarrow$ see "Region E",
(f) $d > d_1, c > c_5, c < c_2 \rightarrow$ see "Region F",
(g) $c < c_1, c < c_2 \rightarrow$ see "Region G",

Parameters c_i $(i = 1..12)$ and d_1 are the following:

$$c_1 = v + \beta - d \tag{13}$$

$$c_2 = v + \alpha \tag{14}$$

$$c_3 = \frac{2\beta(\beta-\alpha) - d(v+\alpha+2\beta)}{\alpha-\beta} \tag{15}$$

$$c_4 = \frac{(v-\alpha-2d)(v+\alpha)}{v+\alpha-2\beta} \tag{16}$$

$$c_5 = v - \alpha \tag{17}$$

$$c_6 = \frac{(v-\alpha)(d(v+\alpha)+(v+\alpha-2\beta)\beta)}{2(v-\beta)\beta} \tag{18}$$

$$c_7 = \frac{\beta(v-\beta)+d(v+\beta)}{2\beta} \tag{19}$$

$$c_8 = \frac{d(v-\alpha)}{\beta-\alpha} \tag{20}$$

$$c_9 = \frac{(v+\alpha)d}{\beta} \tag{21}$$

$$c_{10} = \frac{(v+\alpha)(-2d+v-\beta)}{v+2\alpha-3\beta} \tag{22}$$

$$c_{11} = \frac{v^2+2d\alpha+v\alpha-2d\beta-3v\beta-\alpha\beta+2\beta^2}{v+2\alpha-3\beta} \tag{23}$$

$$d_1 = \beta-\alpha \tag{24}$$

Each region from Region A to Region G is graphically shown in Figs. 2 and 3.

Region A

(i) $v+\alpha > 2\beta$

$$x_A^* = \frac{v-\alpha-c}{2(v-\alpha)}, \quad y_A^* = \frac{d(v-\alpha)-c(\beta-\alpha)}{(v-\alpha)(v+\alpha-2\beta)}, \quad z_A^* = \frac{c\beta-d(v+\alpha)}{2\beta(v+\alpha-2\beta)}$$

$$P^* = \frac{1}{2}(c+v+\alpha), \quad Q^* = \frac{\alpha}{2}, \quad R^* = \frac{d+\beta}{2}$$

$$\Pi^* = \frac{1}{8}\{2v+c(-4+\frac{c}{v-\alpha})+\frac{(c-2d)^2}{v+\alpha-2\beta}+\frac{2d^2}{\beta}\}$$

$$Total\ surplus = \frac{3}{16}\{2v+c(-4+\frac{c}{v-\alpha})+\frac{(c-2d)^2}{v+\alpha-2\beta}+\frac{2d^2}{\beta}\}$$

(ii) $v+\delta\alpha < (1+\delta)\beta$

$$x_A^* = \frac{v-\beta-c+d}{2(v-\beta)}, \quad y_A^* = \frac{c\beta-d(v+\alpha)}{(v+\alpha)(v+\alpha-2\beta)}, \quad z_A^* = \frac{d(v-\alpha)-c(\beta-\alpha)}{2(v-\beta)(v+\alpha-2\beta)}$$

$$P^* = \frac{1}{2}(c+v+\alpha), \quad Q^* = \frac{\alpha}{2}, \quad R^* = \frac{d+\beta}{2}$$

$$\Pi^* = \frac{1}{8}\{2v+c(-4+\frac{c}{v+\alpha})-\frac{(c-2d)^2}{v+\alpha-2\beta}+\frac{2(c-d)^2}{v-\beta}\}$$

$$Total\ surplus = \frac{3}{16}\{2v+c(-4+\frac{c}{v+\alpha})-\frac{(c-2d)^2}{v+\alpha-2\beta}+\frac{2(c-d)^2}{v-\beta}\}$$

Region B

(i) $v+\alpha > 2\beta$

$$x_B^* = z_B^* = \frac{(v-\alpha-2d)(v+\alpha)-c(v+\alpha-2\beta)}{2\{v^2-\alpha^2+2\beta(v+\alpha-2\beta)\}}, \quad y_B^* = \frac{d(v+\alpha+2\beta)-(\beta-\alpha)(c+2\beta)}{v^2-\alpha^2+2\beta(v+\alpha-2\beta)}$$

$$P^* = \frac{1}{2}(c+v+\alpha),$$

$$Q^* = \frac{\beta\{2(c-v+3\alpha)(v-\beta)+(v-3\alpha)(v-\alpha)\}-(d-\alpha)(v^2-\alpha^2)}{2\{v^2-\alpha^2+2\beta(v+\alpha-2\beta)\}},$$

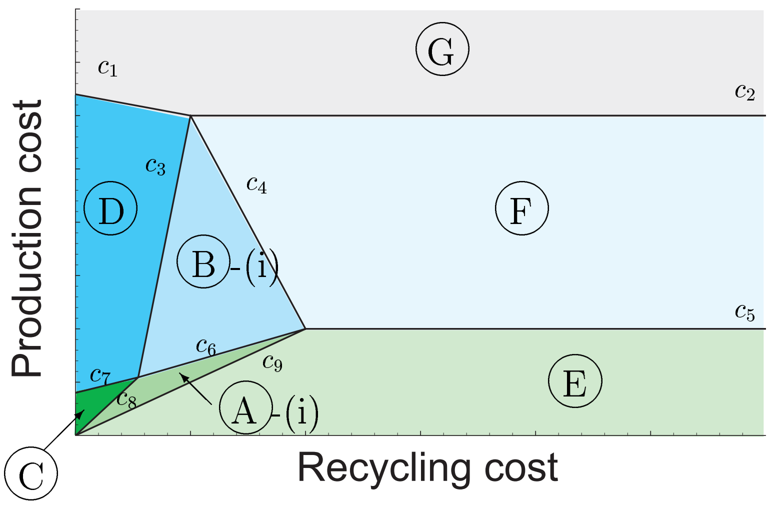

Fig. 2: $v + \alpha > 2\beta$

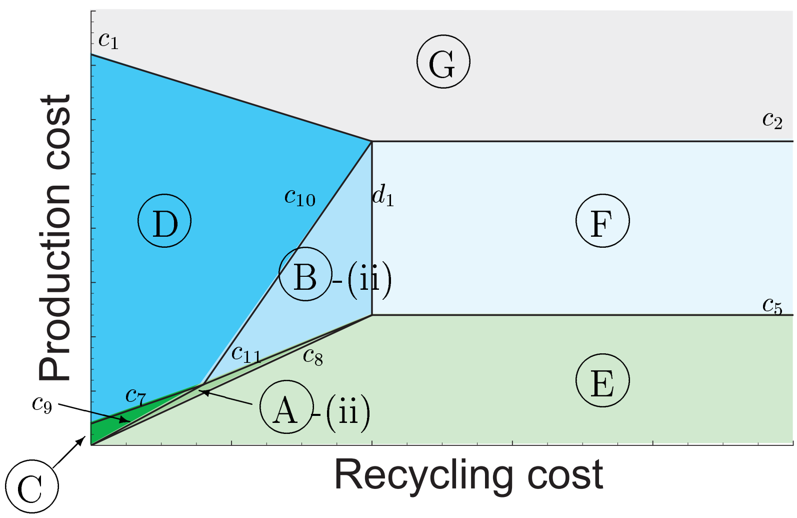

Fig. 3: $v + \alpha < 2\beta$

$$R^* = \frac{\beta\{d(v+\alpha-2\beta)+(c+2\beta)(v-\beta)\}}{v^2-\alpha^2+2v\beta+2\alpha\beta-4\beta}$$

$$\Pi^* = \frac{2(c+d)(v+\alpha)(d-v+\alpha)+(v-\beta)\{(v+\alpha)(v-\alpha+2\beta)+c^2\}+4c\beta(\beta-d-\alpha)}{4\{v^2-\alpha^2+2\beta(v+\alpha-2\beta)\}}$$

$$Total\ surplus = \frac{6(c+d)(v+\alpha)(d-v+\alpha)+3(v-\beta)\{(v+\alpha)(v-\alpha+2\beta)+c^2\}+12c\beta(\beta-d-\alpha)}{8\{v^2-\alpha^2+2\beta(v+\alpha-2\beta)\}}$$

(ii) $v+\delta\alpha < (1+\delta)\beta$

$$x_B^* = z_B^* = \frac{\beta-\alpha-d}{2(3\beta-v-2\alpha)}, \quad y_B^* = \frac{(v+\alpha)(2d-v+\beta)-c(3\beta-v-2\alpha)}{2(v+\alpha)(3\beta-v-2\alpha)}$$

$$P^* = \frac{1}{2}(c+v+\alpha),$$

$$Q^* = \frac{2\{\alpha(v-\beta)+(d-\beta-\alpha)(\beta-\alpha)\}-(v-c-\alpha)(v+2\alpha-3\beta)}{4(v+2\alpha-3\beta)}$$

$$R^* = \frac{c(v+2\alpha-3\beta)+2(v+\alpha-2\beta)(d+2\beta)-(v+\alpha)(v-\beta)}{4(v+2\alpha-3\beta)}$$

$$\Pi^* = \frac{c(v+2\alpha-3\beta)(c-v-\alpha)+(v+\alpha)\{4d(\beta-\alpha)-2(d+\beta)^2+v(v+3\alpha)+(4d-3v+\alpha)\beta\}}{8(v+\alpha)(v+2\alpha-3\beta)}$$

$$Total\ surplus = \frac{3c(v+2\alpha-3\beta)(c-v-\alpha)+3(v+\alpha)\{4d(\beta-\alpha)-2(d+\beta)^2\}}{16(v+\alpha)(v+2\alpha-3\beta}$$
$$+\frac{3(v+\alpha)\{v(v+3\alpha)+(4d-3v+\alpha)\beta\}}{16(v+\alpha)(v+2\alpha-3\beta)}$$

Region C

$$x_C^* = \frac{v-\beta-c+d}{2(v-\beta)}, \quad y_C^* = 0, \quad z_C^* = \frac{c\beta-dv}{2\beta(v-\beta)}$$

$$P^*-Q^* = \frac{c+v}{2}, \quad R^* = \frac{d+\beta}{2},$$

where P^*, Q^* and R^* must be satisfied with $\frac{(\beta-\alpha)P^*+(v+\alpha-2\beta)Q^*}{v-\alpha} \geq R^*$.

$$\Pi^* = \frac{d(dv-2c\beta)+\beta\{(c-v)^2+(2c-v)\beta\}}{4(v-\beta)\beta}$$

$$Total\ surplus = \frac{3d(dv-2c\beta)+3\beta\{(c-v)^2+(2c-v)\beta\}}{8(v-\beta)\beta}$$

Region D

$$x_D* = z_D^* = \frac{v+\beta-c-d}{2(v+3\beta)}, \quad y_D^* = 0$$

$$P^* - Q^* = \frac{(v+\beta)(c+d+v)+\beta(3v-\beta)}{2(v+3\beta)}, \quad R^* = \frac{\beta(c+d+2\beta)}{v+3\beta},$$

where P^*, Q^* and R^* must be satisfied with $\frac{(\beta-\alpha)P^*+(v+\alpha-2\beta)Q^*}{v-\alpha} \geq R^*$.

$$\Pi^* = \frac{(c+d-v-\beta)^2}{4(v+3\beta)}$$

$$Total\ surplus = \frac{3(c+d-v-\beta)^2}{8(v+3\beta)}$$

Region E

$$x_E^* = \frac{v-\alpha-c}{2(v-\alpha)}, \quad y_E^* = \frac{c\alpha}{v^2-\alpha^2}, \quad z_E^* = 0$$

$$P^* = \frac{1}{2}(c+v+\alpha), \quad Q^* = \frac{\alpha}{2},$$

where P^*, Q^*, and R^* must be satisfied with $R^* \geq \frac{\beta}{v+\alpha}P^*$.

$$\Pi^* = \frac{(c-v)^2 v + (2c-v)\alpha^2}{4(v-\alpha)(v+\alpha)}$$

$$Total\ surplus = \frac{3(c-v)^2 v + 3(2c-v)\alpha^2}{8(v-\alpha)(v+\alpha)}$$

Region F

$$x_F^* = z_F^* = 0, \quad y_F^* = \frac{v+\alpha-c}{2(v+\alpha)}$$

$$P^* = \frac{1}{2}(c+v+\alpha),$$

where P^*, Q^* and R^* must be satisfied with $P^* - 2Q^* \geq v-\alpha$ and $R^* \geq \frac{\beta}{v+\alpha}P^*$

$$\Pi^* = \frac{(-c+v+\alpha)^2}{8(v+\alpha)}$$

$$Total\ surplus = \frac{3(-c+v+\alpha)^2}{16(v+\alpha)}$$

Region G

No one purchase goods: $x = y = z = 0$.

These equilibria are summarized in Table 1. ¿From Table 1, we conclude that the sales of recycled units depend on the conditions of cost c and d. Therefore, in a certain circumstance, even if the producer wants to spread recycled units in the society, recycled units are not sold and are eliminated from the market. For example, there are no consumers who purchase recycled units in Regions E and F, where recycling cost d is relatively large.

Table 1: Number of consumers who follow consumption patterns 1, 2 and 3

	Pattern 1	Pattern 2	Pattern 3
A	x_A	y_A	z_A $(< x_A)$
B	x_B	y_B	z_B $(= x_B)$
C	x_C	0	z_C $(< x_C)$
D	x_D	0	z_D $(= x_D)$
E	x_E	y_E	0
F	0	y_F	0
G	0	0	0

4 Experiments

4.1 Experimental design

The market comprises 100 consumers and the monopolistic producer. A subject plays the role of the producer, while each computerized agent plays the role of a consumer. The decision-making process of each is the following.

Producer

The producer determines prices P, Q, and R. If the producer sets prices, then the sales and the profit are calculated and shown on the display (Figs. 4 and 5).

Consumers

We replace human consumers with computerized agents in this experiment. Using this arrangement, we are able to isolate the effect of other subjects who play the role of consumers. We can thereby infer the manner in which a result is affected by behavior of particular subjects. Especially, the behavior of the producer, who makes the market, is crucial. For this reason, we used computerized agents as consumers.

We programmed the following behavior of consumers:

- Each consumer has a preference parameter θ, which is distributed uniformly on $[0, 100]$.
- Each consumer calculates their own utility and makes a decision in consideration of that utility. In other words, each agent selects one of four consumption patterns (Patterns 1–4) to maximize the utility.

Fig. 4: Display in experiments (Price selection)

Fig. 5: Display in experiments (Result)

4.2 Experimental settings

Production cost and recycling cost

As shown in Table 2, we conduct six kinds of experiments with respect to production cost c and recycling cost c.

Table 2: Treatments and costs

	Region	c	d
Treatment 1	Region A	26	10
Treatment 2	Region B	40	10
Treatment 3	Region C	18	4
Treatment 4	Region D	28	4
Treatment 5	Region E	26	18
Treatment 6	Region F	42	24

Durable goods quality

We assume that $v = 1.0$, $\alpha = 0.6$, and $\beta = 0.7$.

Equilibrium in each treatment

Table 3 shows the equilibrium value in each treatment.

Other settings

Experiments were conducted at the Kyoto Sangyo University Experimental Economics Laboratory (KEEL). Subjects were recruited from among undergraduate students at Kyoto Sangyo University. The number of subjects in each treatment is shown in Fig. 4. Subjects were rewarded according to their total profit, calculated as 0.01 yen per one point in the experiments.

Table 3: Equilibria in experimental settings

	P	Q	R	x	y	z	Π
Treatment 1 (A)	97	32	42	18	18	5	1501
Treatment 2 (B)	98	31	42	10	21	10	1199
Treatment 3 (C)	88–200	$P-58$	37	31	0	17	1801
Treatment 4 (D)	90–200	$P-60$	37	24	0	24	1560
Treatment 5 (E)	96	31,32	0–34 42–200	15	26	0	1495
Treatment 6 (F)	104	0–32	0–200	0	36	0	1116

Table 4: Number of subjects

	Number of subjects
Treatment 1	9
Treatment 2	8
Treatment 3	8
Treatment 4	8
Treatment 5	7
Treatment 6	8

4.3 Results

Figure 6 shows the average of the producer's profit in Region A. From Fig. 6, we can infer that subjects realize the large profit that is around the equilibrium. However, most subjects do not select equilibrium prices. This is because there are many near-optimal solutions in this profit-maximizing problem. Many subjects actually fall into near-optimal solutions.

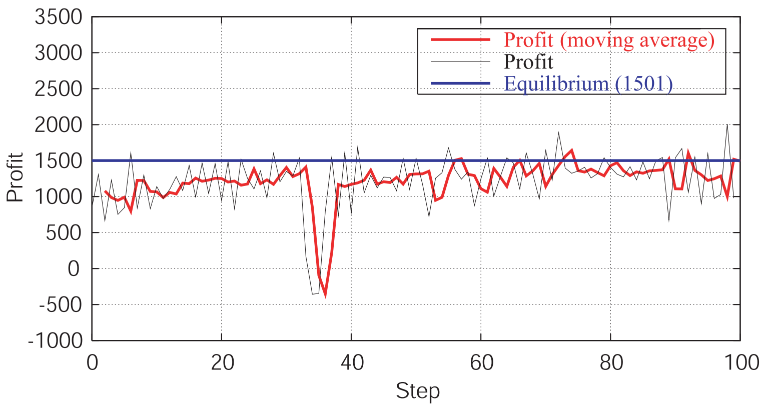

Fig. 6: An example of results (average producer's profit in Region A)

In this paper, we do not specifically address whether a subject attains the equilibrium value, but instead on how a recycling society can be formed. In other words, we examine whether recycled units are sold easily or not.

We define the seven kinds of market states in terms of recycled-unit sales:

- State I: Some recycled units are sold. ($x > z > 0, y > 0$)

- State II: All recycled units are sold. $(x = z > 0, y > 0)$
- State III: Some recycled units are sold. $(x > z > 0, y = 0)$
- State IV: All recycled units are sold. $(x = z > 0, y = 0)$
- State V: No recycled units are sold. $(x > 0, y > 0, z = 0)$
- State VI: No recycled units are sold. $(x = z = 0, y > 0)$
- State VII: No recycled units are sold. $(x > 0, y = z = 0)$

Furthermore, these states are classifiable based on how many Pattern 3 consumers exist. If the number of Pattern 1 consumers is equal to the number of Pattern 3 consumers, all used units that are collected from consumers can be produced as recycled units. We call this state a "High recycling level". Similarly, if the number of Pattern 1 consumers is larger than the number of Pattern 3 consumers, some used units can be recycled. We call this state the "Medium recycling level". If the number of Pattern 3 consumers is zero, no recycled units are produced. We call this the "Low recycling level". We summarize as follows:

High recycling leve $\rightarrow$ State II, State IV

Medium recycling level $\rightarrow$ State I, State III

Low recycling level $\rightarrow$ State V, State VI, State VII

Table 5: Classification of results

	State I	State II	State III	State IV	State V	State VI	State VII
Treatment 1 (A)	0	0	0	0	4	4	4
Treatment 2 (B)	0	3	2	0	2	1	2
Treatment 3 (C)	0	5	1	0	2	2	0
Treatment 4 (D)	1	0	0	0	1	6	2
Treatment 5 (E)	0	0	0	0	3	4	3
Treatment 6 (F)	0	2	0	0	5	4	4

Table 5 shows the number of subjects in each state. In all treatments, the number of subjects in States V, VI and VII is relatively large, meaning that no recycled units are sold and the market is likely to be realized at a "Low recycling level". On the other hand, the number of subjects in State II is large in Treatment 3. In Treatment 3, both production cost and recycling cost are small, so that the market is likely to be realized at a "High recycling level". In Treatment 2, the number in States II and III is low. Accordingly, Treatment 2 engenders properties that would allow a recycling society to be realized. Table 6 presents a summary of these results.

Table 6 relates that, in treatments where the recycling cost is medium or large, the recycling level is not high regardless of the production cost. On the contrary, in treatments where the recycling cost is small, the production cost should also be small to realize a high recycling level.

We imply that recycling technology which lowers the recycling cost is more important than production technology in the case where the recycling cost is high. In other words, even if the production cost is high, the producer should lower the recycling cost. Therefore, it is implied that production technology that lowers the production cost is important to realize a high recycling level in the case where the recycling cost is small. We illustrate this implication in Fig. 7.

Table 6: Recycling levels of respective treatments

		Recycling cost d		
		small	medium	large
Production cost c	small	Treatment 3 (Region C) High recycling level		
	medium	Treatment 4 (Region D) Low recycling level	Treatment 1 (Region A) Low recycling level	Treatment 5 (Region E) Low recycling level
	large		Treatment 2 (Region B) High or medium recycling level	Treatment 6 (Region F) Low recycling level

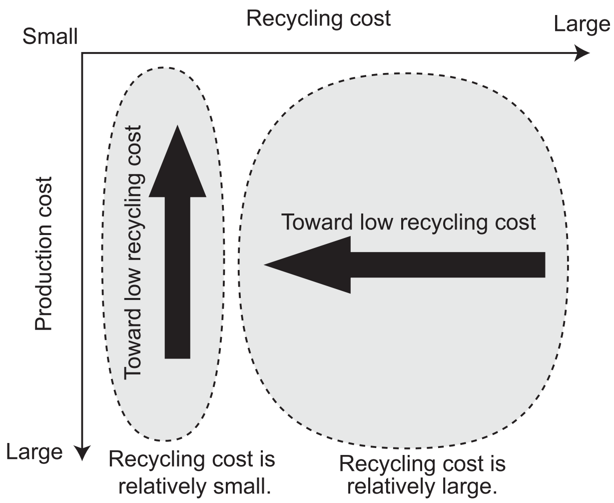

Fig. 7: Implication for direction of technology development

5 Concluding Remarks

This paper addresses the problem of durable goods recycling.

Economic agents such as producers or firms must make decisions in circumstances where the optimal pricing problem of durable goods is difficult to solve mathematically. Furthermore, the problem becomes more complicated when a producer considers recycling of durable goods.

We derive the equilibrium in the recycling market of durable goods, and conduct experiments with human subjects. Those experiments demonstrated that subjects were unable to attain the equilibrium, but were able attain a near optimal solution.

Then we specifically examined not whether subjects attain the equilibrium, but how recycled goods are spread in the market. Results of those experiments engendered our conclusion that when both production cost and recycling cost are large, the recycled goods are not likely to be sold. Therefore, it is implied that the producer should assign priority to recycling-cost reduction.

These analyses are generally useful for understanding decision-making. Furthermore, they are applicable to problems involving institutions and technologies.

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