"*No Return, No Refund*": An Analysis of Deposit-Refund Systems[1]

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Abstract

Firms and governments in developed economies frequently employ deposit-refund systems to promote return and reuse of product packages and containers. We analyze a model of monopoly facing heterogeneous consumers in which recycling (package return by consumers) generates an external benefit. It is shown that when consumers preferences over recycling differ, the monopolist can price discriminate between consumers leading to socially suboptimal recycling. In the absence of any externalities, the analysis can be viewed as a model of *coupons* or *mail-in rebates* which work as price discrimination devices. The role of government subsidies and additional deposits to eliminate suboptimal recycling is also analyzed. Finally, the model is extended to incorporate hustling, *i.e.*, allowing consumers to recycle packages discarded by other consumers.

1 Introduction

Recycling and reuse of product packages and containers are common phenomena in most advanced economies today. This paper examines the consequences of deposit refund systems as an instrument for promoting recycling. A deposit refund system requires consumers to pay a deposit which is subsequently refunded when consumers return the reusable part of the commodity. By affecting the demand for the packaged good a deposit refund system can influence the behavior of both firms and consumers. Numerous governments have enacted legislation to promote recycling as a part of a larger effort to reduce waste management and conserve the environment.[1] Firms in the beverage industry frequently offer a refund in exchange for empty bottles and cans that the firms reprocess and use again (Bohm (1981), and Massel and Parish (1968)). Chaplin (1992) discusses the effect of government initiated and market generated deposit refund schemes in some other product markets like alcohol, milk, toiletries, shampoos, laundry soaps, film cartridges, motor oil and medicines. There is also some empirical evidence in favor of deposit refund systems as a policy tool. Sigman (1995) studies four different public policies including deposit refund schemes using data on lead battery recycling. Interestingly enough, she concludes that price based mechanisms can be successful in increasing lead recovery. A study of solid waste disposal by Palmer, *et al.* (1997) finds deposit refund systems to be the least costly among all other price policies. Deposit refund systems impose a cost on the consumer only when the product is discarded, affecting reduction of waste at the source and also through recycling. By contrast, other policies like advance disposal fees or recycling subsidies only affect either the source or recycling.

[1] Porter (1978,1983) is an extensive study of the effects of mandatory deposits in the state of Michigan. Consequences of mandatory deposits laws, such as "Bottle Bills" are discussed in Bromley (1995) and Lund (1993). For policy and legislative perspectives on deposit-refund systems see New (1986) and OECD (1978, 1993).

Another market where firms offer a refund to facilitate product reuse is the market for "baggage cart rentals" at airports. For instance, *Smarte Carte Inc.*, the worlds largest supplier of baggage carts, is the sole cart provider at the Kennedy International Airport in New York (Kaufman, 1989). A passenger can rent a cart for $1.50 and receive a refund of twenty five cents upon returning it after use to the racks near the cab stations. Most travelers do not return the carts, despite the twenty five cent refund. Usually a large number of hustlers collect the carts around the airport and return them to obtain the refund amount. In contrast, outside the United States refund offers are often regulated by airport authorities ("*Terminal Condition*", Primetime Live, ABC News, January 14, 1993). At the Toronto airport in Canada, the rental amount of one dollar is fully refunded to users who return the carts. Almost all carts are returned after use, apparently due to the large refund. Sometimes departmental stores also use a deposit refund scheme of this type to keep their parking lot tidy.

Voluntary or market generated deposit refund schemes often arise from considerations other than social efficiency, like price discrimination and may not lead to socially optimal outcomes. The industrial organization literature provides many examples the creative use of different instruments through which a firm can price discriminate. For instance, in Mussa and Rosen (1978) firms use product quality, Basu (1988) employs frequency of purchase, Lutz and Padmanabhan (1996) use product warranties and Sarangi and Verbrugge (1999) explore late fees. We develop a model of market generated deposit refund systems that explores the link between recycling and price discrimination. Our model can also demonstrate the effectiveness of mandatory deposit refund systems.

We consider a monopoly firm that offers a refund to its consumers in exchange for its used packages and is able to exercise complete monopsony power in buying back the packages. The refund takes the form of a deposit that is added to the price of the product and is known at the time of purchase.

Consumers who choose to return containers now respond to the net price of the product, while those who discard packages pay the gross price (net price plus a deposit). Hence, *refunds affect demand for the product.* For simplicity we assume that there two kinds of individuals in the population − where one type has a lower marginal disutility (or cost) from recycling than the other. In our model recycling generates an external benefit. For instance, recycling can decrease street litter significantly and thereby help improve the cleanliness of the environment. We also discuss the case of zero external benefits. Packages that take the form of coupons, food stamps or mail-in rebates fall in this category.

In the presence of an external benefit, the amount of recycling induced by a firm can be socially suboptimal simply because the private and social incentives to recycle differ. However, under-recycling can also arise due to other reasons. To see this, let us compare the refund offer of the firm to the net cost of recycling which may be high or low depending on the marginal disutilities. A monopolist can offer a refund at which the low type recycles, but the high type does not, even though a comparison of the costs and benefits of recycling by each type suggests that both types ought to recycle.[2] Clearly for a certain range of the elasticities the monopolist's gain due to increased demand from low cost consumers will exceed his\her loss from lowering the price to these consumers.

Further, we show that under-recycling can arise due to price discrimination despite the absence of any external benefit from recycling. This illustrates the fact that recycling can be socially suboptimal even if there is no divergence of social and private incentives. Government intervention to alleviate the under-recycling problem through a subsidy or an additional deposit-refund offer is studied as well. It is also shown that the possibility of hustling eliminates under recycling.

[2] Perhaps this accounts for the enormous amounts of junk mail discount coupons that end up in recycling bins!

Our model is similar in spirit to Massel and Parish (1968) where the focus is on the use of refunds as a price discrimination device. However, there are several important differences between their model and ours. We derive market demands from the consumer's utility maximization problem and are able to relate market outcomes to underlying economic fundamentals. Secondly, we establish the link between optimal recycling and price discrimination. The presence of the external benefit allows us to go beyond discount coupons and examine socially optimal recycling. Our formulation enables us to identify over-recycling, government intervention and the consequences of hustling in a precise manner.

A large part of the literature on recycling has concentrated on the product side of the market (see for example, Swan (1980) and Hollander and Lassere (1988)). These papers emphasize the interaction between the primary and the secondary market and completely ignore the price discrimination issue. Consumer behavior is also not explicitly modelled in these formulations. Public policies are also typically analyzed keeping in mind a competitive recycling sector. We believe our model provides a different perspective on recycling by introducing heterogenous consumers.

We lay out the basic model in the next section. Section 3 characterizes optimal recycling and examines policies to improve recycling. The next section extends the model to incorporate hustling. Section 5 presents some concluding remarks about possible future research.

2 The Basic Model

Consider a population of N (>1) individuals. Preferences are defined over the consumption of an infinitely divisible commodity (x) containing a reusable part, the quantity of reusable part that is returned r, and a composite commodity m which captures the expenditure on all other goods. The consumer's problem is expressed as follows:

$$\max_{(x_i,r_i,m_i)\geq 0} U_i(x_i, r_1, \ldots, r_N, m_i) = a_i x_i - (1/2)x_i^2 - c_i r_i + m_i + \beta \sum_{j=1}^{N} r_j$$
$$0 \leq c_i \leq a_i,\ 0 \leq \beta \leq c_i,\ 0 \leq x_i \leq a_i$$

$$\text{subject to } px_i + m_i \leq y_i + p'r_i \qquad \text{and} \qquad r_i \leq x_i \text{ for } i = 1, \ldots, N.$$

The parameter c_i captures an individual's aversion or *cost of returning* the package. The external benefit from a returned package is denoted by β and can be conceived as reduced street litter or a better environment due to judicious use of resources. We assume that β can never exceed the private per unit cost of recycling in order to have a non trivial problem. Using data from California, Mrozek (1997) finds that consumer preferences regarding recycling are an important determinant of the amount recycled. He finds that the consumer's disposal decision vis-a-vis the recycling choice depends crucially on the availability of convenient recycling facilities. While we model the preference for recycling we abstract from the latter possibility to keep the analysis simple (see Bohm as well for a discussion of these issues). The specific form of the utility function has been chosen for analytical convenience as it allows us to derive linear demand functions. The first constraint represents the budget set of the consumer, where y_i is the individual's income, p is the price of the product and per unit refund is denoted by p'. The second inequality prevents a consumer from returning bottles or carts discarded by other consumers for the sole purpose of obtaining the refund.

In order to keep the analysis simple we assume that the population consists of individuals of two types. More precisely, a proportion $\alpha \in (0, 1)$ of the population has demand parameters a_1 and c_1 (Type 1) and a proportion $1 - \alpha$ posses demand parameters a_2 and c_2 (Type 2), with $c_2 \geq c_1$. While it is assumed that Type 1 consumers are less averse to recycling, note that there are no restrictions on the values of a_1 and a_2. Solving the consumer's utility maximization problem above, we obtain the demand functions for the commodity and its return as (see Appendix for details):

$$x_i(p, p') = (a_i - p) \quad \text{and} \quad r_i(p, p') = 0 \quad \text{if } p' < c_i - \beta$$

and

$$x_i(p, p') = r_i(p, p') = \{a_i - (c_i - \beta) - (p - p')\} \quad \text{if } p' > c_i - \beta \text{ for } i = 1, 2$$

provided $y_i \geq (a_i/2)^2$. We assume throughout that this restriction on individual incomes holds. Observe that the parameter a_i is inversely related to an individual's elasticity of demand without recycling in the above demand functions.

We now examine the monopolist's problem. The monopolist chooses a price p and offers a refund p' to the consumers for each return. Let τ denote the constant marginal benefit accruing to the monopolist when a consumer returns the container. This can be viewed as the reduction in cost from recycling or the reuse value of a container to the monopolist.[3] The profit function can be written as:

$$\Pi(p, p') = N[(p - k)\{\alpha x_1 + (1 - \alpha)x_2\} - (p' - \tau)\{\alpha r_1 + (1 - \alpha)r_2\}]$$

where $k > 0$ is the constant marginal cost of producing the commodity. Given our interpretation of τ above, we must have $\tau \leq k$. For simplicity, we assume that the monopolist does not receive the external benefit of recycling though our results can be extended to incorporate this possibility.

The monopolist's problem can be broken down into three parts, based on the mutually exclusive ranges of the refund value p'. The exact range of the profit maximizing refund depends on the demand and supply parameters of the model and is discussed in greater detail in the next section.

[3]Note that the firm can benefit from refund offers even if the reuse value of a package to the firm is low (specifically less than the lower net cost of recycling). The argument goes through even if the reuse value of the package is negative. In this instance the monopolist simply dumps the package and incurs the disposal costs.

Case(i) $p' \geq c_2 - \beta$: In this case, both type 1 and type 2 consumers will choose to recycle and the monopolist maximizes[4]

$$\begin{aligned}\Pi_2(p,p') &= N(p-p'+\tau-k)[\alpha\{a_1-(c_1-\beta)-(p-p')\}+ \\ &\quad (1-\alpha)\{a_2-(c_2-\beta)-(p-p')\}\end{aligned}$$

It is easy to check that maximum profits are given by

$$\Pi_2^* = \max \Pi_2(p,p') = N\{(\bar{a}-\bar{c}+\beta+\tau-k)/2\}^2 \tag{1}$$

where $\bar{a}$ ($\bar{c}$) is a convex combination of $a_1(c_1)$ and $a_2(c_2)$ with weights α and $(1-\alpha)$ respectively. Note that the maximum profits do not depend on the precise value of p' as long as it weakly exceeds $(c_2-\beta)$. We assume that for any $\tau, \beta \geq 0$, the following conditions hold

$$(a_i - c_i) \geq k \text{ for } i = 1,2 \quad \text{and} \quad |\,(a_1-c_1)-(a_2-c_2)\,| \leq k \tag{2}$$

These conditions ensure that non-negative quantities are demanded at the profit maximizing net price. The first inequality is analogous to the standard restriction in monopoly models with identical consumers. According to the second inequality, a large difference between (a_1-c_1) and (a_2-c_2) can give rise to negative demands for one of the two types of consumers. Alternatively, one might think of these inequalities as providing an upper bound on the elasticities and the difference between them.

Case (ii) $c_1-\beta \leq p' < c_2-\beta$: In this situation only type 1 consumers will recycle. These consumers respond to the net price while type 2 consumers pay the gross price. The monopolist's profit function is given by

$$\Pi_1(p,p') = N(p-p'+\tau-k)[\alpha\{a_1-(c_1-\beta)-(p-p')\}]+N(1-\alpha)(p-k)(a_2-p)$$

[4]The subscript "2" in the profit function reflects the fact that both types of consumers recycle in this case. This notation system is followed throughout the paper.

Maximizing profits with respect to p and p' we find that $p = (a_2 + k)/2$ and $p' = [\tau + \{a_2 - (a_1 - c_1 + \beta)\}]/2$. Both the gross price and the net price have an interpretation similar to the profit maximizing price in a standard monopoly model with homogeneous consumers.

Note that p' equals half the reduction in production cost plus a term that depends on the demand elasticities of the two types of consumers. In particular, the refund offered will be higher, the greater is a_2 compared to $(a_1 - c_1 + \beta)$. As each of the above parameters is inversely related to the demand elasticity of the corresponding type of consumers, this equation implies that *the monopolist's refund is higher, the more elastic is the demand of type 1 consumers relative to the demand of type 2 consumers.* Also, note that the refund is lower the greater is the per unit benefit β from recycling. This is because a higher β facilitates recycling for type 1 consumers, decreasing their responsiveness to changes in the refund.

It is easy to check that the demand of both types is non-negative under the restrictions given by (**2**). To ensure that the solution to p' lies in the appropriate range we impose the following additional restrictions on the parameters.

$$2(c_1 - \beta) \leq \{a_2 - (a_1 - c_1 + \beta)\} < 2(c_2 - \beta) - k \tag{3}$$

According to inequality (**3**) above, if type 1 demand is more elastic than type 2 demand (specifically $\{a_2 - (a_1 - c_1 + \beta)\} > 0$), then the monopolist will offer a refund of at least $(c_1 - \beta)$ and induce type 1 consumers to recycle. The refund will be less than $(c_2 - \beta)$ if $\{a_2 - (a_1 - c_1 + \beta)\} < 2(c_2 - \beta) - k$.[5] Hence this equation also provides an upper and lower bound on the difference between the elasticities. Given the restrictions imposed by (**3**) it can be checked that the maximum value of Π_1 is:

[5] It is easy to check that if $\{a_2 - (a_1 - c_1 + \beta)\} < 2(c_1 - \beta)$ in the relevant range then, Π_1 is maximized at $p' = (c_1 - \beta)$. Also note that if $\{a_2 - (a_1 - c_1 + \beta)\} \geq 2(c_2 - \beta) - k$, then the monopolist's problem has no solution: Π_1 is an increasing function of p', so the monopolist offers a refund less than $(c_2 - \beta)$ and as close to it as possible.

$$\Pi_1^* = \max \Pi_1(p, p') = N[\alpha\{(a_1 - c_1 + \beta + k - \tau)/2\}^2 + (1-\alpha)\{(a_2 - k)/2\}^2] \quad (4)$$

Case (iii) $p' < c_1 - \beta$: In this case neither type prefers to recycle. The profit function takes a simple form given by:

$$\Pi_0(p, p') = N(p - k)\{\alpha(a_1 - p) + (1 - \alpha)(a_2 - p)\}$$

The following inequality ensures that the individual demands are non-negative.

$$(a_2 + k)/2 \leq a_1 \leq (2a_2 - k) \quad (5)$$

Maximizing the above profit function with these conditions gives us:

$$\Pi_0^* = \max \Pi_0(p, p') = N\{(\bar{a} - k)/2\}^2 \quad (6)$$

with optimal $p = (\bar{a} + k)/2$.

3 Optimality in Recycling

A comparison of the profit functions from the previous section is enough to determine conditions under which the monopolist can engage in price discrimination. In this section we tie up the price discrimination story with optimality in recycling. Different notions of optimality are used for this purpose, since each has its own advantages. One approach is to compare the private benefits $(\tau + \beta)$ with the private costs (c) of the marginal unit. We define recycling to be socially optimal when the marginal social benefits $(\tau + N\beta)$ outweigh the marginal social costs (c). These two notions of optimality are particularly meaningful in the context of recycling as they allow us to concentrate solely on the physical quantity recycled. However, we also identify which of our results survive under the more popular measure of social welfare − total surplus, *i.e.*, the sum of producer's and consumer's surplus and the external benefit. The comparison of private costs and benefits differs from the last two notions of optimality as it helps us to identify conditions that can lead to suboptimal recycling independently of the external benefits of recycling.

Consider first the case of homogeneous cost consumers ($c_1 = c_2 = c$). Recycling is always optimal if we compare private costs and benefits, but may fail to be so only when we account for the externality. So, if $(\tau + N\beta) \geq c > (\tau + \beta)$, then the monopolist will offer a refund less than $(c - \beta)$ and no consumer recycles and the monopolist is unable to price discriminate. Now suppose that the consumers have heterogeneous costs ($c_1 < c_2$) of recycling. The following proposition shows that even if the marginal private benefit of recycling $(\tau + \beta)$ is greater than its cost to a type 2 consumer, the quantity of recycling generated can be less than the optimal level. This occurs because the monopolist offers a refund less than c_2 and the type 2 consumers do not recycle.

Proposition 1 *(Under-recycling): If inequality (**3**) holds and* $c_2 \leq (\tau + \beta) < \gamma^1$*, where* $\gamma^1 = \{c_2 - (a_2 - k)\} + \sqrt{\{(a_2 - k)^2 + \alpha\delta^2\}}$ *, and* $\delta = \{(a_2 - c_2) - (a_1 - c_1)\} < 0$*, then the monopolist's profit maximizing refund is at least* $(c_1 - \beta)$ *but less than* $(c_2 - \beta)$ *and only type 1 consumers will recycle.*

See *Appendix* for proof.

This result is a direct consequence of the monopolist's ability to use the refund to price discriminate between the two types of consumers. The intuition derives from the fact that if type 1 demand is elastic relative to type 2 demand, the firm gains more from an increase in product demand than it loses from lowering the price to type 1 consumers. A special case of the above proposition arises when recycling generates no external benefits for individuals ($\beta = 0$) and the marginal social benefit is just equal to the monopolist's marginal gain τ. *Hence under-recycling can arise even if the private and social incentives to recycle do not diverge.* In the absence of the external benefit, the model can be used to explain the diversity that is prevalent among discount offers and coupons and their usefulness as price discriminating mechanisms.

As the social benefit $(\tau + N\beta)$ of a return exceeds the private benefit, *Proposition 1* suggests that the amount of recycling can be less than socially optimal under this measure. Furthermore, we verify that under-recycling can arise even if we use total surplus to define the level of optimal recycling. It only affects the results qualitatively. Since under-recycling can occur irrespective of the definition of optimality used, this proposition is of significant importance for government instituted deposit refund systems. In the face imperfect information, if the mandatory deposit refund is erroneously selected, then legislation can easily facilitate suboptimal recycling. So policy makers must exercise great care and ensure that they have all the relevant information when instituting such policies.

When under recycling occurs as a consequence of price discrimination the government can use different policy instruments to enhance recycling. For instance, it can offer a subsidy to the monopolist for each package return. The same effect can be generated by a tax on the manufacture of new packages since it is equivalent to a subsidy for each return. The following proposition which follows from *Proposition 1* shows how the government can eliminate under-recycling through a subsidy. Since *Proposition 1* holds even with $\beta = 0$, a similar subsidy from the government can also be worked out to promote the use of coupons.

Proposition 2 *: If $c_2 \leq (\tau + \beta) < \eta^1$ and the government offers a subsidy to the firm greater than or equal to $(\eta^1 - \tau - \beta)$ for each return by consumers, then it is optimal for the firm to offer a refund greater than or equal to $(c_2 - \beta)$ where $\eta^1 = \{c_2 - (a_2 - k)\} + \sqrt{\{(a_2 - k)^2 + \alpha\delta^2\}}$, and $\delta = \{(a_2 - c_2) - (a_1 - c_1)\} \neq 0$.*

Proof. A subsidy greater than or equal to $(\eta^1 - \tau - \beta)$ increases the monopolist's marginal gain from recycling. It is also easy to check that with the subsidy the marginal private benefit of recycling is as high as η^1. Then, it follows from *Proposition 1*, that the optimal refund will be greater than or equal to $(c_2 - \beta)$. ■

Alternatively, the government can introduce an additional deposit-refund d to encourage recycling. The consumer now pays $(p+d)$ for each unit of the commodity and gets a refund of $(p' + d)$ where p' is the refund offer of the monopolist and the net price paid by the consumers is given by $(p-p')$. Thus, d can act both as a tax and a subsidy to the consumers. In what follows we assume that the government deposits that are not collected by consumers are appropriated and used by the government to finance other social welfare programs.[6] In practice however, refunds not collected by the consumers are usually given to retailers to compensate for the handling costs (OECD, 1993). See notes in *Appendix* for details on computing Π_i^* for $i = 0, 1, 2$ taking d into account. The next proposition generalizes the under recycling condition of *Proposition 1* and shows how the government can eliminate any possibility of under-recycling by choosing the deposit d suitably.

Proposition 3 *: If* $(\tau + \beta) \geq c_2$ *and* $[(a_2 - k) - \sqrt{\{(a_2 - k)^2 - \alpha\delta^2\}}\ ] = d_0 \leq d \leq (a_2 - k)$*, then the monopolist will choose a refund at which the total amount refunded will be at least as much as* $(c_2 - \beta)$*, ensuring that both types of consumers recycle.*

See *Appendix* for proof.

Proposition 3 can be easily extended to allow for socially optimal recycling by accounting for social benefits and costs, or if we use total surplus to characterize optimal recycling. There is no qualitative change in the results.

[6] The interesting problem of revenue neutral deposit refund systems has been addressed by Mrozek (1997).

The intuition behind this result stems from the fact that the government intervention takes place after the monopolist selects her optimal policies. The additional deposit refund instituted by the government thus prevents the monopolist from being able to use the refund for price discrimination. Of course as mentioned earlier a faulty choice of deposit refunds by the government can still lead to suboptimal recycling. It is also worth pointing out that the cost to the government of the subsidy policy above will never exceed the total costs of the additional deposit policy. The next proposition shows that under certain conditions, recycling can arise even if its marginal private benefit is low, leading to a suboptimal situation.

Proposition 4 *: If inequality (**3**) holds and* $\mu^1 < (\tau + \beta) \leq c_1$*, then the monopolist's profit maximizing refund is at least* $(c_1 - \beta)$ *but less than* $(c_2 - \beta)$*, or type 1 consumers will recycle, where* $\mu^1 = \max\{0, c_1 - c_1^*\}$ *and* $c_1^* = (a_1 - k) - \sqrt{\{(a_1 - k)^2 - (1 - \alpha)(a_1 - a_2)^2\}}$.

See *Appendix* for proof.

The above proposition says that if type 1 demand with recycling is elastic relative to type 2 demand without recycling, i.e., inequality (**3**) holds, then the monopolist can effectively price discriminate between the two types of consumers. The firm may not find it profitable to offer $p' \geq (c_1 - \beta)$ even if the private benefit of a return is less than c_1. Thus, as long as $(\tau + \beta)$ is greater than μ^1 above but less than c_1, the refund is at least as much as $(c_1 - \beta)$. Once again consider what happens when recycling generates no external benefit. In this situation, type 1 consumers may recycle even if it is not socially optimal (over recycling). This possibility arises in the case of coupons and food stamps where the reuse value of the returned items is insignificant. The firm's sole purpose in using such offers is to price discriminate among consumers with different recycling costs, provided that product demand is responsive to the refund. However, for most genuine recycling problems the external benefit β is not low. Note that even if $(\tau + \beta)$ is less than c_1, the marginal social benefit of recycling can be greater than c_1, especially if the population size N is very large and the external benefit is not too small. Consequently this result does survive under the two notions of optimal recycling that take the external benefit into account.

4 Recycling in the Presence of Hustling

In this section we extend our basic model to analyze the case when consumers can hustle packages. Here the refund is not linked with the purchase of the product, as in the instance of airport carts. A consumer can actually collect and return packages discarded by other consumers in exchange for the refund. This is an attempt to capture the effects of hustling of the type one observes at the Kennedy Airport. Although hustling is more likely to arise in an oligopolistic market, it has serious consequences for deposit refund systems. Consider for instance, the following interesting quote from the OECD (1993) report about the repercussions of hustling on the mandatory deposit refund system in Denmark: "*A disturbance to the system is caused by the fact that not unimportant quantities of beer are bought in Germany (in approved Danish standard bottles). Empty bottles are returned to Danish shops, causing a deficit in the money flow.*" Hence we now investigate this problem while retaining the monopoly assumption. The consumers' utility maximization problem can now be written as:

$$\max U_i(x_i, r_1, \ldots, r_N, m_i)$$
$$0 \leq c_i \leq a_i, \; 0 \leq \beta \leq c_i, \; 0 \leq x_i \leq a_i$$

$$\text{subject to } px_i + m_i \leq y_i + p'r_i \quad \text{and} \quad r_i \leq \sum_{j=1}^{N} x_j - r_{-i} \text{ for } i = 1, \ldots, N.$$

where $r_{-i} = \sum_{j \neq i} r_j$. The second constraint represents the individuals's recycling constraint. An individual can recycle all of the packages discarded by the other consumers (the quantity of packages produced less the units recycled by all the other consumers). It is easy to check that the solution to the consumers problem is given by:

$$x_i(p,p',r_i,r_{-i}) = (a_i - p) \text{ and } r_i(p,p') = 0 \text{ if } p' < (c_i - \beta)$$

and

$$\begin{aligned} x_i(p,p',r_i,r_{-i}) &= \{a_i - (c_i - \beta) - (p - p')\}, \\ r_i(p,p') &= \sum_{j=1}^{N} x_j - r_{-i} \text{ if } p' \geq (c_i - \beta) \text{ for } i = 1,2 \end{aligned} \tag{7}$$

Notice that the demand functions are the same as in the first model, except when $p' \geq (c_i - \beta)$, and consumers can recycle packages discarded by others. As before, by partitioning the parameter space and we find that there is no change in Π_i^*, $i = 0, 2$. However, in the intermediate case where only type 1 consumers recycle, the profit function can be written as:

$$\Pi_1(p,p') = N(p - p' + \tau - k)[\alpha\{a_1 - c_1 + \beta - (p - p')\} + (1 - \alpha)\{a_2 - p\}]$$

Note that the firm receives only the net price on all units sold since type 1 consumers hustle and return all available packages. Since nobody pays a gross price, the firm is unable to price discriminate between the two types of consumers.[7] It is easy to verify that Π_1 is maximized at $p' = (c_1 - \beta)$ and $\Pi_1^* = N\{(\bar{a} - c_1 + \beta + \tau - k)/2\}^2$. The following proposition shows that the monopolist's profit maximizing refund can never exceed $(c_1 - \beta)$, at which type 1 consumers return all the available containers.

Proposition 5 *: If consumers can hustle packages, then the monopolist will offer a refund equal to* $(c_1 - \beta)$ *if and only if* $\tau \geq (c_1 - \beta)$. *If* $\tau < (c_1 - \beta)$, *then the monopolist's profit maximizing refund will be less than* $(c_1 - \beta)$.

[7] The monopolist can still offer a refund to reduce production costs.

Proof. By comparing Π_1^* above with Π_2^*, it is easy to check that $\Pi_2^* < \Pi_1^*$ since $c_1 < \bar{c}$. So the monopolist will never offer a refund greater than or equal to $(c_2 - \beta)$. Now comparing Π_0^* and Π_1^*, we find that $\Pi_1^* \geq \Pi_0^* \Leftrightarrow \tau \geq (c_1 - \beta)$. If $\tau = (c_1 - \beta)$, then for simplicity we assume that the monopolist offers a refund of $(c_1 - \beta)$. The above inequality also implies that if $\tau < (c_1 - \beta)$, the refund offered by the monopolist will also be lower than $(c_1 - \beta)$. ■

This proposition implies that recycling will only arise when the marginal private benefit of recycling is greater than c_1. Yet, if $\beta > 0$, then the marginal social benefit of recycling $(\tau + N\beta)$ is greater than $(\tau + \beta)$. Hence, recycling can be socially suboptimal if the social and private incentives to recycle are divergent and when $\beta = 0$, recycling is always socially optimal. The result obtained here is clearly analogous to the homogeneous consumers' problem. It is also worth pointing that in practice firms often honor coupons of their rivals. Our analysis here suggests that this maybe a form of aggressive price undercutting that makes it difficult for the rival firms to engage in price discrimination.

Note that in spite of the presence of hustling in our current analysis the private marginal cost of recycling is assumed to be linear. This is quite realistic in the absence of hustling. However, when individuals can recycle large amounts of residuals generated by others, this assumption seems increasingly unreasonable. A more realistic alternative would be to assume that there is an upper bound on the amount that consumers can recycle.[8] Situations when either everybody recycles or no one recycles are not important cases. The upper bound becomes interesting only when the low cost consumers participate in recycling, while the high cost consumers opt out since the refund is lower than their net cost of recycling. We will now identify the lowest upper bound under which *Proposition 5* will be unaffected. Let us assume that the low cost consumers recycle everything they purchase and the quantity purchased

[8] One could also consider non-linear private marginal costs of recycling, say, for instance strictly increasing and convex costs.

by the high cost consumers is shared equally by all low cost consumers for the purposes of recycling. Hence each low cost consumer's capacity to recycle is limited by $\bar{r} = x_1 + \frac{(1-\alpha)x_2}{\alpha} = \frac{\bar{a}-p}{\alpha} + p' - (c_1 - \beta)$, which is obtained by substituting the value of x_i, the demand of each type. The recycling constraints can now be written as $r_1 \leq \bar{r}$ and $r_2 \leq x_2$. These constraints will ensure that all packages are recycled, depriving the monopolist of her ability to price discriminate. Moreover, for a given levels of the parameters (a_i, p, p', c_i, and β) the upper bound is inversely related to the number of low type consumers. So for a higher α we need a lower $\bar{r}$. Since $\alpha \geq 1/N$, it can be easily verified that this upper limit is less than the total demand of both consumer types when all agents recycle, providing another candidate for the upper bound. In fact, for $\alpha > 1/2$, and provided $a_1 - c_1 < (2\alpha - 1)(a_2 - c_2)$, we can use an upper bound which is lower than the one just discussed. If the above condition on α, a_i's and c_i's holds, suppose that each type's capacity to recycle is constrained by an upper bound $\widetilde{r} = x_1 + \frac{(1-\alpha)x_2}{\alpha} = \{\bar{a} - (\bar{c} - \beta) - (p - p')\}$, where $x_i = a_i - (c_i - \beta) - (p - p')$. Then, another example of an upper bound on recycling for which *Proposition 5* holds is given by $x_i \leq \widetilde{r}$. While the bound is inconsequential when no recycles or everyone recycles, it ensures that all containers are recycled when only the low cost types recycle and unlike $\bar{r}$ we now do not require a separate constraint for x_2. Finally, if all containers are not recycled by the low cost consumers when hustling occurs we are back to the analysis of the previous section. As long as some containers are left unreturned, the monopolist makes additional profit from them making both price discrimination and under-recycling quite feasible.

5 Conclusion

This paper analyzes the consequences of monopoly power in markets where firms use deposit-refund schemes to promote return and reuse of product packages. In particular, we have shown that a monopoly firm can use a deposit-refund offer to price discriminate among consumers. Our study departs from the few earlier studies on this topic by explicitly modeling the consumer's decision problem and the role of recycling in improving the environment. We show that under-recycling can arise not only because private and social incentives to recycle diverge, but also due to the possibility of price discrimination. We look at two price based government intervention policies and also analyze what happens when we allow for hustling. However, some interesting questions still remain unanswered. Some of these questions pertain to the environmental aspects of the problem and the others are concerning market structure and regulatory issues.

One aspect of the problem that requires further investigation is to model the consumer's disposal decision with recycling being one of several options. This will help capture social optimality in a more complete fashion. It is also necessary to allow firms to choose between alternative packaging technologies. Market generated deposit refund systems are almost absent in the developed world while they are still quite popular in the developing world. Cheaper technology and the convenience of disposable (single use) containers made it possible for firms to move away from the voluntary deposit refunds of the sixties in developed countries. Increased environmental concerns led to the subsequent introduction of mandatory deposits in many parts of the world.

The product side of the market especially issues relating to the market structure requires further study. It would be interesting to study different aspects of oligopolistic markets and their welfare implications. Results of price and quantity competition in the product and recycling market, or perfectly competitive recycling market with an oligopolistic product market are possible extensions. Sometimes firms brand their own packaging, thereby exercising monopsony power over buying back their packages. This can be used to examine a model of differentiated products. An important regulation related issue is to model the interaction between mandatory deposit refund systems and the pricing policies of firms as a strategic game. Hustling is a serious issue in oligopolistic markets. In Denmark where a mandatory deposit-refund system is in effect, some firms offer a greater refund than others. Although consumers buy the beverages at the regular prices, they often return them to stores that offer higher a refund (OECD, 1993). Extensions of our model in these directions could be of great use to policy makers.

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Appendix

1. *Notes on the consumers utility maximization problem*: Note that the utility function is monotonically increasing in x_i and m_i. This implies that the budget constraint is always binding. Substituting for m_i in the utility function we obtain:

$$U_i(\cdot) = (a_i - p)x_i - (1/2)x_i^2 + \{(p' - (c_i - \beta))r_i + y_i + \beta \sum_{j \neq i} r_j\}$$

If p' is less than $(c_i - \beta)$, then marginal utility of recycling for the above utility function is negative. Therefore $r_i = 0$ and at the maximum $x_i = (a_i - p)$. However, if p' is greater than $(c_i - \beta)$, then marginal utility of recycling is positive and $r_i = x_i$. Substituting for r_i in the utility function and maximizing with respect to x_i, we obtain $x_i = r_i = \{a_i - (c_i - \beta) - (p - p')\}$. Finally, note that if $p' = (c_i - \beta)$, the individual is indifferent between recycling and discarding packages and we assume that they choose to recycle all packages in this case.

2. *Proof of Proposition* 1: Let us first establish the importance of (**3**). From this inequality we have $\{a_2 - (a_1 - c_1 + \beta)\} < 2(c_2 - \beta) - k$ $\Leftrightarrow (a_2 - c_2) - (a_1 - c_1) < (c_2 - \beta) - k \leq 0$ as $(\tau + \beta) \geq c_2 \Rightarrow (k + \beta) \geq c_2$. Hence we, obtain $\delta < 0$. When $\{a_2 - (a_1 - c_1 + \beta)\} < 2(c_2 - \beta) - k$ is reversed, then as mentioned earlier, p' is set as close to $(c_2 - \beta)$ as possible for price discrimination. Notice that if $(\tau + \beta) \geq c_2$, then a refund of $(c_2 - \beta)$ is beneficial to the firm as each additional unit recycled yields a net benefit of $(\tau + \beta - c_2)$ without a concurrent increase in product demand. Hence under-recycling will not arise in this case.

To prove the proposition we need to compare the monopolist's profit maximizing values under the three relevant refund ranges. Comparing the value of p' under Π_1^* and Π_2^* we get: $\Pi_1^* > \Pi_2^* \Leftrightarrow N\{(\bar{a} - \bar{c} + \beta + \tau - k)/2\}^2 - N[\alpha\{(a_1 - c_1 + \beta + k - \tau)/2\}^2 + (1 - \alpha)\{(a_2 - k)/2\}^2] < 0$. Simplifying and rearranging terms gives us the following quadratic: $\eta^2 + 2(a_1 - k + \delta)\eta + \{(a_1 - k + \delta)^2 - \alpha\delta^2 - (a_2 - k)^2\} < 0$, where $\eta = (\tau + \beta - c_1)$. Solving this we get $(\eta - \eta_1)(\eta - \eta_2) < 0$, where $\eta_1 = c_2 - c_1 - (a_2 - k) + \Delta$ and $\eta_2 = c_2 - c_1 - (a_2 - k) - \Delta$ with $\Delta = \sqrt{\alpha\delta^2 + (a_2 - k)^2}$. So $(\eta - \eta_1)(\eta - \eta_2) < 0 \Leftrightarrow \eta_1 < \eta < \eta_2 \Leftrightarrow \gamma^2 < (\tau + \beta) < \gamma^1$, where $\gamma^1 = c_2 - (a_2 - k) + \Delta$ and $\gamma^2 = c_2 - (a_2 - k) - \Delta$. Note that $\gamma^1 > c_2$. Also, from inequality (**2**) since $(a_2 - c_2) > k$, we get $\gamma^2 < 0$. Therefore, we obtain $c_2 \leq (\tau + \beta) < \gamma^1 \Rightarrow \Pi_1^* > \Pi_2^*$. Next we compare the refunds from Π_0^* and Π_2^*. Using equations (**1**) and (**6**) we find that if $(\tau + \beta) \geq c_2 > \bar{c}$, then $\Pi_0^* < \Pi_2^*$. Putting all of this together we get $c_2 \leq (\tau + \beta) < \gamma^1 \Rightarrow \Pi_1^* > \Pi_2^* > \Pi_0^*$ i.e., under these conditions it is optimal for the monopolist to offer a refund greater than or equal to $(c_1 - \beta)$, but less than $(c_2 - \beta)$. ■

3. *Notes on the monopolist's problem with government initiated deposit-refunds*: Note that if $(p' + d) \geq (c_2 - \beta)$, both types of consumers recycle and respond to the net price $(p - p')$. Consequently, Π_2^* remains unchanged. However, if $(c_1 - \beta) \leq (p' + d) < (c_2 - \beta)$, then only type 1 consumers recycle and the monopolist's profit function becomes $\Pi_1 = N(p - p' + \tau - k)[\alpha\{a_1 - c_1 + \beta - (p - p')\}] + N(1 - \alpha)\{(p - k)(a_2 - p - d)\}$. It can be checked that Π_1 is maximized at $p = (a_2 + k - d)$, $p' = [\tau - d + \{a_2 - (a_1 - c_1 + \beta)\}]/2$ with $\Pi_1^* = N\alpha\{(a_1 - c_1 + \beta + \tau - k)/2\}^2 + N(1 - \alpha)\{(a_2 - k - d)/2\}^2$. Finally, if $(p' + d) < (c_1 - \beta)$, then nobody recycles and the profit function becomes $\Pi_0 = N(p - k)\{\alpha(a_1 - p - d) + (1 - \alpha)(a_2 - p - d)\}$, which is maximized at $p = (\bar{a} + k - d)/2$ with $\Pi_0^* = N\{(\bar{a} - k - d)/2\}^2$.

4. *Proof of Proposition 3*: We will first show that $\Pi_1^* > \Pi_2^*$ if $(\tau + \beta) < S_1$ where $S_1 = \{c_2 - (a_2 - k)\} + \sqrt{\{(a_2 - d - k)^2 + \alpha\delta^2\}}$ and δ is as defined before. This assertion is important since it identifies the conditions under which for a given d the monopolist's profits with only type 1 consumers returning packages are higher than profits with both types recycling. Comparing Π_1^* and Π_2^* after inclusion of the additional deposit d, gives the following quadratic: $\Pi_1^* > \Pi_2^* \Leftrightarrow \rho^2 + (a_2 - k)\rho - \{(d/2)^2 - (a_2 - k)(d/2) + \alpha(\delta/2)^2\} <$

$0 \Leftrightarrow (\rho - \rho_1)(\rho - \rho_2) < 0$, where $\rho = (\tau + \beta - c_2)$, $\rho_1 = -(a_2 - k) + Q$, $\rho_2 = -(a_2 - k) - Q$, and $Q = \sqrt{\{(a_2 - k - d)^2 + \alpha\delta^2\}}$. Note that from this we have $\Pi_1^* > \Pi_2^* \Leftrightarrow \rho_2 < \rho < \rho_1 \Leftrightarrow S_2 < (\tau + \beta) < S_1$, where $S_1 = -(a_2 - k - c_2) + Q$ and $S_2 = -(a_2 - k - c_2) - Q$. Since $(a_2 - c_2) > k$, $S_2 < 0$. So we have $\Pi_1^* > \Pi_2^* \Leftrightarrow 0 < (\tau + \beta) < S_1$. It can be easily checked that in the given range of d we have $S_1 \leq c_2$ and $\Pi_1^* \leq \Pi_2^*$ if $(\tau + \beta) \geq S_1$. Putting these together we obtain $(\tau + \beta) \geq c_2 \Rightarrow (\tau + \beta) \geq S_1 \Rightarrow \Pi_2^* \geq \Pi_1^*$. Now notice that $\Pi_2^* > \Pi_0^* \Leftrightarrow N\{(\bar{a} - \bar{c} + \beta + \tau - k)/2\}^2 > N\{(\bar{a} - d - k)/2\}^2$. However, if $(\tau + \beta) \geq c_2 > \bar{c}$, then $N\{(\bar{a} - \bar{c} + \beta + \tau - k)/2\}^2 > N\{(\bar{a} - k)/2\}^2 \geq N\{(\bar{a} - d - k)/2\}^2$, equivalently from above $\Pi_2^* > \Pi_0^*$. This allows us to argue that if $(\tau + \beta) \geq c_2$, then the monopolist will offer a refund such that the total refund is at least as great as $(c_2 - \beta)$. Therefore, in this case both types of consumers will recycle. ■

5. *Proof of Proposition 4*: Comparing Π_1^* and Π_0^* we get $\Pi_1^* > \Pi_0^* \Leftrightarrow N[\alpha\{(a_1 - c_1 + \beta + k - \tau)/2\}^2 + (1 - \alpha)\{(a_2 - k)/2\}^2] > N\{(\bar{a} - k)/2\}^2$. Rearranging terms, the above expression becomes $(\eta/2)^2 + 2(a_1 - k)(\eta/2) + (1 - \alpha)(a_1 - a_2)^2 > 0$. Solving this we get $\{(\eta/2) - \Delta_1\}\{(\eta/2) - \Delta_2\} > 0$, where $\Delta_1 = \{-(a_1 - k) + R\}/2$, and $\Delta_2 = \{-(a_1 - k) - R\}/2$ with $R = \sqrt{\{(a_1 - k)^2 - (1 - \alpha)(a_1 - a_2)^2\}}$. So $\Pi_1^* > \Pi_0^* \Leftrightarrow \Delta_1 < (\eta/2)$ or $(\eta/2) < \Delta_2$. Now consider $(\eta/2) < \Delta_2 \Leftrightarrow (\tau + \beta) < \{-(a_1 - c_1 - k) - R\}$. From inequality (**2**), we have $(a_1 - c_1) > k$. This makes the right hand side of the previous inequality negative. But this is not possible as $(\tau + \beta)$ is non-negative. Hence this inequality does not hold. Now consider $\Delta_1 < (\eta/2) \Leftrightarrow (\tau + \beta) > c_1 - (a_1 - k) + R \Leftrightarrow (\tau + \beta) > (c_1 - c^*)$ where $c^* = (a_1 - k) - R$. Since $(\tau + \beta)$ is non-negative, the above implies that $\Pi_1^* > \Pi_0^* \Leftrightarrow (\tau + \beta) > \mu^1 = \max\{0, (c_1 - c^*)\}$. Hence, $\mu^1 < (\tau + \beta) \leq c_1 \Rightarrow \Pi_1^* > \Pi_0^*$. Finally note that $\Pi_0^* > \Pi_2^*$ for $(\tau + \beta) < c_1 < \bar{c}$. Putting these together we get $\mu^1 < (\tau + \beta) \leq c_1 \Rightarrow \Pi_1^* > \Pi_0^* > \Pi_2^*$. Hence, if $\mu^1 < (\tau + \beta) \leq c_1$, it is optimal for the monopolist to offer a refund greater than or equal to c_1 but less than c_2. ■