An Investigation of Zero Waste Management Based on Perceived Consumer Effectiveness
지각된 소비자 효율에 따른 제로웨이스트 경영의 실행 가능성

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This study examines viability of zero waste manufacturing model in which manufacturing firms recycle parts and reuse materials to make a new product. Grounded on an economic model, we identify the conditions under which the monopolistic firm's zero waste action brings profit. We examine the profitability of the versioning strategy in the presence of two consumer types, including primary and eco-conscious consumers. The eco-conscious consumers are specified by a perceived consumer effectiveness that explains the consumers' consideration and inclination to solve the prevalent societal problem. We find that offering single version is dominant over offering both versions under certain conditions, even though we also verify that the preeminence of versioning is usually applicable. We further analyze the impact of subsidies for the zero waste on firm's profit and the social welfare. We find subsidies do not always benefit the manufacturer; if the subsidy does not exceed a certain level, it does not increase social welfare. We show that the high subsidy does not guarantee increasing social welfare when the market structure is known. Contrary to the manufacturer profit, social welfare can increase with lower subsidy level.

Key Words: Zero waste, eco-friendly consumer, versioning, subsidy, corporate social responsibility (CSR)

Ⅰ. Introduction

As consumers highly appreciate firms' efforts to pursue business ethics and fairness, corporate social responsibility (CSR) gradually became an inevitable part of corporate activity for modern businesses in various areas, from brand management to global affairs. One of the critical transboundary CSR initiatives is an environmental concern. Environmental problems include not only endangered animals that suffer from human-disposed waste, but also human race whose health is threatened directly by incomplete purification process and excessive chemical usage. Accompanying the

Submission Date: 03. 17. 2023 Accepted Date: 04. 10. 2023

matter, environmental consciousness is becoming a facet that businesses must consider seriously in the present days. Green consumption movement, often driven by the government's initiative, is now changing consumers' perception of firm value as well; a majority of consumers would favor the companies taking CSR (Butler, 2017). Laroche et al. (2001) show that the number of consumers who are willing to pay more for eco-friendly products is growing.

These days, beyond the necessarily passive practices, companies are reshaping their view in a way that supporting societal needs are not just ancillary activities to make their image better but profitable business itself. Shared value concept squares economic and social problem-solving efforts with enhancing of companies' competitiveness (Kramer & Porter, 2011; Porter & Kramer, 2019). For example, GE's ecomagination program that surely derived from a business standpoint immersing itself in technologies to reduce the energy consumption and other resources in manufacturing, generated sales of $18 billion in 2010, increasing $10 billion from the program's launch in 2005 (Lohr, 2011). Along with reduction of resources consumption, waste management attracted public attention, there came a movement of zero waste to landfill. Car manufacturers are in the lead: carmakers such as GM, Ford, and Toyota have been trying to reduce waste to landfills as well as into the air by building up zero waste facilities. Ford with 82 zero waste facilities worldwide reduced 61 percent of waste to landfill over the last five years (Ford, 2018). Toyota with 27 zero waste facilities in North America reduced 96 percent of its unregulated waste. As sending waste to landfills became costly from the 2000s, active recycling and reuse resulted in considerable cost reduction and positive public relations (Friess, 2017). In extensive industries, this tendency grows as well. Lego plans to get out of the dependence on petroleum-based plastics, and manufacture the products entirely from eco-friendly and recycled materials by 2030. Coca-Cola and Unilever are also leading in recycling through their manufacturing process (Reed, 2018).

Together with this industrial move, it is worth studying whether the manufacturing firms have an incentive to voluntarily practice zero waste management and what role consumer perspective plays in this mechanism. Reduction of pollution by reuse or less use seems encouraging, but also it has downside and faces impediments: repulsion caused by sanitary concerns and malfunction are major obstacles among them. The state of California, one of the world-leading states in water recycling, displays its action plan for expanding reclaimed water production. The mayor of L.A. elucidates that the city will recycle all of its wastewater and provide one-third of the city's supply by 2035 (Boxall, 2019). The state of Texas aims to supply 10 percent of water in

necessity through reclaimed water by 2060 (Monks, 2015).

In this paper, we aim to understand the circumstances under which firm's zero waste action may be beneficial to the firm and to the society. We postulate consumer division, the influence of each segment, and firm's versioning strategy thereof. As a factor to divide consumer group, we demonstrate the possible impact of consumer attitude or belief on the consequences of their action. This paper is organized as follows. Section 2 shows a literature review. Section 3 outlines our basic model setup. Section 4 extends the model to market segmentation. Section 5 examines subsidization effect on consumers and a manufacturer, respectively, and also gives an insight to a policy maker. We conclude with managerial implication and directions for future research.

Ⅱ. Literature Review

Zero waste research spans several streams. One of these is remanufacturing; it has been mainly treated in the operations and marketing streams. Whether the remanufacturing can be a competitive strategy interests researchers. Majumder & Groenevelt (2001) examine the effect of competition in remanufacturing by presenting a two period model of competition between an original equipment manufacturer and a local remanufacturer. Debo et al. (2005) study characteristics of the market segments and the production technology that decide a remanufacturing strategy. They find that the consumer profile determines the profitability of remanufacturing, and an interaction between the consumer profile and the fixed cost determines the optimal remanufacturability level. Atasu et al. (2008) give a guideline for remanufacturing decisions. Their research shows that the decision is directed by competition, cost savings, cannibalization, and product life-cycle. Örsdemir et al. (2014) investigate a competition between an original equipment manufacturer and an independent remanufacturer. Their results indicate that the original equipment manufacturer depends more on quality as a strategic lever when its position is competitive, whereas it relies more on quantity control when it has a weaker competitive position.

Product versioning is another important part of the operations strategy. Agi & Yan (2019) identify green product launching conditions that improve the supply chain profit in both the centralized system and decentralized systems when the retailer or the manufacturer is the leader of the supply chain. Liu & Kim (2020) investigate the monopolist's decision on the old technology disposal in the face of a new technology. They find that the firm should keep the old technology product

if the new technology product is remarkably superior to the old one. They also show that improving the old can boost the demand of old and new products in certain conditions.

This paper also relates to CSR literature. Servaes & Tamayo (2013) present the debate on CSR's role in corporate strategy by demonstrating an interaction between advertising intensity and CSR activities. They show that CSR increases the value of the firm in high public awareness (advertising intensity), but in contrast, it can destroy it with CSR concerns. Du et al. (2011) find CSR can be an efficient lever to a challenger's competitiveness against a market leader. They test how the challenger obtains approving attitudinal and behavioral reactions from consumers who experienced its CSR initiative. They find that manufacturer exhibiting CSR case is significantly superior to the other. Following these streams, we examine the firm's versioning strategy in consideration of market segmentation and subsidization, and a guideline for policy makers.

Ⅲ. Model Setup

We build a model grounded on vertical quality differentiation (Kim et al., 2011; Mussa & Rosen, 1978; Ronnen, 1991). There exist a monopolistic automaker and consumers. The firm has three options as to whether it will produce the product with virgin materials only or by zero waste manufacturing, otherwise supply both versions. Zero waste is considered to be achieved for more than 90 percent diversion of waste from landfills and incinerators. In this paper, we limit the zero waste manufacturing concept into the case of recycling or reusing materials to make a new product. Consumers choose between the regular new which consists of virgin components only, the zero waste product which includes recycled parts, or not buying option given her type.

Consumers are heterogeneous in their taste, denoted with θ which is uniformly distributed between 0 and 1. ν represents product quality level, thus, from a product of ν a consumer of type θ enjoys the value $\theta\nu$. A consumer of any type evaluates the value of the product built from virgin materials at $\theta\nu$ and the value from the zero waste product at $\delta\theta\nu$, where δ $(0 < \delta < 1)$ as a value discount compared to the regular version (Örsdemir et al., 2014). δ means quality inferiority, or incompatibility that recycled materials might cause in new products. Embedded recycled parts can be outwardly the same as virgin ones, yet they may not behave in the expected way concerning safety and quality requirements. Especially they have a risk that may not function in the correct way during an accident. p_n and p_z denote the price for a regular one and a product of the zero waste manufacturing,

respectively. Consistent with the literature, we assume $p_n \rangle p_z$.

Selling regular product only. When the firm offers only a regular product, a consumer enjoys the utility of

$$u_n = \theta\nu - p_n. \quad (1)$$

The firm's expected profit is given by

$$E\pi_n = (p_n - c_n)\left(1 - \frac{p_n}{\nu}\right), \quad (2)$$

where c_n denotes the unit cost for making a regular product. Then the firm's optimal price becomes $p_n^* = \frac{1}{2}(c_n + \nu)$, and the corresponding profit is $E\pi_n^* = \frac{(\nu - c_n)^2}{4\nu}$.

Selling zero waste product only. When the firm offers zero waste product, a consumer utility and the firm's expected profit are given by

$$U_z = \delta\theta\nu - p_z, \quad (3)$$

$$E\pi_z = (p_z - c_z)\left(1 - \frac{p_z}{\delta\nu}\right). \quad (4)$$

Then the optimal price is $p_z^* = \frac{1}{2}(c_z + \delta\nu)$, and the corresponding profit is $E\pi_z^* = \frac{(c_z - \delta\nu)^2}{4\delta\nu}$, where c_z is the unit cost for the zero waste manufacturing that is made up of cost reduction from less waste and disposal, and also challenge for transforming the disposed to the usable material. Zero waste movement has incentivized firms to reduce the production cost, so that many manufacturers are switching their manufacturing process to green production. As some countries importing waste, however, decided to stop getting scrap plastic and paper, the cost of placing waste and sorting out recycling material from trash seriously increased. Therefore, some municipalities started to accept the economic impracticality of recycling and send the material to incinerators, even though they maintain customary recycling efforts for decades like placing recycling bins (Corkery, 2019). The discrepancy between reality and conventional belief that recycling is cheaper than virgin one makes firms directionless to this issue. Savaskan et al. (2004) assume a remanufactured product is less costly than a regular one, but inserting recycled materials than using virgin ones only can be more expensive in many cases (Perella, 2017). So c_z can be either higher or lower than c_n, or rather they can be the same as well.

Offering both versions. By solving consumers' decision on their individual rationality and incentive constraints, consumers buy the regular version if conditions are satisfied with $U_n \geq 0$ and $U_n \geq U_z$ or purchase the zero waste version if $U_z \geq 0$ and $U_z \geq U_n$. Then demand is $q_n = \frac{p_n - p_z}{(1-\delta)\nu}$ and $q_z = \frac{p_n - p_z}{(1-\delta)\nu} - \frac{p_z}{\delta\nu}$ if $\delta c_n > c_z$. Likewise, $q_n = 1 - \frac{p_n}{\nu}$ and no

demand for the zero waste if $\delta c_n \leq c_z$. Assuming the firm chooses the quality first and the price consequently, we recognize that when $\nu \leq \frac{\delta c_n + \delta(c_z + \delta\nu) - \delta c_z - c_z}{\delta^2}$, there is no demand for the zero waste version. That is, consumers require some level of quality to consider any zero waste product.

Ⅳ. A Mix of Primary and Eco-conscious Consumers

Unlike conventionally presumed consumers whose utility is from value minus price, socially conscious consumers pursue multiple purposes through their consumption: they want their purchase to help social problems be solved. In the marketing and the psychological research stream, socially conscious consumers are defined by personality, attitude, and socioeconomic characteristics (Webster, 1975). The socially conscious consumer is the one who cares consequences of her individual consumption and believes it can be effective in the environmental problem abatement (Kinnear et al., 1974). They play an active role in her individual behavior as a consumer as well as in organized activities (Anderson & Cunningham, 1972). The growing ecologically conscious consumers (Roberts & Bacon, 1997) and environmentally conscious consumers (Dembkowski & Hanmer-Lloyd, 1994) create important incentives for manufacturers to include recycling at least in a certain phase of their commercialization process. We henceforth call them eco-conscious consumers. We extend the basic model by assuming that there exist two groups of consumers in the market: primary consumers (Atasu et al., 2008) and eco-conscious consumers.

4.1 Offering a single version

Selling zero waste product only. When the firm sells the regular version, there is no difference between consumers, however, when it offers the zero waste version, consumers are differentiated according to their preference. The eco-conscious consumers get the following utility from this version:

$$U_z^E = \delta\theta\nu - p_z + t\eta, \qquad (5)$$

let η be a perceived consumer effectiveness (PCE), that is, consumers' attitudes that can positively influence the environment (Balderjahn, 1988; Ellen et al., 1991; Kinnear et al., 1974; Straughan & Roberts, 1999), where t captures the degree of PCE scaled between 0 and 1. The η is generally defined as a belief that the individual effort can make a difference in the solution to a problem; it has long been linked to socially conscious attitude and tested empirically (Ellen et al., 1991). Since the param-

eter has been treated in the existing studies on green consumption and the environment problem, we adopt the parameter in our model. This parameter explains the consumers' consideration and inclination to solve the prevalent societal problem, and it is consequently reflected in the eco-conscious consumers' utility.

Let α denote the proportion of the eco-conscious group, and $1-\alpha$ for the primary. Then, the expected profit of the market is

$$E\pi_z = \alpha(p_z - c_z)\left(1 - \frac{p_z - t\eta}{\delta\nu}\right) + (1-\alpha)(p_z - c_z)\left(1 - \frac{p_z}{\delta\nu}\right). \quad (6)$$

A further investigation leads to the optimal choice of the monopolist.

Proposition 1. *There exists a unique cutoff point that determines the optimal single version strategy. Offering the zero waste version is an optimal strategy for the monopolist, when (i) $\delta < \hat{\delta}$, and ($\eta < \hat{\eta}$ or $\eta > \tilde{\eta}$), (ii) $\hat{\delta} \le \delta < \tilde{\delta}$ and $\eta > \tilde{\eta}$, (iii) $\delta \ge \tilde{\delta}$; while offering the regular version, conversely, gives more profit, when (i)$\delta < \hat{\delta}$, and $\hat{\eta} < \eta < \tilde{\eta}$, (ii) $\hat{\delta} \le \delta < \tilde{\delta}$, and $\eta < \tilde{\eta}$.*

Proposition 1 subdivides δ and η space into two regions of optimal single strategies. Along with the value discount δ, major factors that determine a strategy are the level of the perception and the size of consumers that put emphasis on the environmental issues. Proposition 1 indicates that the manufacturer should select a version depending on the quality gap between products and how consumers react to the environmental issues. There are certain cutoff points of $\hat{\eta}$ and $\tilde{\eta}$ that make a zero waste version more profitable than the other according to δ scope. It is conspicuous that the higher η brings the more profit to the zero waste production. And a large δ which is a small quality gap between products reduces aversion to the zero waste product. The demand for the zero waste version will increase as consumers highly appreciate the product's value or care more about the environmental issues. For example, vests of an American outdoor clothing company, Patagonia—who devised a fleece material made from plastic bottles—are quite expensive but popular insomuch that the Wall Street men who recognize the fleece vest as an essential business-wear accessory. The company pledged 1 percent of annual sales to environmental causes and became a staple in the financial industry (Hoang, 2017). It even announced new limits on the sales that it will focus on selling their products to good companies supporting global issues or the environment (Otani, 2019).

In Figure 1, we show two regions of δ and η space. The threshold partitioning these two regions is skewed cone. It is noteworthy that the low η can also make the zero waste man-

ufacturing a better option when the value gap between the regular and the zero waste is big. If the PCE is low, the optimal price will decrease so that more demand for the zero waste version rises letting the zero waste manufacturing only beneficial.

〈Figure 1〉 Regions of Optimal Single Version Strategy
($\nu = 2$, $c_n = 0.7$, $c_z = 0.5$, $t = 0.3$, $\alpha = 0.2$)

4.2 Offering both versions

Now we analyze the case when the manufacturer offers both versions in the market that two segments coexist.

Case $\delta c_n - c_z > t\alpha\eta$. First, we look at the case when $\delta c_z - c_z > t\alpha\eta$, primary consumers buy a regular product if $U_n^P \geq U_z^P$ and $U_n^P \geq 0$. On the other hand, they buy a zero waste product if $U_n^p \leq U_z^p$ and $U_z^p \geq 0$. Under versioning, $1 - \frac{p_n - p_z}{(1-\delta)\nu}$ of the primary consumers buy the regular products and $\frac{p_n - p_z}{(1-\delta)\nu} - \frac{p_z}{\delta\nu}$ of the primary consumers purchase the zero waste version. Likely, eco-conscious consumers buy a regular version if $U_n^E \geq U_z^E$ and $U_n^E \geq 0$; they purchase a zero waste version if $U_n^E \leq U_z^E$ and $U_z^E \geq 0$. So, the expected profit from both segments is

$$
\begin{aligned}
E\pi_1 = \alpha \Big[& (p_n - c_n)\left(1 - \frac{p_n - p_z + t\eta}{(1-\delta)v}\right) \\
& + (p_z - c_z)\left(\frac{p_n - p_z + t\eta}{(1-\delta)v} - \frac{p_z - t\eta}{\delta v}\right)\Big] \\
& + (1-\alpha)\Big[(p_n - c_n)\left(1 - \frac{p_n - p_z}{(1-\delta)v}\right) \\
& + (p_z - c_z)\left(\frac{p_n - p_z}{(1-\delta)v} - \frac{p_z}{\delta v}\right)\Big].
\end{aligned} \tag{7}
$$

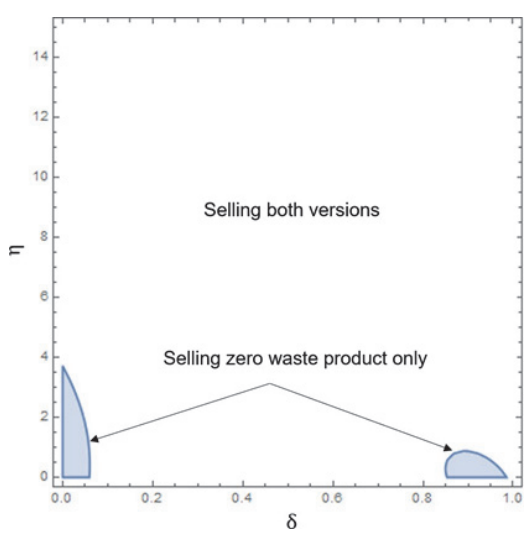
Case $\delta c_n - c_z \leq t\alpha\eta$. This case is divided into two instances: $\delta c_n - c_z \leq -t$ and $-t\eta < \delta c_n - c_z \leq t\alpha\eta$. In the condition of $\delta c_n - c_z \leq -t\eta$, $1 - \frac{p_n}{\nu}$ of consumers regardless of their type, purchase only the regular version and hence the same result as selling the regular version only. If $-t\eta < \delta c_n - c_z \leq t\alpha\eta$, there is a demand for the zero waste version from the eco-conscious, but primary consumers do not buy the zero waste version. Then, the expected profit from this condition is

$$E\pi_2 = \alpha\left[(p_n - c_n)\left(1 - \frac{p_n - p_z + t\eta}{(1-\delta)v}\right)\right. \quad (8)$$
$$\left. + (p_z - c_z)\left(\frac{p_n - p_z + t\eta}{(1-\delta)v} - \frac{p_z - t\eta}{\delta v}\right)\right]$$
$$+ (1-\alpha)(p_n - c_n)\left(1 - \frac{p_n}{v}\right).$$

Proposition 2. *If* $-t\eta < \delta c_n - c_z \leq t\alpha\eta$, *selling zero waste only is dominant over selling both versions when* $\delta < \hat{\delta}$ *or* $\delta > \tilde{\delta}$, *and* $\eta < \dot{\eta}$.

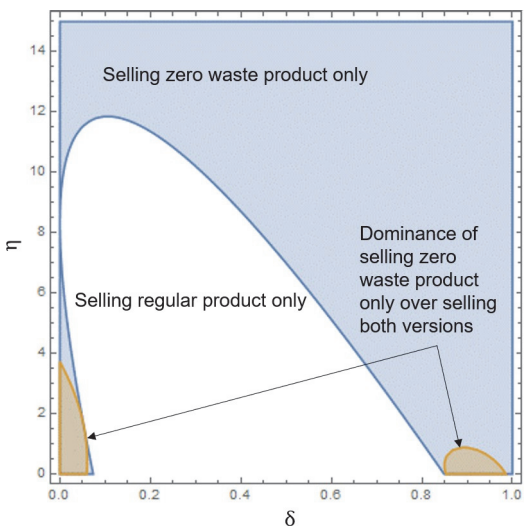
Proposition 2 shows a different result from a prevalent idea such that versioning can catch more consumers of various tastes and hence a better strategy than concentrating on a single version. In the market that the primary consumers do not buy the zero waste version, there is a region that the zero waste only offering prevails over versioning. Since the eco-conscious consumers are the only buyers in this span when there are both options, the zero waste revenue goes along with the size of the segment.

Figure 2 partitions δ and η space into region that the zero waste only is optimal vs. versioning is optimal. In the range of moderate δ, versioning is dominant; however, polarized δ guarantees zero waste dominating. A small δ which gives a big difference to the regular can press down the price of the zero waste and it promotes the zero waste demand, when the zero waste is the only option in the market. As the population of the eco-conscious increases, the region that the zero waste only offering dominates decreases. Ostensibly, large η will positively affect a zero waste offer, but an excessive level of PCE and the size of the eco-conscious cause too high prices and it may crowd out demand. In the presence of a number of eco-conscious consumers, the price of the zero waste rises, so only low PCE can make the zero waste optimal because α, η and δ positively affect the price of the zero waste. Low level of PCE presses down the optimal price such that the manufacturer decides to only produce the zero waste version and it may draw demand of the primary who would not have chosen if there were an alternative.



〈Figure 2〉 Regions of Selling Zero Waste Only and Selling Both Versions as a Dominant Strategy
($\nu = 2$, $c_n = 0.7$, $c_z = 0.5$, $t = 0.3$, $\alpha = 0.2$)

Figure 3 integrates Figure 1 and Figure 2. It shows that the region that selling zero waste only dominates over versioning does not cross the region of selling the regular only.



〈Figure 3〉 Regions of Optimal Strategies
($\nu = 2$, $c_n = 0.7$, $c_z = 0.5$, $t = 0.3$, $\alpha = 0.2$)

Ⅴ. Impact of Subsidies and Social Surplus

The common objectives of the government are to minimize its spending or to maximize the social welfare. The policy maker institutes subsidy program, aiming to maximize social welfare. If the price setting is exogenous, the direct effect of the subsidy is a transfer and hence there is no effect on social welfare. But in the market that customized products are often launched, the firms prefer setting price endogenously considering consumer demand. Taking endogenous pricing into consideration, the government may determine the object and scale of the subsidy program. Then manufacturer launches single or both versions under constraints of consumer demand. The social welfare consists of the sum of the consumer surplus and the producer surplus, minus the government expenditure. The subsidy program may indirectly affect the social welfare by shifting either a demand or supply curve. The government may subsidize different players (Wu & Li, 2021). So, we run into the problem as to which part between consumers and producers should be backed. Yu et al. (2018) show that if retail price is exogenously given, a subsidy on manufacturers is useless so the subsidy should be offered to consumers. However, when the price is determined endogenously, whether to subsidize and to whom it should go depend on the situation. We examine the cases that the government subsidizes consumers and the manufacturer, respectively, and how the entire welfare changes.

5.1 Subsidy on consumers

In this section we look on how the policy works for a firm if the government subsidize consumers. When consumers are subsidized with s upon purchase, the primary consumers

get the utility of

$$U_{zs}^{P} = \delta\theta\nu - p_z + s, \qquad (9)$$

and the eco-conscious consumers enjoy

$$U_{zs}^{E} = \delta\theta\nu - p_z + t\eta + s. \qquad (10)$$

The same logic as above is applied. In this section there can be divided into two cases as well: *case* $\delta c_n - c_z \geq s + t\alpha\eta$ and *case* $\delta c_n - c_z < s + t\alpha\eta$ in general; for the latter, specific three instances as $\delta c_n - c_z \geq t(\alpha-2)\eta + s$ & $\delta c_n - c_z \geq t\alpha\eta - s$, $t\alpha\eta - s > \delta c_n - c_z \geq s - t$ or $s - t\eta > \delta c_n - c_z \geq t\alpha\eta - s$ are derived. Both segments buy the zero waste version inasmuch as $\delta c_n - c_z \geq t(\alpha-2)\eta - s$. If the version is subsidized, the span of demand is extended. When $\delta c_n - c_z \geq s + t\alpha\eta$, $\delta c_n - c_z \geq t(\alpha-2)\eta + s$ & $\delta c_n - c_z \geq t\alpha\eta - s$, or $s - t\eta > \delta c_n - c_z \geq t\alpha\eta - s$, the primary of $\frac{p_z - p_n - s}{(\delta-1)\nu}$ $-\frac{p_z - s}{\delta\nu}$ and the eco-conscious of $\frac{p_z - p_n - s - t\eta}{(\delta-1)\nu}$ $-\frac{p_z - s - t\eta}{\delta\nu}$ purchase the zero waste version. So we can divide the cases again to whether both segments buy the zero waste product or only the eco-conscious buy them. For the case of $\delta c_n - c_z \geq t\alpha\eta - s$, in which there is demand in both segments for the zero waste version and consumers are subsidized, the expected profit is described as

$$\begin{aligned} E\pi_1^c = (1-\alpha)\Big[&(p_n - c_n)\Big(1 - \frac{p_z - p_n - s}{\delta v - v}\Big) \qquad (11)\\ &+ (p_z - c_z)\Big(\frac{p_z - p_n - s}{\delta v - v} - \frac{p_z - s}{\delta v}\Big)\Big]\\ &+ \alpha\Big[(p_n - c_n)\Big(1 - \frac{p_z - p_n - s - t\eta}{\delta v - v}\Big)\\ &+ (p_z - c_z)\Big(\frac{p_z - p_n - s - t\eta}{\delta v - v} - \frac{p_z - s - t\eta}{\delta v}\Big)\Big]. \end{aligned}$$

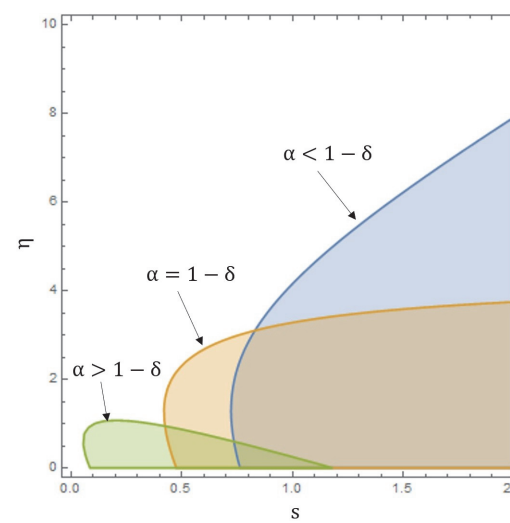
Proposition 3. *If* $\delta c_n - c_z > t\alpha\eta - s$, *subsidies for the zero waste make the manufacturer better off; if* $t\alpha\eta - s > \delta c_n - c_z \geq s - t\eta$, *subsidization below a certain cutoff level* $\hat{s}$ *can lead the manufacturer worse off.*

Proposition 3 indicates that subsidization gives more profit to the manufacturer, when the firm offers both version in the market and where demand arises across consumers. Even though subsidies generally increase the manufacturer′s optimal profit, if subsidies are not high enough, that is, insufficiently set below $\hat{s}$ in the market where the eco-conscious are the sole buyer of the zero waste, subsidization is not a helpful policy for the manufacturer. This result implies that the proportion of the eco-conscious is important in this special market. The subsidy level is to be decided upon the eco-conscious proportion, because no matter how much the subsidy is raised the primary do not cross over their consumption under this condition. The subsidy level $\hat{s}$ is affected by the size of the group and the PCE.

Proposition 4. *If* $t\alpha\eta - s > \delta c_n - c_z \geq s - t\eta$, *offering only a zero waste version dominates over offering both versions under (i)* $s > \ddot{s}$ *when* $\alpha < 1-\delta$, *(ii)* $s > \hat{s}$ *and* $\eta < \check{\eta}$ *when* $\alpha = 1-\delta$, *(iii)* $\dot{s} < s < \ddot{s}$ *and* $\eta < \check{\eta}$ *when* $\alpha > 1-\delta$.

Proposition 4 shows the proportion of the eco-conscious group is related to the quality gap between two versions when versioning decision is made. If the eco-conscious group is smaller than the quality gap, subsidy is the only factor that causes the zero waste only strategy. High subsidy makes the zero waste only strategy more profitable than versioning. However, as the segment gets bigger, compared to quality gap, PCE becomes another major feature that decision makers consider. If the proportion of the group is the same as the quality gap, low PCE with mid and high subsidization makes the firm better off with the zero waste only provision. If the proportion is larger than the quality gap, little PCE with low subsidy enables the zero waste only strategy better than versioning. Figure 4 demonstrates optimal region of selling the zero waste only (colored graphic), and the outer part shows versioning is optimal. When the population is big, PCE does not need to be high, and more than appropriate subsidization can rather lead to inefficiency.

Subsidies serve to arouse demand in groups that have not previously had a need for it. For example, in the market that the zero waste products are in demand only by the eco-conscious when versioning, if there exists a small population of the eco-conscious with low PCE, the monopolist can draw primary consumers who are interested in subsidization by contracting to single version with high subsidy. This result is applicable regardless of each cost scale since subsidy prevails over cost difference.



〈Figure 4〉 Regions of Selling Zero Waste Only is Optimal

($\nu = 2$, $c_n = 0.7$, $c_z = 0.5$, $t = 0.3$,$\alpha = 0.5$; $\delta = 0.8, 0.5, 0.2$ from bottom left to upper right)

5.2 Subsidy on manufacturer

In this section we find how the policy works for a firm if the government directly subsidize the manufacturer. The cases above can be re-

arranged to a case that both segments all buy the zero waste version and the other case that only the eco-conscious buy the zero waste version, when there are two versions offered in the market. If the manufacturer is subsidized, demand does not change but there can be a profit growth. When demand exists across the market, which is the case of $\delta c_n - c_z \geq t\alpha\eta - s$, with manufacturer subsidy, the expected profit is

$$\begin{aligned} E\pi_1^m = \alpha\Big[&(p_z - c_z + s)\left(\frac{p_z - p_n - t\eta}{(\delta-1)v} - \frac{p_z - t\eta}{\delta v}\right) \\ &+ (p_n - c_n)\left(1 - \frac{p_z - p_n - t\eta}{(\delta-1)v}\right)\Big] \\ &+ (1-\alpha)\Big[(p_z - c_z + s)\left(\frac{p_n - p_z}{(1-\delta)v} - \frac{p_z}{\delta v}\right) \\ &+ (p_n - c_n)\left(1 - \frac{p_z - p_n}{(\delta-1)v}\right)\Big]. \end{aligned} \quad (12)$$

Proposition 5. *In the market that both segments buy the zero waste, the monopolist is indifferent between subsidization on manufacturer or on consumers, whereas subsidization on manufacturer is an optimal policy where there is demand for the zero waste from the eco-conscious only.*

Proposition 5 shows that the firm will respond to the subsidy policy with persuading the government to give subsidies to itself, because it does not know which market it will encounter. The manufacturer will try to negotiate with the authorities emphasizing the government will spend the same budget. It will also suggest active cooperation with government policies such as creating jobs, investing in the infrastructure, etc.

5.3 Social welfare

Welfare is defined by the consumer surplus and the producer surplus, minus the government expenditures (Cohen et al., 2015):

$$SW = CS + PS - G. \quad (13)$$

The government spending G is composed of the subsidy s on consumers or a producer, minus the benefit of waste reduction ω by zero waste manufacturing. Now we investigate the impact of subsidy programs on the social welfare and a policy maker's possible decision. If consumers are subsidized, both segments buy the zero waste in the range of $\delta c_n - c_z \geq t\alpha\eta - s$. Then social welfare becomes

$$\begin{aligned} SW_1^c = \alpha\Bigg[&\int_{\frac{p_z - p_n - s - t\eta}{\delta v - v}}^{1} (\theta v - p_n)\, d\theta + (p_n - c_n)\left(1 - \frac{p_z - p_n - s - t\eta}{\delta v - v}\right) \\ &+ \int_{\frac{p_z - s - t\eta}{\delta v}}^{\frac{p_z - p_n - s - t\eta}{\delta v - v}} (\delta\theta v - p_z + s + t\eta)\, d\theta \\ &+ (p_z - c_z - s + \omega)\left(\frac{p_z - p_n - s - t\eta}{\delta v - v} - \frac{p_z - s - t\eta}{\delta v}\right)\Bigg] \\ &+ (1-\alpha)\Bigg[\int_{\frac{p_z - p_n - s}{\delta v - v}}^{1} (\theta v - p_n)\, d\theta + (p_n - c_n)\left(1 - \frac{p_z - p_n - s}{\delta v - v}\right) \\ &+ \int_{\frac{p_z - s}{\delta v}}^{\frac{p_z - p_n - s}{\delta v - v}} (\delta\theta v - p_z + s)\, d\theta \\ &+ (p_z - c_z - s + \omega)\left(\frac{p_z - p_n - s}{\delta v - v} - \frac{p_z - s}{\delta v}\right)\Bigg]. \end{aligned} \quad (14)$$

If the producer is subsidized, both consumers buy the zero waste when $\delta c_n - c_z \geq t\alpha\eta$. The welfare function is

$$
\begin{aligned}
SW_1^m = \alpha \Bigg[& \int_{\frac{p_z - p_n - t\eta}{\delta v - v}}^{1} (\theta v - p_n)\, d\theta + (p_n - c_n)\left(1 - \frac{p_z - p_n - t\eta}{\delta v - v}\right) \\
& + \int_{\frac{p_z - t\eta}{\delta v}}^{\frac{p_z - p_n - t\eta}{\delta v - v}} (\delta\theta v - p_z + t\eta)\, d\theta \\
& + (p_z - c_z + s - (s - \omega))\left(\frac{p_z - p_n - t\eta}{\delta v - v} - \frac{p_z - t\eta}{\delta v}\right)\Bigg] \qquad (15) \\
& + (1 - \alpha)\Bigg[\int_{\frac{p_z - p_n}{\delta v - v}}^{1} (\theta v - p_n)\, d\theta + (p_n - c_n)\left(1 - \frac{p_z - p_n}{\delta v - v}\right) \\
& + \int_{\frac{p_z}{\delta v}}^{\frac{p_z - p_n}{\delta v - v}} (\delta\theta v - p_z)\, d\theta + (p_z - c_z + s - (s - \omega))\left(\frac{p_z - p_n}{\delta v - v} - \frac{p_z}{\delta v}\right)\Bigg].
\end{aligned}
$$

In the same manner, only the eco-conscious buy the zero waste under $t\alpha\eta - s > \delta c_n - c_z \geq s - t\eta$, if consumers are subsidized. And if the producer is subsidized, only the eco-conscious buy the zero waste under $t\alpha\eta \geq \delta c_n - c_z > -t\eta$.

Proposition 6. *In the general market an optimal subsidy is lower than or equal to that of the market that only the eco-conscious buy the zero waste ($s_1^* \leq s_2^*$); however, social welfare of the general market is higher than or equal to that of the other market.*

Proposition 6 indicates that the unconditionally high subsidy does not guarantee increasing social welfare. With lower subsidy, social welfare can increase, and the government can save extra expenditures. The subsidy (s_1^*) of the general market is lower than the subsidy (s_2^*) of the market that only the eco-conscious buy the zero waste, but social welfare is higher if the subsidy is applied. Depending on the subsidy level, primary consumers or eco-conscious consumers that were not interested in the zero waste may head for the products. There are optimal subsidy levels for each market, but the lower subsidy creates the larger social welfare in this case. Policy makers can induce consumers from both segments to buy the zero waste by setting slightly low subsidies for the zero waste and increase social welfare.

Ⅵ. Conclusion

Recycling have long been claimed as alternatives to the sustainable production. Zero waste model is one of the ways that can realize both environmental preservation and sustainable production. Contrary to the idea, it is difficult to be well accepted by consumers who want their consumption is flawless. A basic premise of the research is that not every consumer is selfish unlike an assumption of a rational profit seeker as a sole responder to a firm, so we differentiate consumer groups as the way in which it has been dealt in behavioral studies. This observation motivates us to investigate viability of zero waste production under consumer segmentation,

and implication for policymakers. We further analyze versioning decision and social welfare problem when subsidies are given.

Our results have meaningful implications despite of several limitations. We find the condition under which offering single version is dominant over offering both versions, even though we also verify that the preeminence of versioning is usually applicable. Positive factor η and α for the zero waste can affect negatively the zero waste manufacturing, if they are too high. Rather low PCE can make the zero waste only optimal.

Our findings further extend to policy and welfare problems. We analyze the impact of subsidies on each side and social welfare. Under subsidization, versioning strategies differ upon the range of a perceived consumer effectiveness, the size of a subsidy, and a proportion of the eco-conscious group. We show subsidies are not always functional from the perspective of a manufacturer. With consumer subsidy, the manufacturer will gain more profit in general market, however, the profit will decrease compared to no subsidization if the subsidy is not high enough for the manufacturer.

We show that the high subsidy does not guarantee increasing social welfare, when market structure is known. Contrary to the manufacturer profit, social welfare increases with lower subsidy and hence the government can save budget. The optimal subsidy level of the general market that both segments buy the zero waste is lower than the optimal subsidy of the market that only the eco-conscious buy the zero waste. Even though the subsidy is small, it creates the larger social welfare. Policy makers can implement an effective policy by setting small subsidies for the zero waste and increase social welfare. This article can be improved by inspiring future research to verify by extending the period and involving more players. It would also be useful to examine how the quality decision is impacted by consumer perception and subsidies.

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〈Appendix〉

Proof of Proposition 1. We compare the expected optimal profit from selling regular version only ($E\pi_n^{m*}$) to the expected optimal profit from selling zero waste version only ($E\pi_z^{m*}$) when there is a mix of consumers.

$$E\pi_n^m = \alpha(p_n - c_n)\left(1 - \frac{p_n}{v}\right) + (1-\alpha)(p_n - c_n)\left(1 - \frac{p_n}{v}\right) \tag{16}$$

leads to

$$E\pi_n^{m*} = \frac{(v - c_n)^2}{4v}, \tag{17}$$

and

$$E\pi_z^m = \alpha(p_z - c_z)\left(1 - \frac{p_z - t\eta}{\delta v}\right) + (1-\alpha)(p_z - c_z)\left(1 - \frac{p_z}{\delta v}\right) \tag{18}$$

to the optimal price $p_z^{m*} = \frac{1}{2}(c_z + t\alpha\eta + \delta v)$ where there is a mix of consumers. Then the expected profit thereof becomes

$$E\pi_z^{m*} = \frac{(t\alpha\eta - c_z + \delta v)^2}{4\delta v}. \tag{19}$$

Then, we get $\hat{\delta} = \frac{-2vc_n + c_n^2 + 2vc_z + v^2}{2v^2} - \frac{1}{2}\sqrt{\frac{-4v^3c_n - 8v^2c_nc_z + 6v^2c_n^2 + 4vc_n^2c_z - 4vc_n^3 + c_n^4 + 4v^3c_z + v^4}{v^4}}$ and $\tilde{\delta} = \frac{-2vc_n + c_n^2 + 2vc_z + v^2}{2v^2} + \frac{1}{2}\sqrt{\frac{-4v^3c_n - 8v^2c_nc_z + 6v^2c_n^2 + 4vc_n^2c_z - 4vc_n^3 + c_n^4 + 4v^3c_z + v^4}{v^4}}$, also $\hat{\eta} = \frac{c_z - \delta v}{\alpha t} - \sqrt{\frac{\delta c_n^2 - 2\delta v c_n + \delta v^2}{\alpha^2 t^2}}$ and $\tilde{\eta} = \frac{c_z - \delta v}{\alpha t} + \sqrt{\frac{\delta c_n^2 - 2\delta v c_n + \delta v^2}{\alpha^2 t^2}}$ by comparing (17) and (19). ■

Proof of Proposition 2. The optimal prices for each version are $p_z^{2*} = \frac{1}{2}(c_z + t\eta + \delta v)$ and $p_n^{2*} = \frac{1}{2}(c_n + v)$. The optimal profit is

$$E\pi_2^* = \frac{1}{4(\delta-1)\delta v}[\delta(\delta-\alpha\delta-1)c_n^2 + 2\delta c_n(\alpha c_z - \alpha t\eta - \delta v + v) + \alpha c_z(2t\eta - c_z) - \alpha t^2\eta^2 + (\delta-1)\delta v^2]. \quad (20)$$

In the condition of $\delta c_n - c_z \leq -t\eta$, there is no demand for the zero waste. The optimal profit from both versions (20) is greater than the regular version (17). However, (19) is greater than (20) under the condition that δ is less than $\hat{\delta}$ or greater than $\tilde{\delta}$, and η is less than $\dot{\eta} = \sqrt{\frac{1}{\alpha t^2(\alpha\delta-\alpha+1)^2} * Y} + \frac{-\delta c_n + \delta c_z + \delta^2(-v) + \delta v}{t(\alpha\delta-\alpha+1)}$,

where $Y = (-\alpha^2\delta^3 c_n^2 + \alpha^2\delta^2 c_n^2 + \alpha\delta^3 c_n^2 - 2\alpha\delta^2 c_n^2 + \alpha\delta c_n^2 + \delta^2 c_n^2 - \delta c_n^2 + 2\alpha\delta^2 v c_n - 2\alpha\delta v c_n - 2\delta^2 v c_n + 2\delta v c_n + 2\alpha^2\delta^2 c_n c_z - 2\alpha^2\delta c_n c_z - 2\alpha\delta^2 c_n c_z + 2\alpha\delta c_n c_z - 2\alpha\delta^2 v c_z + 2\alpha\delta v c_z + 2\delta^2 v c_z - 2\delta v c_z - \alpha^2\delta c_z^2 + \alpha^2 c_z^2 + 2\alpha\delta c_z^2 - 2\alpha c_z^2 - \delta c_z^2 + c_z^2 + \alpha\delta^3 v^2 - 2\alpha\delta^2 v^2 + \alpha\delta v^2 + \delta^3(-v^2) + 2\delta^2 v^2 - \delta v^2)$. ■

Proof of Proposition 3. Since $\frac{\partial^2 E\pi_1^S}{\partial p_n^2} = -\frac{2}{v-\delta v} < 0$, the F.O.C. results in $p_n = \frac{1}{2}(c_n - c_z + 2p_z - s - t\alpha\eta - \delta v + v)$. $\frac{\partial^2 E\pi_1^S}{\partial p_z^2} = -\frac{2}{\delta v - \delta^2 v} < 0$ leads to $p_z = \frac{1}{2}(-\delta c_n + c_z + 2\delta p_n + s + t\alpha\eta)$. So, $p_n^* = \frac{1}{2}(c_n + v)$ and $p_z^* = \frac{1}{2}(c_z + s + t\alpha\eta + \delta v)$, then the optimal profit is

$$E\pi_1^{c*} = \frac{1}{4(1-\delta)\delta v}(\delta c_n^2 + 2\delta c_n(s - c_z + t\alpha\eta + \delta v - v) - 2c_z(s + \alpha t\eta) + c_z^2 + s^2 + 2t\alpha\eta s + t^2\alpha^2\eta^2 - \delta^2 v^2 + \delta v^2). \quad (21)$$

By comparing (33) and (21), the first statement of Proposition 3 is proved. Now we analyze the case that the specific consumer segment buys the zero waste version. In the case of $t\alpha\eta - s > \delta c_n - c_z \geq -t\eta$, where there is no demand for the zero waste in the primary, the expected profit with consumer subsidy is

$$E\pi_2^c = (1-\alpha)(p_n - c_n)\left(1 - \frac{p_n}{v}\right) + \alpha\left[(p_n - c_n)\left(1 - \frac{p_z - p_n - s - t\eta}{\delta v - v}\right) + (p_z - c_z)\left(\frac{p_z - p_n - s - t\eta}{\delta v - v} - \frac{p_z - s - t\eta}{\delta v}\right)\right]. \quad (22)$$

The optimal price and corresponding profit are $p_z^* = \frac{1}{2}(c_z + s + \eta t + \delta v)$ and

$$E\pi_2^{c*} = \frac{1}{4(1-\delta)\delta v}[\delta\big((\alpha-1)\delta+1\big)c_n^2 + 2\delta c_n(\alpha(s+t\eta) - \alpha c_z + (\delta-1)v) - 2\alpha c_z(s+t\eta) + \alpha c_z^2 + \alpha s^2 + 2t\alpha\eta s - t^2\alpha^3\eta^2 + 2t^2\alpha^2\eta^2 - \delta^2 v^2 + \delta v^2]. \quad (23)$$

It is clearly obtained that (20) is bigger than (23),
when $s < \hat{s}\ \left(\hat{s} = c_z - t\eta - \delta c_n + \sqrt{\delta^2 c_n^2 + 2\delta\eta t c_n - 2\delta c_n c_z - 2\eta t c_z + c_z^2 + \alpha^2\eta^2 t^2 - 2\alpha\eta^2 t^2 + 2\eta^2 t^2}\right)$. ■

Proof of Proposition 4. The profit from mix of consumers with subsidy, when selling the zero waste only is

$$E\pi_{zs}^m = \alpha(p_z - c_z)\left(1 - \frac{p_z - s - \eta t}{\delta v}\right) + (1-\alpha)(p_z - c_z)\left(1 - \frac{p_z - s}{\delta v}\right). \quad (24)$$

The optimal price and profit thereof are $p_{zs}^{m*} = \frac{1}{2}(c_z + s + \alpha\eta t + \delta v)$ and

$$E\pi_{zs}^{m*} = \frac{(-c_z + s + \alpha\eta t + \delta v)^2}{4\delta v}. \quad (25)$$

By comparing (23) and (25), (23) can be greater than (23) in certain conditions. The conditions are $s > \ddot{s}\left(= \frac{-\alpha\delta c_n + \alpha c_z + \delta c_z - c_z - \alpha\delta\eta t + \delta^2(-v) + \delta v}{\alpha+\delta-1} + \sqrt{\frac{1}{(\alpha+\delta-1)^2}H}\right)$, where $H = -\alpha\delta^3 c_n^2 + 2\alpha\delta^2 c_n^2 - \alpha\delta c_n^2 + \delta^3 c_n^2 - 2\delta^2 c_n^2 + \delta c_n^2 + 2\alpha^2\delta^2\eta t c_n - 2\alpha^2\delta\eta t c_n - 2\alpha\delta^2\eta t c_n + 2\alpha\delta\eta t c_n + 2\alpha\delta^3 v c_n - 4\alpha\delta^2 v c_n + 2\alpha\delta v c_n - 2\delta^3 v c_n + 4\delta^2 v c_n - 2\delta v c_n + \alpha^4\eta^2 t^2 - 2\alpha^3\eta^2 t^2 + \alpha^2\eta^2 t^2 - 2\alpha^2\delta^2\eta t v + 2\alpha^2\delta\eta t v + 2\alpha\delta^2\eta t v - 2\alpha\delta\eta t v - \alpha\delta^3 v^2 + 2\alpha\delta^2 v^2 - \alpha\delta v^2 + \delta^3 v^2 - 2\delta^2 v^2 + \delta v^2$, when $\alpha < 1-\delta$;
$s > \hat{s}\left(= \frac{1}{2\alpha\delta c_n - 2\alpha c_z - 2\delta c_z + 2c_z + 2\alpha\delta\eta t + 2\delta^2 v - 2\delta v}(-\alpha\delta^2 c_n^2 + \delta^2 c_n^2 - \delta c_n^2 - 2\alpha\delta\eta t c_n - 2\delta^2 v c_n + 2\delta v c_n + 2\alpha\delta c_n c_z + 2\alpha\delta\eta t c_z + 2\delta^2 v c_z - 2\delta v c_z - \alpha c_z^2 - \delta c_z^2 + c_z^2 + \alpha^3\eta^2 t^2 - \alpha^2\delta\eta^2 t^2 - \alpha^2\eta^2 t^2 - 2\alpha\delta^2\eta t v + 2\alpha\delta\eta t v - \delta^3 v^2 + 2\delta^2 v^2 - \delta v^2)\right)$ and $\eta < \breve{\eta}\left(= \frac{-\delta^2 c_n + \delta c_n + \delta^2 v - \delta v}{(\alpha^2-\alpha)t} - \sqrt{\frac{1}{(\alpha-1)^2\alpha^2 t^2}K}\right)$, where $K = \alpha\delta^3 c_n^2 - 2\alpha\delta^2 c_n^2 + \alpha\delta c_n^2 + \delta^4 c_n^2 - 3\delta^3 c_n^2 + 3\delta^2 c_n^2 - \delta c_n^2 - 2\alpha\delta^3 v c_n + 4\alpha\delta^2 v c_n - 2\alpha\delta v c_n - 2\delta^4 v c_n + 6\delta^3 v c_n - 6\delta^2 v c_n + 2\delta v c_n + \alpha\delta^3 v^2 - 2\alpha\delta^2 v^2 + \alpha\delta v^2 + \delta^4 v^2 - 3\delta^3 v^2 + 3\delta^2 v^2 - \delta v^2$.
Also, $\dot{s}\left(= \frac{-\alpha\delta c_n + \alpha c_z + \delta c_z - c_z - \alpha\delta\eta t + \delta^2(-v) + \delta v}{\alpha+\delta-1} - \sqrt{\frac{1}{(\alpha+\delta-1)^2}H}\right) < s < \ddot{s}$ and $\eta < \breve{\eta}$, when $\alpha > 1-\delta$. ■

Proof of Proposition 5. The optimal profit is

$$E\pi_1^{m*} = \frac{1}{4(1-\delta)\delta v}(\delta c_n^2 + 2\delta c_n(-c_z + s + \alpha\eta t + \delta v - v) - 2c_z(s + \alpha\eta t) + c_z^2 + s^2 + 2\alpha\eta st + \alpha^2\eta^2 t^2 - \delta^2 v^2 + \delta v^2), \tag{26}$$

and this is the same result as the consumer subsidy case (21). The expected profit in the case where there is no demand for the zero waste in the primary becomes

$$E\pi_2^m = \alpha\left[(p_z - c_z + s)\left(\frac{p_z - p_n - t\eta}{(\delta-1)v} - \frac{p_z - t\eta}{\delta v}\right) + (p_n - c_n)\left(1 - \frac{p_z - p_n - t\eta}{(\delta-1)v}\right)\right] + (1-\alpha)(p_n - c_n)\left(1 - \frac{p_n}{v}\right), \tag{27}$$

and the tied profit is

$$\pi_2^{m*} = \frac{1}{4(1-\delta)\delta v}[\delta\big((\alpha-1)\delta + 1\big)c_n^2 + 2\delta c_n(\alpha(s + t\eta) - \alpha c_z + (\delta-1)v) - 2\alpha c_z(s + t\eta) + \alpha c_z^2 + \alpha s^2 + 2t\alpha\eta s + t^2\alpha\eta^2 - \delta^2 v^2 + \delta v^2]. \tag{28}$$

And (28) is larger than (23). ■

Proof of Proposition 6. In the same manner as (11), only the eco-conscious buy the zero waste under $t\alpha\eta - s > \delta c_n - c_z \geq s - t\eta$, if consumers are subsidized. Social welfare of this case is

$$\begin{aligned} SW_2^c = \alpha\Bigg[&(p_n - c_n)\left(1 - \frac{p_z - p_n - s - t\eta}{\delta v - v}\right) \\ &+ (p_z - c_z)\left(\frac{p_z - p_n - s - t\eta}{\delta v - v} - \frac{p_z - s - t\eta}{\delta v}\right) \\ &+ \int_{\frac{p_z - s - t\eta}{\delta v}}^{\frac{p_z - p_n - s - t\eta}{\delta v - v}} (t\eta - p_z + s + \delta\theta v)\, d\theta + \int_{\frac{p_z - p_n - s - t\eta}{\delta v - v}}^{1} (\theta v - p_n)\, d\theta \\ &- (s - \omega)\left(\frac{p_z - p_n - s - t\eta}{\delta v - v} - \frac{p_z - s - t\eta}{\delta v}\right)\Bigg] \\ &+ (1-\alpha)\{(p_n - c_n)\left(1 - \frac{p_n}{v}\right) + \int_{\frac{p_n}{v}}^{1} (\theta v - p_n)\, d\theta\}. \end{aligned} \tag{29}$$

And if the producer is subsidized, only the eco-conscious buy the zero waste under $t\alpha\eta \geq \delta c_n - c_z > -t\eta$. Then social welfare is

$$
\begin{aligned}
SW_2^m = \alpha \Bigg[& (p_z - c_z + s)\left(\frac{p_z - p_n - t\eta}{\delta v - v} - \frac{p_z - t\eta}{\delta v}\right) + (p_n - c_n)\left(1 - \frac{p_z - p_n - t\eta}{\delta v - v}\right) \\
& - (s - \omega)\left(\frac{p_z - p_n - t\eta}{\delta v - v} - \frac{p_z - t\eta}{\delta v}\right) + \int_{\frac{p_z - t\eta}{\delta v}}^{\frac{p_z - p_n - t\eta}{\delta v - v}} (t\eta - p_z + \delta\theta v)\, d\theta \\
& + \int_{\frac{p_z - p_n - t\eta}{\delta v - v}}^{1} (\theta v - p_n)\, d\theta \Bigg] \\
& + (1 - \alpha)\left[(p_n - c_n)\left(1 - \frac{p_n}{v}\right) + \int_{\frac{p_n}{v}}^{1} (\theta v - p_n)\, d\theta\right].
\end{aligned} \tag{30}
$$

If consumers or producers are subsidized, both segments buy the zero waste in the range of $\delta c_n - c_z \geq t\alpha\eta - s$. Then social welfare becomes

$$
\begin{aligned}
SW_1^* = \frac{1}{8(\delta - 1)\delta v} [& -3\delta c_n^2 - 2\delta c_n(\delta c_n - 4c_z + 4\alpha\eta t + 3\delta v - 3v + 4\omega) \\
& + (\delta c_n - c_z + \alpha\eta t + 2\omega)^2 - 2\alpha\eta t(\delta c_n - c_z + \alpha\eta t + 2\omega) \\
& - 4\omega(\delta c_n - c_z + \alpha\eta t + 2\omega) + 2c_z(\delta c_n - c_z + 4\alpha\eta t + 4\omega) - 3c_z^2 \\
& + \alpha^2\eta^2 t^2 - 4\alpha\eta^2 t^2 - 4\alpha\eta t\omega + 3\delta^2 v^2 - 3\delta v^2].
\end{aligned} \tag{31}
$$

SW_1 is concave in s, so the optimal subsidy is $s_1^* = \delta c_n - c_z + t\alpha\eta + 2\omega$. In the same manner, only the eco-conscious buy the zero waste under $t\alpha\eta - s > \delta c_n - c_z \geq s - t\eta$, regardless of which side is subsidized. The social welfare is

$$
\begin{aligned}
SW_2^* = \frac{1}{8\delta v(1 - \delta)} [& 3\delta\big((\alpha - 1)\delta + 1\big)c_n^2 \\
& + 2\delta c_n(\alpha(\delta c_n - c_z + 4\eta t + 4\omega) - 3\alpha c_z + 3(\delta - 1)v) \\
& - \alpha(\delta c_n - c_z + \eta t + 2\omega)^2 + 2\alpha\eta t(\delta c_n - c_z + \eta t + 2\omega) \\
& + 4\alpha\omega(\delta c_n - c_z + \eta t + 2\omega) - 2\alpha c_z(\delta c_n - c_z + 4\eta t + 4\omega) + 3\alpha c_z^2 \\
& + 3\alpha\eta^2 t^2 + 4\alpha\eta t\omega - 3\delta^2 v^2 + 3\delta v^2],
\end{aligned} \tag{32}
$$

and $s_2^* = \delta c_n - c_z + t\eta + 2\omega$. Therefore, $s_1^* \leq s_2^*$, but $SW_1^* \geq SW_2^*$. ■