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ECONOMIC AND ENVIRONMENTAL EFFECTS OF REFILL PACKS

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ABSTRACT

It is common sense that refill packs can increase the repeated use of durable goods, reduce resource waste and be conducive to environmental protection. However, their existence also has an economic effect. For instance, we find that the profit of a monopolistic firm will increase as a result of selling the refill packs when the depreciation rate of the durable good is low. In an extension of the model, we point out that there is an entrant that competes with the incumbent in relation to the composite goods and the refill packs. In order to compete in terms of the prices of the composite goods, the incumbent sells the refill packs not only to increase profit, but also to reduce the amount of waste resulting from the durable goods. As for competing in regard to the prices of the refill packs, if the cost of the composite goods is small, then the incumbent's profit from selling the composite goods will increase. By comparing two extensions of the model, we find that the environmental effect of the price competition in regard to the refill packs is greater than the environmental effect of the price competition in relation to the composite goods.

Keywords: price competition, refill packs, transaction cost

JEL classification numbers: L22, Q53

I. INTRODUCTION

The 3R (Reduce, Reuse and Recycle) Initiative was agreed upon at the G8 Summit held on Sea Island, Georgia, U.S.A. from 8 to 10 June, 2004. By implementing the 3R, people can avoid wasting the world's resources and reduce the amount of waste. Using and selling refill packs is the best way of implementing the initiative (the 3R Initiative (Japan) website).

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Refill packs have become an important issue in both the economy and the environment. Canada and some Western European countries in the 1970s prohibited the importation of un-refilled bottles of beer in order to encourage the containers to be reused. This action caused the United States to launch a protest with the GATT, but the GATT ruled in favour of Canada in 1993. Brewers in the United States compromised with this verdict through the adoption of beer bottles that could be re-used (Institute for Local Self-Reliance, 1992). Hence, many international enterprises have regarded refill packs as an important part of green marketing. For example, Palmolive introduced a new design for its refill packs of liquid detergent for the kitchen sink (Ottman, 1997). Following the trend of global environmental protection, manufacturers in Taiwan have made great efforts to provide refill packs, including for washing liquids, sanitizers and pens. Moreover, while traditional telephone cards were in the past thrown away after being used up, innovative telephone cards now have a value-restoring function.

Many products are composed of durable as well as exhaustible goods. The exhaustible goods are exhausted within a short time period, while the durable goods can still be used. If we take shampoo as an example, the liquid shampoo is an exhaustible product, whereas the container of the liquid shampoo is a durable product. The combination of the two can result in a composite product. The life cycle of the composite goods can be prolonged by providing refills of exhaustible goods (e.g., liquid shampoo) that are placed in the durable goods (e.g., the containers). As such, exhaustible goods always appear in the market alongside the refillable goods. Because the refill packs prolong the use of the durable goods, the amount of the durable goods wasted is reduced. It is obvious that there is an environmental protection effect for a firm selling refill packs. However, the behaviour of a consumer that purchases the refill packs depends on the consumer's transaction cost. If the transaction cost is high, then the consumer will choose to repurchase a new composite good, and if the transaction cost is low, then the consumer will choose to buy the refill packs.

This paper focuses on the price competition between a multi-product firm and a single-product firm. A multi-product firm produces both the composite goods and the exhaustible goods. A single-product firm only produces either the composite goods or the exhaustible goods. Hence, we consider two scenarios whereby the single-product firm competes with the multi-product firm either in the composite goods or in the exhaustible goods. Because the productive types of the two firms are different, the market structure in this paper is defined as an 'asymmetric' duopoly. Consumers are heterogeneous since each of them has a different transaction cost. Our model is closely related to Matutes and Regibeau (1988), Farrell *et al.* (1998), Liao and Urbano (2002) and Liao and Tauman (2002). We summarize the major differences among these papers and this one in Table 1.

Besides the four papers in Table 1, a number of studies also focus on the components and the compatibility of modules, for example, Katz and Shapiro (1985), Economides (1989), Economides and Salop (1992), Tauman *et al.* (1997), etc. However, the model set-up of these articles is a one-period setting, although some articles do incorporate a two-period setting and formally model the transaction cost for consumers, for example, Klemperer (1988, 1989), Beggs and Klemperer (1992), etc. We use a two-period set-up and employ the transaction cost to characterize the consumers' heterogeneity in our paper.

The previous literature reveals a lack of analysis on the environmental effect. Thus we establish a two-period, one-stage model with heterogeneous consumers to discuss the environmental and economic effects of selling the refill packs. In the first period all consumers purchase one unit of composite good. Consumers can then choose to buy the refill packs or the composite goods in the second period. If the consumers choose to buy the refill packs in the second period, then the consumers have to bear a transaction cost. The transaction cost depends on each consumer's ability. If the consumer has a high (low) degree of ability to combine the refill packs and the

TABLE 1
Comparison of model set-ups among related articles

	Matutes and Regibeau (1988)	*Farrell et al. (1998)*	*Liao and Urbano (2002)/Liao and Tauman (2002)*	*Current Research*
Market structure	Duopoly	Oligopoly	Duopoly/ monopoly and duopoly	Asymmetric duopoly
Types of consumers	Heterogeneous	Homogeneous	Heterogeneous	Heterogeneous
Per unit costs	Zero	Stochastic	Variable depends on products and firms	Variable depends on products and firms
Game structure	One-period one stage	One-period one stage	One-period two stage	Two-period one stage
Focus	Economic effect	Economic effect	Economic effect	Economic effect and environmental effect

durable goods and let the composite goods work, then the transaction cost is low (high). Hence, a consumer with a high transaction cost will prefer to repurchase the composite goods instead of buying the refill packs.

The remainder of the paper is organized as follows. The benchmark model is set up in Section II. Section III presents the solutions and the results of the benchmark model. Section IV extends the benchmark model to the duopoly model. In Section V, we re-discuss the model after relaxing some assumptions, and compare our results with the literature. Section VI concludes this paper.

II. THE BENCHMARK MODEL

The benchmark model is a two-period monopolistic model. The monopolistic firm sells composite goods, which are made up of durable goods and exhaustible goods in two periods. The composite goods, durable goods and exhaustible goods are defined respectively as Z, X and Y, where X and Y are complementary products. For example, the container (X) is filled up with detergent (Y) to become a composite good (Z). The exhaustible goods also include the 'refill packs'.

We assume that the life cycle of the durable good is two periods, while the life cycle of the exhaustible good is only one period. The durable goods incur depreciation after being used for one period. Like a penholder that becomes slightly broken after being used, depreciation lowers the consumers' reservation utility from keeping the ballpoint pen. To describe this phenomenon, we define θ as the extent of the depreciation of the durable good, where $\theta \in [0, 1]$. The depreciation becomes serious when θ is large.

We assume that the consumers are uniformly distributed at one-unit intervals and that all consumers buy one unit of composite goods in the first period. However, the consumer can choose to repurchase the composite goods or buy the refill packs in the second period. If a consumer's location is $L \in [0, 1]$ and this consumer chooses to buy refill packs, then the consumer's transaction cost is tL, where $t > 1$. Because each consumer has a different degree

of knowledge regarding a product's recombination, the transaction cost setting is reasonable. The transaction cost setting also implies that each consumer is heterogeneous. The parameter V is defined as the reservation utility derived by the consumer from buying one unit of the composite goods in the first period.

The unit production costs of Z, X and Y for the monopolistic firm are c_Z, c_X and c_Y, respectively. Without loss of generality, we assume that $V > c_Z > c_X + c_Y > c_X, c_Y > 0$. The condition $V > c_Z$ guarantees that each consumer is willing and able to buy one unit of the composite goods. Because a cost is incurred as different items are combined to obtain the composite goods, the condition $c_Z > c_X + c_Y$ must be satisfied.

In the first period, the monopolistic firm does not know the consumers' second-period choices, and thus we adopt backward induction to solve the sub-game perfect Nash equilibrium. Because this is a two-period model, we define δ as the discount rate, where $\delta \in [0, 1]$.

III. THE BENCHMARK MODEL SOLUTION

The consumer's net utility from buying Y in the second period is $(1 - \theta)V - P_Y - tL$, where P_Y is the price of Y. The consumer's net utility from repurchasing Z in the second period is $V - P_{Z2}$, where P_{Z2} is the price of Z in the second period. The rational constraint of a consumer who is located at L and buys Y in the second period is

$$(1 - \theta)V - P_Y - tL \geq 0 \tag{1}$$

The incentive constraint of this consumer is

$$(1 - \theta)V - P_Y - tL \geq V - P_{Z2} \tag{2}$$

Because θ and $L \in [0, 1]$, and $t \geq 1$, it is necessary to make sure that $P_{Z2} \geq P_Y$ holds. This shows that the price of the refill packs is always no higher than the price of the composite goods. On the other hand, if the consumer's transaction cost is large enough, then the consumer will choose not to buy the refill packs, but will instead repurchase the composite goods.

The profit maximization problem for the monopolistic firm in the second period is

$$\underset{P_Y, P_{Z2}}{\text{Max}}\ \pi_2^m = (P_Y - c_Y)Q_Y + (P_{Z2} - c_Z)Q_{Z2} \tag{3a}$$

$$\text{s.t. } (1 - \theta)V - P_Y - tL \geq 0 \tag{3b}$$

$$V - P_{Z2} \geq 0 \tag{3c}$$

$$(1 - \theta)V - P_Y - tL \geq V - P_{Z2} \tag{3d}$$

$$V - P_{Z2} \geq (1 - \theta)V - P_Y - tL \tag{3e}$$

where Q_Y and Q_{Z2} are the quantities demanded of Y and Z, respectively. Equation (3a) is the profit function for the monopolistic firm in the second period. Equations (3b) and (3c) are rational constraints for the consumer to buy Y and Z, respectively. Equations (3d) and (3e) are incentive constraints for a consumer to buy Y and Z, respectively.

From Equations (3d) and (3e), the marginal consumer who is indifferent towards buying Y or buying Z is

$$L^m = [(1 - \theta)V - P_Y - (V - P_{Z2})]/t \tag{3f}$$

Hence, the quantity of Y demanded is $Q_Y = L^m$ and the quantity of Z demanded is $Q_{Z2} = 1 - L^m$. The optimal problem can be simplified as follows:

$$\underset{P_Y, P_{Z2}}{\text{Max}}\ \pi_2^m = (P_Y - c_Y)Q_Y + (P_{Z2} - c_Z)Q_{Z2} \tag{3g}$$

$$\text{s.t. } V - P_{Z2} \geq 0 \tag{3h}$$

It is convenient to use the Lagrangian to solve this problem. The optimal prices and the optimal outputs of Y and Z in the second period are

$$P_Y^* = [(2 - \theta)V + c_Y - c_Z)]/2 \tag{4a}$$

$$P_{Z2}^* = V \tag{4b}$$

$$Q_Y^* = (c_Z - \theta V - c_Y)/2t \tag{4c}$$

$$Q_{Z2}^* = 1 - Q_Y^* \tag{4d}$$

where $c_Z \geq \theta V + c_Y$ to ensure that there is an interior solution to this model.

Following the previous assumption that all consumers buy one unit of Z in the first period, the monopolistic firm will set the price of Z in the first period to maximize the sum of the two periods' profit functions. Because the profit function in the second period is a constant, that is, $\pi_2^{m*} = (P_Y^* - c_Y)Q_Y^* + (P_{Z2}^* - c_Z)Q_{Z2}^*$, the profit maximization problem for the first period can be written as follows:

$$\underset{P_{Z1}}{\text{Max}}\ \pi_1^m = (P_{Z1} - c_Z)Q_{Z1} \tag{5a}$$

$$\text{s.t. } V - P_{Z1} \geq 0 \tag{5b}$$

where $Q_{Z1} = 1$. It is obvious that the optimal price of Z in the first period is $P_{Z1}^* = V$ which extracts the consumer's surplus completely. The optimal profit for a monopolistic firm in the first period is $\pi_1^{m^*} = V - c_Z$. Hence, the monopolistic firm's profit functions from selling the refill packs in the second period are

$$\Pi_S^{m^*} = \pi_1^{m^*} + \delta\pi_2^{m^*} \tag{6}$$

In the case where the refill packs are not sold, because the monopolistic firm knows that all consumers will buy one unit of Z in each period, the profit maximization problem for the monopolistic firm is

$$\underset{P_Z}{\text{Max}}\ \Pi_{NS}^m = (P_Z - c_Z)Q_{Z1} + \delta(P_Z - c_Z)Q_{Z2} \tag{7a}$$

$$\text{s.t. } V - P_Z \geq 0 \tag{7b}$$

where $Q_{Z1} = Q_{Z2} = 1$. It is obvious that the monopolistic firm's optimal pricing strategy is $P_Z^* = V$. The optimal profit in this case is

$$\Pi_{NS}^{m^*} = (1 + \delta)(V - c_Z) \tag{8}$$

By comparing $\Pi_S^{m^*}$ and $\Pi_{NS}^{m^*}$, we confirm that the monopolistic firm has an incentive to sell the refill packs.

Proposition 1. The monopolistic firm has an incentive to sell the refill packs when the loss of utility to consumers after using the durable goods is small.

Proof. The difference for $\Pi_S^{m^*} - \Pi_{NS}^{m^*}$ is $(\theta V - c_Z + c_Y)(\theta V - c_Z - c_Y)/4t$, where $\theta V - c_Z + c_Y \leq 0$ based on the interior solution condition. In other words, if $\Pi_S^{m^*} - \Pi_{NS}^{m^*} \geq 0$, then $\theta V \leq c_Z + c_Y$.

From Proposition 1 we know that, when the durable goods are sufficiently rugged, the consumers are willing to buy the refill packs. Another reason is that the monopolistic firm is willing to sell the refill packs in the market. By contrast, if the durable goods are not rugged, then the consumers will choose to repurchase the composite goods in the second period. Hence, there is no incentive for the monopolistic firm to sell the refill packs. It also causes the amount of the durable goods wasted to increase. We now offer a proposition regarding the environmental effect as follows:

Proposition 2. If the extent of depreciation of the durable goods is high, then the abatement effect on the wastage of these durable goods is insignificant.

Proof. When θ is high, it induces Q_Y^* to decrease and Q_{Z2}^* to increase in Equation (4c). In other words, when the durable goods deteriorate, the amount of the durable goods wasted increases in the second period.

IV. MODEL EXTENSIONS

We extend the benchmark model to the duopoly market structure where the incumbent and the entrant compete over the composite goods and refill packs.

IV.1 A potential firm enters the market and competes with the incumbent over composite goods in the second period

In this subsection we study the case where a potential firm enters the market in the second period and competes with the incumbent in regard to Z. We assume that there is no entry cost and that the entrant has the same cost structure as the incumbent. Here, p_Z and π_E represent the pricing of the entrant for Z and the profit of the entrant, respectively. The profit of the incumbent is defined as π_I. The profit functions of the entrant and the incumbent in the second period are

$$\pi_E = (p_{Z2} - c_Z)Q_{Z2}^E \tag{9a}$$

$$\pi_I = (P_Y - c_Y)Q_Y + (P_{Z2} - c_Z)Q_{Z2}^I \tag{9b}$$

where $Q_Y + Q_{Z2}^E + Q_{Z2}^I = 1$. Furthermore, Q_Y is the quantity of the refill packs demanded and Q_{Z2}^i is the quantity of the composite goods produced by firm i demanded, for $i = E, I$.

The net utility of the consumer purchasing refill packs in the second period is $(1 - \theta)V - P_Y - tL$. The net utilities of the consumer repurchasing composite goods from the incumbent and entrant in the second period are $V - P_{Z2}$ and $V - p_{Z2}$, respectively. The incentive constraints of a consumer who is located at L and who buys the refill packs in the second period should satisfy

$$(1 - \theta)V - P_Y - tL \geq V - P_{Z2} \tag{10a}$$

$$(1 - \theta)V - P_Y - tL \geq V - p_{Z2} \tag{10b}$$

Because L, $\theta \in [0, 1]$, and $t > 1$, this implies that $P_Y \leq P_{Z2}$, and $P_Y \leq p_{Z2}$. There are two firms competing in regard to Z based on price competition, and thus the equilibrium

price for Z is

$$P_{Z2}^{**} = p_{Z2}^{**} = c_Z \tag{11}$$

From Equations (10a), (10b) and (11), the marginal consumer who is indifferent between buying Y and buying Z is

$$L^C = [(1-\theta)V - P_Y - (V - c_Z)]/t \tag{12}$$

The term L^C represents a ratio that is based on the consumer's purchases of the refill goods when the two firms compete in the composite goods. The quantity demanded of Y is L^C, that is, $Q_Y = L^C$. Similarly, the quantity demanded of Z in this case is $1 - L^C$, that is, $Q_{Z2}^E + Q_{Z2}^I = 1 - L^C$. The equilibrium market shares of the incumbent and the entrant in regard to Z are

$$Q_{Z2}^{E**} = Q_{Z2}^{I**} = (1 - L^C)/2. \tag{13}$$

The incumbent's profit from Z is zero when engaging in price competition with the entrant. Thus, the profit maximization problem of the incumbent in the second period can be simplified as follows:

$$\underset{P_Y}{\text{Max}}\, \pi_I = (P_Y - c_Y)Q_Y \tag{14a}$$

$$\text{s.t. } (1-\theta)V - P_Y - tL \geq 0 \tag{14b}$$

$$(1-\theta)V - P_Y - tL \geq V - c_Z \tag{14c}$$

The optimal prices and the optimal outputs of Y and Z in the second period are

$$P_Y^{**} = (c_Y + c_Z - \theta V)/2 \tag{15a}$$

$$P_{Z2}^{**} = c_Z \tag{15b}$$

$$Q_Y^{**} = (c_Z - \theta V - c_Y)/2t \tag{15c}$$

$$Q_{Z2}^{**} = 1 - Q_Y^{**} \tag{15d}$$

where $c_Z \geq \theta V + c_Y$ in order to ensure that there is an interior solution in this model.

By comparing P_Y^{**} and P_Y^*, we find that $P_Y^{**} < P_Y^*$. This implies that when the market structure switches from a monopoly to a duopoly, then the incumbent will strategically reduce the price of the refill packs to maintain the quantity of refill packs sold, that is, $Q_Y^{**} = Q_Y^*$.

Given the result in the second period, the optimal price of the composite goods, which the incumbent will charge in the first period is $P_{Z1}^* = V$. The equilibrium profits of the incumbent in the two periods are $(V - c_Z) + \delta[(P_Y^{**} - c_Y)Q_Y^{**}]$ for the case where the incumbent sells the refill packs and $(V - c_Z)$ for the case where the incumbent does not sell the refill packs. It is obvious that $(V - c_Z) + \delta[(P_Y^{**} - c_Y)Q_Y^{**}] > (V - c_Z)$. Hence, it is profitable for the incumbent to sell the refill packs to those consumers with low transaction costs. It is also beneficial to the environment for the incumbent to sell the refill goods, because it can decrease the quantity of wasted containers by Q_Y^{**} units. We now have the following proposition:

Proposition 3. There are positive economic and environmental effects when the incumbent sells refill packs in the case where the entrant competes with the incumbent over the composite goods in the second period.

IV.2 The potential entrant competes with the incumbent over the refill packs in the second period

This subsection considers the case where the potential firm enters the market in the second period and competes with the incumbent over Y. Let p_Y represent the pricing of the entrant in regard to Y.

In the second period, the net utilities of consumers buying refill packs from the incumbent and from the entrant are $(1-\theta)V - P_Y - tL$ and $(1-\theta)V - p_Y - tL$, respectively. If a consumer repurchases composite goods from the incumbent in the second period, then the consumer's net utility is $V - P_{Z2}$. The incentive constraints of consumers purchasing refill packs in the second period are

$$(1-\theta)V - P_Y - tL \geq V - P_{Z2} \tag{16a}$$

$$(1-\theta)V - p_Y - tL \geq V - P_{Z2} \tag{16b}$$

Because L, $\theta \in [0, 1]$, and $t > 1$, it is implied that $P_Y \leq P_{Z2}$, and $p_Y \leq P_{Z2}$. There are two firms competing over Y under price competition. Thus, the equilibrium price for Y is

$$P_Y^{***} = p_Y^{***} = c_Y \tag{17}$$

Based on Equations (16a), (16b) and (17), the marginal consumer who is indifferent to buying Y or buying Z is

$$L^R = (-\theta V - c_Y + P_{Z2})]/t \tag{18}$$

The term L^R represents a ratio whereby the consumer purchases the refill goods when two firms compete over the refill packs. The quantity of Y demanded is L^R, that is, $Q_Y^E + Q_Y^I = L^R$. Here, Q_Y^E and Q_Y^I are the quantities of Y demanded that are produced by the entrant and the incumbent, respectively. The quantity of Z demanded and produced by the incumbent is $1 - L^R$; that is, $Q_{Z2} = 1 - L^R$. The equilibrium market shares of the incumbent and the entrant in regard to Y are

$$Q_Y^{E***} = Q_Y^{I***} = L^R/2 \tag{19}$$

The incumbent's profit from sales of Y is zero when engaging in price competition with the entrant. Thus, the profit maximization problem of the incumbent in the second period can be expressed as follows:

$$\underset{P_{Z2}}{\text{Max}}\, \pi_I = (P_{Z2} - c_Z)Q_{Z2} \tag{20a}$$

$$\text{s.t. } V - P_{Z2} \geq 0 \tag{20b}$$

$$(1-\theta)V - c_Y - tL \leq V - P_{Z2} \tag{20c}$$

The optimal prices and the optimal outputs of Y and Z in the second period are

$$P_Y^{***} = c_Y \tag{21a}$$

$$P_{Z2}^{***} = (\theta V + c_Y + c_Z + t)/2 \tag{21b}$$

$$Q_Y^{***} = (c_Z - \theta V - c_Y + t)/2t \tag{21c}$$

$$Q_{Z2}^{***} = 1 - Q_Y^{***} \tag{21d}$$

TABLE 2
Comparison of the equilibrium results

		Duopoly market	
		The competition on composite goods	*The competition on refill packs*
Incumbent's profit (Economic effect)	$\theta = 0$	$\Pi_I^C\|_{\theta=0} = (V - c_Z) + \delta[(c_Z - c_Y)^2/4t] > 0$	$\Pi_I^R\|_{\theta=0} = (V - c_Z) + \delta[(c_Y - c_Z + t)^2/4t] > 0$
	$\theta = 1$	$\Pi_I^C\|_{\theta=1} = (V - c_Z) > 0$	$\Pi_I^R\|_{\theta=1} = (1 + \delta)(V - c_Z) > 0$
The percentage of consumers using refill packs (Environmental effect)	$\theta = 0$	$L^C\|_{\theta=0} = (c_Z - c_Y)/2t > 0$	$L^R\|_{\theta=0} = (c_Z - c_Y + t)]/2t > 0$
	$\theta = 1$	$L^C\|_{\theta=1} = 0$	$L^R\|_{\theta=1} = 0$

where $\theta V + c_Y - t \leq c_Z \leq (2 - \theta)V - c_Y - t$ in order to ensure that there is an interior solution in this model and $P_{Z2}^{***} \leq V$.

From Equation (21b), we find that there is a positive relationship between the depreciation rate of the durable goods and the price of the composite goods. The reason is that the incumbent is a monopolist in regard to composite goods, and thus the incumbent can extract a consumer's surplus through monopolistic pricing. We also find that the proportion of consumers buying refill packs in the case where the two firms compete on refill goods is higher than the proportion in the case of two firms that compete on composite goods, that is, $Q_Y^{***} > Q_Y^{**}$. Thus price competition in relation to the refill goods can decrease the amount of durable goods wasted. We therefore have the following proposition:

Proposition 4. The environmental effect of the refill packs under price competition is more significant than that of the composite goods under price competition.

V. DISCUSSION

In this section, we not only relax the model's assumptions and re-discuss them, but we also compare the results of our paper with those of the literature.

V.1 Relaxing the assumptions in our model

We now relax the assumption that the life cycle of durable goods in our model extends over two periods. It may be the case that the durable goods are never any worse for wear or else that the durable goods in the second period are the worse for wear for those consumers who purchase composite goods in the first period.

In the case where the durable goods are never any worse for wear, this means that the extent of the depreciation of the durable goods $\theta = 0$. On the contrary, if the durable goods are no longer of any use in the second period, this means that $\theta = 1$. We therefore recalculate the equilibrium results in Section 4 by substituting the parameters $\theta = 0$ and 1 and arrange the results in Table 2 as follows:

TABLE 3
Payoff matrix of the incumbent and the entrant

		Incumbent *Produces the composite goods*
Entrant	Produces the composite goods	$(0, (V - c_Z) + \delta[(c_Z - c_Y - \theta V)/4t])$
	Produces the refill packs	$(0, (V - c_Z) + \delta[(\theta V + c_Y - c_Z + t)/4t])$

The symbol $\Pi_I^j|_{\theta=I}$ in Table 2 represents the sum of the incumbent's profit over the two periods when $j = C$ (the competition over the composite goods) or R (the competition over the refill packs) and $I = 0$ or 1. In Table 2 we find when the durable goods are fully used up at the end of the first period, the consumer will not purchase the refill packs in the second period. Hence, there is a bad environmental protection effect when the durable goods cease to be of any use. For the case where the durable goods never get damaged, there will be a high ratio of consumer purchases of refill packs when the two firms compete over refill packs, that is, $L^R|_{\theta=0} > L^C|_{\theta=0}$. This result arises from the competition over the refill packs that induce a low price for the refill packs. A low price increases the consumer's willingness to buy the refill packs.

As for the economic effect, for the case where the durable goods will be fully used up after one period, no consumers will purchase the refill packs during the second period. In other words, all consumers will re-purchase composite goods in the second period. This shows that there is nothing to be gained by the entrant entering the refill packs market in the second period. On the contrary, it is good for the incumbent to sell the composite goods in the second period. At this time, if the entrant also sells the composite goods in the second period, then the incumbent's profit will be eroded, that is, $\Pi_I^C|_{\theta=1} < \Pi_I^R|_{\theta=1}$. However, for the case where the durable goods are never damaged by use, the incumbent will generate an uncertain profit depending on whether he competes over the composite goods or the refill packs. That is $\Pi_I^C|_{\theta=0} \geq (<)\Pi_I^R|_{\theta=0}$ if and only if $c_Z - c_Y \geq (<)t/2$.

V.2 Comparison with the literature

In our paper, the composite goods and refill packs produced by the two firms may be fully substituted, one for the other. Furthermore, the durable goods produced by the incumbent and the refill packs produced by the entrant are fully compatible so that consumers can assemble their own systems. Matutes and Regibeau (1988) also discuss the compatibility issue. They conclude that product prices will be higher if firms produce the compatible products and compete in prices. In our paper, we find that if the entrant produces refill packs that are fully compatible with the durable goods in the second period and competes with the incumbent's refill packs in terms of prices, this will then lead to low product prices.

Farrell *et al.* (1998) discuss competition with regard to both systems and components within an industry. They conclude that firms will prefer to compete over components in a duopoly market. We map the competition over systems with the competition over composite goods in our model, and map the competition over components with the competition over refill packs. In order to compare the results with Farrell *et al.* (1998), we need to examine whether both the incumbent and the entrant in our paper prefer competition over composite goods to competition over refill packs. It is easy to arrive at the equilibrium result by using Table 3.

Because of price competition, the entrant generates no profit regardless of whether it produces composite goods or refill packs. Hence, the entrant is indifferent between producing composite

goods and producing refill packs. In other words, the equilibrium of the game is decided by the incumbent. We compare the incumbent's profit size between $(V - c_Z) + \delta[(c_Z - c_Y - \theta V)/4t]$ and $(V - c_Z) + \delta[(\theta V + c_Y - c_Z + t)/4t]$ by letting $\Delta = \{(V - c_Z) + \delta[(\theta V + c_Y - c_Z + t)/4t]\} - \{(V - c_Z) + \delta[(c_Z - c_Y - \theta V)/4t]\}$. Furthermore, if $\Delta \geq 0$, then $c_Z \leq \theta V + c_Y + t/2$; if $\Delta \leq 0$, then $c_Z \geq \theta V + c_Y + t/2$. We conclude our finding with Proposition 5.

Proposition 5. The incumbent prefers the refill packs (composite goods) competition when the cost of the composite goods is high (low).

The economic intuition underlying this proposition is that the incumbent with a first mover advantage does not like to produce a high cost product instead of a low cost product under price competition. The low price strategy induces the incumbent to make more profit. This result differs from Farrell *et al.* (1998).

VI. CONCLUDING REMARKS

In this paper we study the environmental and economic effects of refill packs. In the benchmark model, we set up a two-period monopolistic model, where the firm sells a product consisting of durable and exhaustible goods. The durable goods can be used for two periods (this assumption is relaxed in the discussion section), while the exhaustible goods can only be used for one period. There are two extensive models in this paper. The first one is that the entrant enters the market and competes with the incumbent over the composite goods in the second period. The second one is that the entrant competes with the incumbent over the refill packs in the second period.

This paper leads us to the following conclusion. The durable goods and refill packs are products that are fully compatible with each other. When the entrant enters the market in the second period and competes with the incumbent over refill packs, this will induce the prices of refill packs to fall. This result differs from that of Matutes and Regibeau (1988) who claim that compatibility leads to higher prices than incompatibility. We map the competition in composite goods and the competition in refill packs in our model with the competition over systems and the competition over components as in Farrell *et al.*'s (1998) model, respectively. While Farrell *et al.* (1998) conclude that firms prefer the competition over components in the duopoly market, this paper finds that whether or not the incumbent will prefer competition over composite goods or competition over refill packs will depend on the costs of the composite goods.

Since the previous literature in this field only highlights the economic effect, while it ignores the environmental effect, this study comes up with two suggestions regarding the environment. First, the government should encourage firms to produce rugged durable goods to lower the depreciation rate, prolong the product's life cycle, decrease the amount of waste and, most importantly, increase the firm's profit. This suggestion is based on the finding that when the rate of depreciation for the durable goods is low, the monopolistic firm's profit will increase through the sales of refill packs. Moreover, when the rate of depreciation for the durable goods is small, there will be a significant environmental effect as a result of selling the refill packs. Secondly, the government should encourage price competition in regard to the refill packs. Price competition leads to a low refill pack price, which will in turn induce consumers to purchase the refill packs and re-use the durable goods. This suggestion is based on the finding that the environmental effect of price competition in relation to the refill packs is superior to the environmental effect of the price competition in regard to the composite goods.

Finally, we provide a direction for research in the future. This study is based on the condition that the market is fully served. This condition could be relaxed to consider the case where the

market is partially served by using a vertical product differentiation model that was developed along the lines of Gabszewicz and Thisse (1979), Shaked and Sutton (1982) and Tirole (1988).

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