THE EFFECTIVENESS OF A TAKE-BACK POLICY TO AVOID THE NON-OPTIMAL EXCLUSION OF REMANUFACTURING

MIGUEL BUÑUEL
Universidad Complutense de Madrid
mbunuel@hotmail.com

Abstract: As opposed to recycling, remanufacturing keeps as much value added as possible in a discarded product, and avoids much of the pollution caused by manufacturing a new good. However, remanufacturing is hampered by technological barriers caused by original equipment manufacturers (OEMs). Hence, incentives for OEMs to internalize all the effects of their technological choices on remanufacturing should be created, such as a take-back policy, that is, making OEMs responsible for the disposal of their products after consumers discard them. If made responsible for product disposal, OEMs with market power exclude remanufactures from the market only when it is socially optimal, but they never remanufacture in optimal amounts.

JEL codes: D62, H89, K32, L51, Q28.

1. Introduction

Remanufacturing serves both to save energy and materials, and reduce wastes. Figure 1 illustrates the differences between all the forms of recycling in a broad sense: reusing, remanufacturing, and recycling in a restricted sense (from now on simply recycling). From an environmental perspective, reusing goods is, in principle, the best of all three, since it means meeting a demand for consumption without increasing waste emission or the use of natural resources (ignoring that transporting goods from their old to their new users may generate pollution and use natural resources). Thus, reusing can be represented as an arrow coming from the consumption rectangle into itself, that is the shortest path for the flow of discarded products (represented by dotted lines) to return to consumption. However, reusing can perpetuate the use of products causing larger negative impacts on the environment than new-vintage products. For instance, that may be the case of selling used cars when they are less energy-efficient and more polluting than new models. In this example, the net effect on the environment depends upon the difference between the environmental impacts of new- and old-vintage cars, and the environmental impacts of producing new cars. For all those products whose use does not pollute, reusing is the most environment-friendly way of disposing of them when discarded, whether through a garage sale, a used-product dealer, or an imaginative business initiative.[1]

As opposed to recycling —which reduces a discarded product to a raw-material state, therefore destroying the value added into it—, remanufacturing keeps as much value added as possible in a discarded product, and avoids much of the wastes generated by manufacturing a new good from recycled materials. Therefore, remanufacturing saves more natural resources (and capital and labor) and avoids more wastes than recycling. As depicted in Figure 1, remanufacturers acquire discarded products —the *cores*—, whether from producers (e.g. industrial A/C compressors, metal cutting machines, industrial valves) or consumers (e.g. toner cartridges, tires, carburetors).[2] Remanufacturers disassemble the core into all of its components, which are cleaned and examined for damage or wear; discard those components that cannot be reused or repaired, replacing them by others —new or repaired—; refurbish all the useful components; reassembly and test the product; and sell it.[3] Remanufacturing minimizes the use of inputs by saving all possible value added in the core, which returns to the producers or consumers as a remanufactured good. It has been calculated that the (embodied) energy recaptured by remanufacturing is about five times the energy used in this activity.[4] On the other hand, recycling requires more raw materials and inputs to transform discarded products into raw materials, which will become new products only after more inputs

[1] For instance, see David Bollier, "Recycling Clothes While Building Customer Loyalty," in David Bollier, *Aiming higher: 25 stories of how companies prosper by combining sound management and social vision*, New York: AMACOM, 1996.

[2] Actually, in many cases it is an intermediate agent who collects the cores and sells them to the remanufacturers.

[3] Robert T. Lund, "Remanufacturing," in Janice A. Klein and Jeffrey G. Miller, editors, *The American Edge: Leveraging Manufacturing's Hidden Assets*, New York: McGraw-Hill, 1993, pp. 228-229.

[4] *Ibidem*, p. 237.

are applied to them in the production process. Thus, remanufacturing not only economizes resources with respect to recycling, but also avoids the wastes that manufacturing a new product generates. Besides its environment-friendly appeal, remanufacturing is also desirable because it is a labor-intensive activity, and provides workers with training useful for other industries.[5]

Lund[6] estimates that 73,000 firms may compose the remanufacturing "industry" in the U.S., giving direct employment to 480,000 workers, and with total annual sales of $53 billion.[7] These firms span 46 Standard Industrial Classification (SIC) codes of product categories, and Lund believes that remanufacturing may exist in other 40 product categories.[8] According to Lund's sample of firms, the main industrial sectors with remanufacturing activities are the following (with typical remanufactured products in parenthesis): automotive (alternators, starter motors, water pumps, clutches, engines); compressors, refrigeration (A/C and refrigeration compressors); electrical apparatus (transformers, electrical motors, switch gear); machinery, all types (machinery and equipment for various industries); office furniture (desks, files partitions); tires, retreaded (truck, auto and off-road tires); toner cartridges (laser toner and ink jet cartridges); and valves, industrial (control and relief valves).[9] The importance of remanufacturing has been overlooked because of the small size of those firms and their dispersion through many product sectors. Still, the size of the remanufacturing "industry" is very small compared to its potential, and the social benefits that generates.

Original equipment manufacturers (OEMs) often regard remanufactureres as competitors, and, as a consequence, intentionally create technological barriers to

---

[5] Robert T. Lund, *The Remanufacturing Industry: Hidden Giant*, Boston: Boston University, 1996, p. 3.

[6] *Ibidem*, p. vii.

[7] Lund's estimation is restricted to firms that only remanufacture; it does not include the original equipment manufacturers that remanufacture their own products.

[8] *Op. cit.*, p. 7.

[9] *Ibidem*, Table 2, p. 12.

remanufacturing. By designing hard-to-remanufacture products in purpose, OEMs try to eliminate competition from remanufacturers. For example, Japanese motorcycle manufacturers introduced frequent design changes that made parts for newer and older models incompatible, as a means to discouraging the remanufacturing of their products.[10] In other cases, design specifications only known by OEMs are required for refurbishing or testing, and OEMs may not release their private information to foreclose remanufacturing. For instance, according to Nasr,[11] it is technically feasible to remanufacture ABS breaks, but only the OEMs posses the proprietary technology for testing the electronic components. It seems that OEMs want to prevent the remanufacturing of ABS breaks, since the efforts to procure the transfer of this technology to remanufacturers have not been successful yet.

If the potential buyers of new products are also potential buyers of remanufactured goods, remanufacturers are in fact OEMs' competitors. Competition by remanufacturers is not an issue if the industry is competitive even without remanufacturers. However, should OEMs have market power, they will try to prevent competition from remanufacturers. In this case, creating technological barriers that hamper remanufacturing is one of the mechanisms most likely to be used by OEMs to eliminate or limit remanufacturing. This paper studies when remanufactured products are excluded from the market by OEMs, and if a take-back policy —that is, a policy that makes OEMs responsible for the disposal of their products after consumers discard them— can correct this exclusion when it is not socially optimal.

[10] Robert T. Lund, *Remanufacturing: The Experience of the United States and Implications for Developing Countries*, World Bank Technical Paper No. 31, Integrated Resource Recovery Series No. 2, Washington, D.C.: World Bank, 1984, p. 57.

[11] Nasr, *op. cit.*

2. The model

2.1. Introduction

The model stems from Mussa and Rosen's model of monopoly pricing under quality differentiation.[12] This kind of model is applicable because new and remanufactured products are the same good, but they are perceived by consumers as products of different quality. Certainly, there may be an objective quality difference between a new and a remanufactured product. For instance, if a tire can be retreaded up to six times, even though the retreaded tire performs as well as a newly manufactured one, it can be considered that each time that the tire is retreaded its quality decreases, since it loses a *life*. However, consumers seldom get anything in return when discarding products that can be remanufactured; on the contrary, they often must pay for their disposal. If a consumer does not capture any share of the value of the discarded tire, his or her perception of a retreaded tire quality as inferior to that of a new tire that performs exactly as the retreaded one is entirely subjective. For the purpose of setting up the model, what matters is that a differential quality is an adequate way of modeling consumers' different perception of —and hence willingness to pay for— new and remanufactured products. Thus, a durable good with different quality, q, is considered.

2.2. Consumers

Consumers have different tastes for quality, whose intensity is measured by the parameter θ, which is a positive continuous random variable with density function $f(\theta)$, and cumulative distribution function $F(\theta)$, defined on the interval $[\theta_{min}, \theta_{max}]$. It is assumed that consumers have a unit demand. Ignoring the existence of other goods, consumers solve the following problem:

$$\max_{q>0} \; U(q, p^q; \theta) = \theta q - p^q, \text{ subject to } p^q \leq y,$$

[12] Michael Mussa and Sherwin Rosen, "Monopoly and Product Quality," *Journal of Economic Theory* 18, 1978, pp. 301-317.

where $U(q, p^q; \theta)$ is the utility of a type-θ consumer who buys one unit of the good of quality q at price p^q, and y is income. Assuming that the budget constraint is not binding, a type-θ consumer purchases one unit of the product of quality $q^* \equiv \arg\max U(q, p^q; \theta)$ if $U(q^*, p^{q^*}; \theta) \geq 0$. Otherwise, the consumer buys nothing.

2.3. Qualities and production costs

Since, in principle, we are interested only in new versus remanufactured products, the model departs from Mussa and Rosen's, and, like Ferrer,[13] assumes that only two qualities are available: the qualities of new, q^n, and remanufactured goods, q^r, for $q^r < q^n$. Let k denote the quality of new products, and let α denote the factor of proportion between the perceived qualities of new and remanufactured goods; $q^n = k$, and $q^r = \alpha k$, for $0 < \alpha < 1$. The unit cost for a given quality is constant; that is, it is independent of the number of units produced. The cost of remanufacturing a core, c^r, is less than the unit cost of original manufacturing, c^n, since remanufacturing keeps part of the value added when the discarded product was originally manufactured. Let c denote the cost of manufacturing a new product, and let β denote the factor of proportion between both unit costs; $c^n = c$, and $c^r = \beta c$, for $0 < \beta < 1$.

2.4. Firms and prices

It is assumed that new products are manufactured by a single firm with monopolistic power derived from proprietary technology. This is the best assumption for this analysis, since our concerns is that OEMs may intentionally use technology as a barrier against remanufacturers; if perfect competition should exist already among OEMs, there would not be any reason for them to prevent remanufacturing. Remanufacturing will be limited to a single firm whenever the OEM remanufactures its own products and can exclude competition from other firms. When the OEM is unable to prevent the remanufacturing of its products by other firms, remanufacturing is assumed to occur in a perfectly competitive environment. In this

[13] Geraldo Ferrer, *Market Segmentation and Product Line Design in Remanufacturing*, INSEAD Working Paper 96/66/TM, Fontainebleau, France: INSEAD, 1996.

case, the OEM —a monopolist— has in principle no reason to engage in remanufacturing, since this activity generates zero profits. These assumptions correspond to actual remanufacturing conditions. OEMs, which in many instances are large corporations with market power, remanufacture their products mostly when they are the only ones that do so thanks to proprietary technology and/or close relations with their clients (e.g. Rank Xerox' photocopy machines, Kodak's disposable cameras). Otherwise, remanufacturing tends to be done by a large number of small firms, since OEMs have no barriers to prevent these small business from remanufacturing. These are cases in which the technological requirements for remanufacturing are very small, and there do not exist increasing returns to scale; almost anybody who can acquire a core can become a remanufacturer (e.g. printer cartridges, many automotive parts).

Since new and remanufactured products are only different in consumers' perception of their quality, they are in principle assumed to be traded in a single market. It is assumed that the monopolist knows the distribution of consumers' tastes, but cannot tell the consumers apart before an actual sale, and cannot avoid personal arbitrage. Therefore, the OEM cannot exercise perfect price discrimination, but can engage in second-degree price discrimination when it is the monopolistic producer of both new and remanufactured products. In this case, which is studied by Ferrer[14] for determining the optimal market segmentation between new and remanufactured products for a firm that produces both, the OEM uses the differently-perceived quality of the goods as a means for discriminating among consumers. The OEM offers two bundles of the type (q, p^q): (k, p^n) and $(\alpha k, p^r)$; and chooses —by setting p^n and p^r— the consumers with the lowest quality-valuations ever to buy new and remanufactured products. Let θ^n and θ^r denote, respectively, those two valuations. The monopolist chooses these parameters so as to maximize its profits subject to two kinds of constraints: the individual-rationality constraints (I-RCs) and the incentive-compatibility constraints (I-CCs). The I-RCs require that consumers are actually willing to make a purchase, that is, $\theta k - p^n \geq 0, \forall \theta \in [\theta^n, \theta_{max}]$, and $\theta \alpha k - p^r \geq 0, \forall \theta \in [\theta^r, \theta^n)$. The I-CCs impose that consumers do not practice personal arbitrage, that is, $\theta k - p^n \geq \theta \alpha k - p^r, \forall \theta \in [\theta^n, \theta_{max}]$, and

[14] *Loc. cit.*

$\theta\, \alpha\, k - p^r \geq \theta\, k - p^n$, $\forall\, \theta \in [\theta^r, \theta^n)$. Solving the problem of maximizing the monopolist's profits subject to the I-RCs would lead to choosing $p^r = \theta^r\, \alpha\, k$, and $p^n = \theta^n\, k$, since these are the maximum prices that can be charged to make all the consumer with valuations above θ^n buy the new product, and all the consumer with valuations between θ^r and θ^n buy the remanufactured product. However, $p^n = \theta^n\, k$ does not satisfy the I-CCs for the consumers in $[\theta^n, \theta_{max}]$; the maximum price that can be charged for the new product must be found from these constraints: $p^n = \theta^n\, k - \theta^n\, \alpha\, k + p^r = [\theta^r\, \alpha + \theta^n\, (1 - \alpha)]\, k$. Therefore, the maximum prices that the monopolist can charge, that is, the prices that maximize its profits subject to both the I-R and I-CCs, are

$$p^r = \theta^r \alpha\ k,\ \text{ and }\ p^n = [\theta^r \alpha + \theta^n (1-\alpha)]\, k. \qquad (1)$$

If remanufacturing is perfectly competitive, the OEM only offers (k, p^n), and hence it only chooses θ^n. Since remanufacturing is done in perfectly competitive conditions, the price of the remanufactured product equals its unit cost —which is also its marginal cost—, and the OEM prices the new product as before. Therefore, prices are as follows in this case:

$$p^r = \beta c,\ \text{ and }\ p^n = \beta c + \theta^n (1-\alpha)\, k. \qquad (2)$$

From $p^r = \beta\, c$, it follows that

$$\theta^r = \frac{\beta c}{\alpha k}. \qquad (3)$$

2.5. Market equilibrium

Both when the OEM remanufactures and when remanufacturing is done by a competitive group of firms that sell in the same market as the OEM, market equilibrium is described by prices p^n and p^r —(1) in the first case and (2) in the second—, and the number of goods of each quality sold. Assuming that the budget constraint is not binding for any consumer, the number of new, n^n, and remanufactured goods sold, n^r, depends upon θ^n and θ^r only —that is, on prices:

$$n^n = N[1 - F(\theta^n)], \text{ and } n^r = N[F(\theta^n) - F(\theta^r)], \tag{4}$$

where N is the total number of consumers.

When the OEM is the only producer of new and remanufactured goods, and using (1) and (4), the OEM's problem can be written as:

$$\max_{\theta^r, \theta^n \geq 0} \Pi = [\theta^r \alpha k + \theta^n (1-\alpha) k - c][1 - F(\theta^n)] + (\theta^r \alpha k - \beta c)[F(\theta^n) - F(\theta^r)]$$
$$\text{subject to } \theta_{min} \leq \theta^r \leq \theta^n \leq \theta_{max},$$

whose Kuhn-Tucker necessary —and sufficient if we assume that the hazard rate of the distribution of consumer types,

$$\frac{f(\theta)}{1 - F(\theta)},$$

is an increasing function of θ[15]— conditions if none of the constraints are binding reduce to:

$$\alpha k\left[1 - F\left(\theta^{n*}\right)\right] + \alpha k\left[F\left(\theta^{n*}\right) - F\left(\theta^{r*}\right)\right] - \left(\theta^{r*} \alpha k - \beta c\right) f\left(\theta^{r*}\right) = 0,$$

with respect to θ^r, and

$$(1-\alpha) k\left[1 - F\left(\theta^{n*}\right)\right] - \left[\theta^{r*} \alpha k + \theta^{n*}(1-\alpha) k - c\right] f\left(\theta^{n*}\right) + \left(\theta^{r*} \alpha k - \beta c\right) f\left(\theta^{n*}\right) = 0,$$

with respect to θ^n. Hence, when $\theta^{r*} < \theta^{n*} < \theta_{max}$,[16] the OEM's optimal choice of the consumers with the lowest valuations for quality who buy each type of product are:

[15] This is true of many distributions, such as the normal, the uniform, the logistic, the exponential, and, in general, any distribution with non-decreasing density.

[16] The constraint $\theta_{min} \leq \theta^{r*}$ can be ignored, since has no implications for product exclusion, although it does for consumer exclusion; $\theta_{min} = \theta^{r*}$ means that it is optimal for the OEM to serve all the consumers.

$$\theta^{r*} = \frac{1 - F\left(\theta^{r*}\right)}{f\left(\theta^{r*}\right)} + \frac{\beta\, c}{\alpha\, k} \text{ and } \theta^{n*} = \frac{1 - F\left(\theta^{n*}\right)}{f\left(\theta^{n*}\right)} + \frac{c\,(1-\beta)}{(1-\alpha)\, k}. \tag{5}$$

The conditions for product exclusion can now be derived using solutions (5) and studying the cases in which the constraints are binding:[17]

(i) New goods are produced and remanufactured products are excluded from the market when $\theta^{r*} \geq \theta^{n*}$ and $\theta^{n*} < \theta_{max}$. The assumption of the hazard rate being an increasing function and $\theta^{r*} \geq \theta^{n*}$ imply that

$$\frac{\beta\, c}{c\,(1-\beta)} \geq \frac{\alpha\, k}{(1-\alpha)\, k} \Rightarrow \beta \geq \alpha. \tag{6}$$

Thus, (6) is the condition for the OEM to exclude remanufactured products; remanufacturing is not profitable if its cost, relative to the costs savings that generates, is larger or equal than the perceived quality of a remanufactured good, relative to the perceived loss of quality in a remanufactured good in comparison with a new one. That is, remanufacturing is only worth it to the OEM if the cost savings that generate with regard to producing a new good are not surpassed by the loss of revenues due to the differential in consumers' willingness to pay for remanufactured versus new products.

(ii) The OEM excludes the new product and provides only the remanufactured good when $\theta^{n*} \geq \theta_{max} > \theta^{r*}$. $\theta^{n*} \geq \theta_{max}$ implies that $F(\theta^{n*}) = 1$, from which it follows that:

$$c\,(1-\beta) \geq \theta_{max}\,(1-\alpha)\, k \Rightarrow \alpha \geq 1 - \frac{c\,(1-\beta)}{\theta_{max}\, k}. \tag{7}$$

Condition (7) means that the OEM produces exclusively remanufactured goods if the cost savings that remanufacturing provides are larger or equal than what the consumer with the

[17] The cases in which both products are excluded are uninteresting, and therefore they are ignored.

highest valuation for quality is willing to pay to have a new product rather than a remanufactured one. In this case, it does not pay off to produce new goods at all.

(iii) From conditions (6) and (7), it follows that the OEM offers both the new and remanufactured products —that is, $\theta_{max} > \theta^{n*} > \theta^{r*}$— when the following conditions are satisfied:

$$\beta < \alpha < 1 - \frac{c\,(1-\beta)}{\theta_{max}\,k}. \tag{8}$$

The intuition behind conditions (8) is simply the reverse of that of conditions (6) and (7).

3. Considering product disposal: Efficient equilibrium and take-back policy

As in previous sections, assume that the only environmental costs attached to the manufacturing of new goods are product-disposal costs, which are equal to e per unit. It is assumed that D products —manufactured in a non-modeled past— are discarded. Therefore, if a take-back policy is implemented, the OEM pays $(D - n^r)\,e$ in disposal costs, where it is assumed that $D > n^r$.[18] Since the model is static, the OEM ignores that currently produced new goods will have to be discarded in a non-modeled future.

The welfare function is the sum of consumer and producer surpluses minus the costs of disposing of the discarded products that are not remanufactured, that is:

$$W = \int_{\theta^n}^{\theta_{max}} (\theta\,k - c)\,f(\theta)\,d\theta + \int_{\theta^r}^{\theta^n} (\theta\,\alpha\,k - \beta\,c + e)\,f(\theta)\,d\theta - e\,D.$$

The social planner's problem is:

[18] This assumption has been made implicitly all along this paper; remanufacturing does not face core-availability constraints.

$$\max_{\theta^r, \theta^n \geq 0} W \text{ subject to } \theta_{min} \leq \theta^r \leq \theta^n \leq \theta_{max},$$

whose Kuhn-Tucker necessary and sufficient conditions when the constraints are not binding reduce to:

$$\left(\theta^{r*} \alpha\, k - \beta\, c + e\right) f\left(\theta^{r*}\right) = 0,$$

with respect to θ^r, and

$$\left(\theta^{n*}\, k - c\right) f\left(\theta^{n*}\right) - \left(\theta^{n*} \alpha\, k - \beta\, c + e\right) f\left(\theta^{n*}\right) = 0,$$

with respect to θ^n. Thus, the solutions are:

$$\theta^{r*} = \frac{\beta\, c - e}{\alpha\, k} \text{ and } \theta^{n*} = \frac{c\,(1 - \beta) + e}{(1 - \alpha)\, k}. \quad (9)$$

As before, the conditions for product exclusion are derived from these solutions by studying when the constraints are binding:

(i) The condition for remanufactured products to be excluded from the market ($\theta^{r*} \geq \theta^{n*}$) is the following:

$$\frac{\beta\, c - e}{c(1 - \beta) + e} \geq \frac{\alpha\, k}{(1 - \alpha)\, k} \Rightarrow \beta - \frac{e}{c} \geq \alpha. \quad (10)$$

Condition (10) means that remanufacturing is not socially beneficial if its social costs (its private costs net of the product-disposal savings that generates), relative to the social costs that it saves in comparison with original manufacturing, are larger or equal than the perceived quality of a remanufactured good, relative to the extra quality perceived in a new good with respect to a remanufactured product. That is, remanufacturing is only worthwhile to society if the cost savings that generates with regard to producing a new good are not surpassed by the loss of utility due to the differential in consumers' perception of the quality of remanufactured and new products.

(ii) The condition for excluding the new product ($\theta^{n*} \geq \theta_{max}$) is as follows:

$$c\,(1-\beta) + e \geq \theta_{max}\,(1-\alpha)\,k \;\Rightarrow\; \alpha \geq 1 - \frac{c\,(1-\beta)+e}{\theta_{max}\,k}. \tag{11}$$

Condition (11) expresses the optimality for society of only producing remanufactured goods when the social cost savings of remanufacturing (both in terms of production and in terms of disposal costs) are larger or equal than what the consumer with the highest valuation for quality is willing to pay to have a new product rather than a remanufactured one.

(iii) Finally, the OEM does not exclude either the new or the remanufactured products ($\theta_{max} > \theta^{n*} > \theta^{r*}$) when the following conditions hold:

$$\beta - \frac{e}{c} < \alpha < 1 - \frac{c\,(1-\beta)+e}{\theta_{max}\,k}. \tag{12}$$

If a take-back policy is implemented, the OEM's problem becomes:

$$\max_{\theta^r,\theta^n \geq 0} \Pi = [\theta^r \alpha\, k + \theta^n (1-\alpha)\, k - c]\,[1 - F(\theta^n)] + (\theta^r \alpha\, k - \beta\, c + e)\,[F(\theta^n) - F(\theta^r)] - e\,D$$

$$\text{subject to } \theta_{min} \leq \theta^r \leq \theta^n \leq \theta_{max},$$

whose Kuhn-Tucker necessary and sufficient conditions reduce to the following when no constraint binds:

$$\alpha\,k\left[1 - F\left(\theta^{n*}\right)\right] + \alpha\,k\left[F\left(\theta^{n*}\right) - F\left(\theta^{r*}\right)\right] - \left(\theta^{r*}\alpha\,k - \beta\,c + e\right)\,f\left(\theta^{r*}\right) = 0,$$

with respect to θ^r, and

$$(1-\alpha)\,k\left[1 - F\left(\theta^{n*}\right)\right] - \left[\theta^{r*}\alpha\,k + \theta^{n*}(1-\alpha)\,k - c\right)\,f\left(\theta^{n*}\right) + \left(\theta^{r*}\alpha\,k - \beta\,c + e\right)\,f\left(\theta^{n*}\right) = 0,$$

with respect to θ^n. Hence, the solutions to the OEM's problem are:

$$\theta^{r*} = \frac{1 - F\left(\theta^{r*}\right)}{f\left(\theta^{r*}\right)} + \frac{\beta c - e}{\alpha k} \text{ and } \theta^{n*} = \frac{1 - F\left(\theta^{n*}\right)}{f\left(\theta^{n*}\right)} + \frac{c(1 - \beta) + e}{(1 - \alpha) k}. \tag{13}$$

The conditions for product exclusion can be derived as previously, and they coincide with (10)-(12); the take-back policy makes the OEM to exclude the products only when it is socially optimal. However, the OEM does not produce in optimal amounts either new or remanufactured goods, since it is a monopoly. Its optimal choice of the consumers with the lowest valuations for quality who buy the products, (13), are larger than the socially optimal, (9); that is, the OEM excludes from the market too many consumers.

Notice that even if remanufacturing occurs in competitive conditions —and therefore the OEM only produces the new good—, the number of remanufactured products would be suboptimal. With competitive remanufacturing, θ^r equals (3), which is larger than the optimal θ^r in (9); that is, still too many consumers are excluded from the market. When the cost of disposal per product is larger than the difference between the unit cost of remanufacturing and consumers' willingness to pay, the OEM may be interested in subsidizing competitive remanufacturers. In particular, the OEM would subsidize the price of remanufactures when (13) < (3), that is:

$$\frac{1 - F\left(\theta^{r*}\right)}{f\left(\theta^{r*}\right)} + \frac{\beta c - e}{\alpha k} < \frac{\beta c}{\alpha k} \Rightarrow e > \alpha k \frac{1 - F\left(\theta^{r*}\right)}{f\left(\theta^{r*}\right)},$$

where θ^{r*} is the OEM's optimal solution. Therefore, the lower of (13) and (3) is the lowest values that θ^r can ever take; its optimal value, (9), is never attained. This shows that the OEM's market power makes impossible to attain the optimal amount of remanufacturing, even when this activity is performed competitively and a take-back policy is implemented.

7. CONCLUSIONS

As opposed to recycling, remanufacturing keeps as much value added as possible in a discarded product, and avoids much of the pollution caused by manufacturing a new good. Besides saving more natural resources, capital and labor, and avoiding more wastes than recycling, remanufacturing is also desirable because it is a labor-intensive activity, and provides workers with training useful for other economic activities. However, several technological obstacles hamper this desirable activity. Since these obstacles are the result of the technological choices of OEMs, the most general policy recommendation of this paper is that incentives for OEMs to internalize the effects of those choices on remanufacturing should be created. Among the possible incentives, making OEMs responsible for the disposal of their own products seems a powerful and effective one, and it is widely recommended.[19] The advantage of remanufacturing as a mechanism to save resources, capital, and labor is already taken into account by OEMs, since it translates into lower costs of production, but the advantage of reducing waste generation is not internalized, since the cost of wastes is borne by society. Transferring the burden of this cost to OEMs, by making them responsible for the disposal of their products after discarded by consumers, would make OEMs take into account the effects of their technological decisions on remanufacturing.[20]

However, OEMs often consider remanufactureres as competitors. This is the case whenever the sets of potential consumers for new and remanufactured products intersect. Faced with competition from remanufacturers, OEMs may intentionally create technological barriers to remanufacturing (e.g. designs that make this activity harder or impossible, keeping design specifications required for refurbishing or testing as private information). Since remanufacturing can serve OEMs as a means of product diversification, and an instrument for price discrimination, it can be in their best interest to engage also in this activity. However,

[19] See, for instance, Robert U. Ayres and Leslie W. Ayres, *Industrial Ecology: Towards Closing the Materials Cycle*, Cheltenham, U.K., and Brookfield, U.S.: Edward Elgar, 1996.

[20] Notice that disposal costs are only a part of the environmental costs of production; if OEMs do not bear the costs of the pollution generated in the production process, they will not internalize the social benefits provided by remanufacturing in terms of pollution avoided.

the reasons for OEMs not to remanufacture may be more substantial than, as Lund puts it, being "proud," "shortsighted" or "dumb."[21] As concluded by Mussa and Rosen,[22] it may be optimal for a monopolist to exclude from the market the consumers with the lowest valuation. This conclusion also applies to remanufactured products; it is a rational profit-maximizing behavior that leads some OEMs to not remanufacturing their own products. OEM only find remanufacturing worthwhile if the cost savings that generate with regard to producing a new good are not surpassed by the loss of revenues due to the differential in consumers' willingness to pay for remanufactured versus new products. On the other hand, OEM find that producing only remanufactured goods is a profit-maximizing strategy when the cost savings that remanufacturing provides are larger than what the consumer with the highest willingness to pay is ready to pay to have a new product rather than a remanufactured one. The case of Kodak's disposable cameras is probably the single example of an OEM excluding new products and producing only remanufactures.[23]

If a take-back policy is implemented, OEMs only exclude remanufactured products from the market if it is socially optimal. Nevertheless, although OEMs with market power will now remanufacture their products if they did not do so already, such OEMs will never remanufacture in socially optimal amounts. Therefore, a competitive environment should be preferred in order to increase remanufacturing. However, this environment faces the opposition of OEMs, which will try to foreclose competition using technological barriers whenever available. Since these barriers are often based on proprietary technology, it is very difficult to implement policies that favor competitive remanufacturing. However, more barriers to remanufacturing can be avoided if some OEMs' proposals of *anti-piracy* legislation —which requires product owners to buy parts only from OEMs— are rejected, as suggested by Lund.[24] But even if remanufacturing occurs in competitive conditions, the

[21] Taylor McNeil, "The Return of the Screw," *Bostonia*, Spring 1997, p. 32.

[22] Mussa and Rosen, *op. cit.*

[23] Geraldo Ferrer, *Product Recovery Management: Industry Practices and Research Issues*, INSEAD Working Paper 96/55/TM, Fontainebleau, France: INSEAD, 1996, p. 11.

[24] Lund, *op. cit.*, 1993, p. 239.

number of remanufactured products would be suboptimal. Since remanufacturing generates a positive externality by saving OEMs the costs of product disposal, its perfectly-competitive market level of output is inefficient; a per-unit subsidy equal to the unit cost of disposal is required to increase remanufacturing to its optimal level. If remanufacturers do not compete with OEMs, these would provide the required subsidy to increase remanufacturing output to its efficient level. However, the OEMs will not subsidize remanufacturing to that level when they suffer competition from remanufacturers; the OEMs' market power makes impossible to attain the optimal amount of remanufacturing, even when this activity is performed competitively and a take-back policy is implemented.

Bibliography

Ayres, Robert U., and Leslie W. Ayres, *Industrial Ecology: Towards Closing the Materials Cycle*, Cheltenham, U.K., and Brookfield, U.S.: Edward Elgar, 1996.

Bollier, David, "Recycling Clothes While Building Customer Loyalty," in David Bollier, *Aiming higher: 25 stories of how companies prosper by combining sound management and social vision*, New York: AMACOM, 1996.

Brauner, Marygail K., James S. Hodges, and Daniel A. Relles, *An Approach to Understanding the Value of Parts*, Rand Report MR-313-A/USN, 1994.

D'Aspremont, C., J. Jaskold Gabszewicz, and J.-F. Thisse, "On Hotelling's Stability in Competition," *Econometrica* 17, 1979, pp. 1145-1151.

Ehrenfeld, John, Michael Lenox, Ryan Frazier, Karina Funk, and Ben Jordan, *Implementing Design for Environment: A Primer*, Program on Technology, Business & Environment, Massachusetts Institute of Technology, Cambridge, Massachusetts: M.I.T., 1997.

Ferrer, Geraldo, *Product Recovery Management: Industry Practices and Research Issues*, INSEAD Working Paper 96/55/TM, Fontainebleau, France: INSEAD, 1996.

Ferrer, Geraldo, *Market Segmentation and Product Line Design in Remanufacturing*, INSEAD Working Paper 96/66/TM, Fontainebleau, France: INSEAD, 1996.

Guide, V. Daniel R., Jr., Mark E. Kraus, and Rajesh Srivastava, “Scheduling Policies for Remanufacturing,” *International Journal of Production Economics* 48, January 1997, pp. 187-204.

Hotelling, Harold, “Stability in Competition,” *Economic Journal* 39, 1929, pp. 41-57.

Lund, Robert T., *The Remanufacturing Industry: Hidden Giant*, Boston: Boston University, 1996.

Lund, Robert T., “Remanufacturing,” in Janice A. Klein and Jeffrey G. Miller, editors, *The American Edge: Leveraging Manufacturing’s Hidden Assets*, New York: McGraw-Hill, 1993, pp. 225-240.

Lund, Robert T., *Remanufacturing: The Experience of the United States and Implications for Developing Countries*, World Bank Technical Paper No. 31, Integrated Resource Recovery Series No. 2, Washington, D.C.: World Bank, 1984.

McNeil, Taylor, “The Return of the Screw,” *Bostonia*, Spring 1997, pp. 30-32.

Mussa, Michael, and Sherwin Rosen, “Monopoly and Product Quality,” *Journal of Economic Theory* 18, 1978, pp. 301-317.

Nasr, Nabil, *Automotive Parts Rebuilders Association (APRA) Anti-Lock Brake System (ABS) Remanufacture Research Project*, Rochester, New York: Rochester Institute of Technology, 1996.

Roberts, Michelle, “Recycling: Executive Order Leaves Paper Industry Reeling,” *World Wastes*, December 1993.

Salop, Steven C., “Monopolistic Competition with Outside Goods,” *Bell Journal of Economics* 10, 1979, pp. 141-156.

Van der Laan, Erwin, Rommert Dekker, and Marc Salomon, “Product Remanufacturing and Disposal: A Numerical Comparison of Alternative Control Strategies,” *International Journal of Production Economics* 45, August 1996a, pp. 489-498.

Van der Laan, Erwin, Rommert Dekker, Marc Salomon, and Ad Ridder, “An (s, Q) Inventory Model with Remanufacturing and Disposal,” *International Journal of Production Economics* 46, December 1996b, pp. 339-350.

Van Leynseele, Tania, *Internalizing the Product*, INSEAD Working Paper 96/44/EPS, Fontainebleau, France: INSEAD, July 1996.

Figure 1: The economic functions of the natural environment and remanufactuing