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Recycling of a Primary Resource and Market Power: The Alcoa Case*

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Abstract

The purpose of this paper is threefold. First, it investigates the influence of the prospect of recycling on the per-period market power of an extractor, which can be associated with Alcoa when the recycling sector it faces is competitive. Second, it analyzes whether or not the extractor's first period market power is affected when it is capacity-constrained. Third, it explores whether the structure of the recycling sector affects the extractor's per-period market power or not. Toward these ends, we study a two-period Cournot framework where the extractor produces aluminum over two consecutive periods. In the second period, it engages in competition with a recycling sector that can be competitive or not. Our results run as follows. (1) When the recycling sector is not competitive, recycling does not affect the extractor's first period market power but increases its second period market power. (2) When the recycling sector is competitive, the extractor's second period market power increases with the recycled output but becomes lower (compared to the non-competitive case), while its first period market power can be lower or higher (compared to the non-competitive case). Then, it can increase or decrease with the recycled output. (3) In either case, the extractor's first period market power further increases when the primary resource constraint is binding. (4) We also show that the extractor's market power can increase or decrease over time.

Keywords: Market Power, Recycling, Cournot Competition, Capacity Constraint.

JEL Codes: D43, L13, L61, L72.

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1 Introduction

The classical example of a dominant firm facing competition from recycled goods is the Aluminum Company of America before World War II (Grant, 1999). This company, better known as Alcoa, possessed more than 90 percent of virgin aluminum production capacities in the United States, thus exceeding the legal treshold of monopolisation (De Beir and Girmens, 2009; Grant, 1999; Swan, 1980). It was therefore accused by Judge Learned Hand[1] to constitute an illegal monopoly (Swan, 1980) and was found in violation of the Sherman Act (Grant, 1999). In the scope of its defense, Alcoa countered that the virgin aluminum is recycled by a competitive recycling fringe, which reduces its part of production to 64 % (De Beir and Girmens, 2009). This conflict was called by Adams (1951) "one of the most celebrated judicial opinions of our time". It covered the front pages at that time and lead several authors to investigate, both theoretically and empirically, whether the presence of a competitive recycling sector affects Alcoa's market power or not.

Theoretically, several papers show that the presence of a competitive recycling sector does not affect Alcoa's market power (for instance, see Gaskins, 1974; Swan, 1980; Martin, 1982; Hollander and Lasserre, 1988; Grant, 1999; De Beir and Girmens, 2009) in that it charges a price higher than its marginal cost. Notice that Gaskins (1974) finds that the presence of a competitive fringe makes things worse by increasing the short-run market power. Recently, two papers have explored the effect of recycling on the virgin resource producer's market power (Gaudet and Long, 2003; Baksi and Long, 2009). They show that the presence of recycling increases the primary producer's market power. More recently, Sourisseau et al. (2017) explore this research question by considering an oligopoly that operates within the iron and steel sector. They show that the long-run market power of the oligopoly can increase or decrease depending on whether the level of recycling is low or high.

From an empirical standpoint, the following conclusions are drawn. Gaskins (1974) shows

[1] He was, at that time, a Judge at the court of appeals in the United States.

that the presence of recycling makes things worse in the short-run in the sense that the initial price charged by Alcoa becomes higher. Swan (1980) finds that the price charged by Alcoa is higher than the competitive price and slightly lower than the pure monopoly price, even in the presence of the recycling sector. Suslow (1986) finds that Alcoa maintains its market power despite the presence of recycling. Grant (1999), in turn, shows that Alcoa preserves a significant degree of market power in the steady state.

The present paper joins the earlier literature by investigating a similar research question that can be phrased as follows. Does the prospect of recycling affect Alcoa's (or the primary aluminum extractor's) per-period market power ? In addition, we explore the influence of the capacity constraints (the extracted aluminum constraint and the recycled aluminum constraint) on the extractor's per-period market power. In order to answer the above questions, we postulate a two-period Cournot framework in which the extractor, that has some degree of market power, produces aluminum over two consecutive periods. In the second period, it faces the entry of a recycling sector which can be competitive or not. The recycling sector is considered to be competitive when the whole scrap collected in the first period is recycled. In this case, the extractor is designated by the term "Alcoa" because this corresponds exactly to the Alcoa case. Conversely, when the whole scrap collected in the first period is not recycled (i.e. the recycled output is low), the recycling sector will be considered to be non-competitive. In this case, the extractor is called a "monopolist" in order to distinguish this case to that of Alcoa. The extractor and the recycling sector engage in Cournot competition in the second period. It is worth noting that the choice of the two-period model is motivated by the fact that there is a time lag between extraction and recycling. Thus, this two-period setting enables us to capture the sequential aspect between these two activities.

Our main results can be summarized as follows. (1) When the recycling sector is not competitive, recycling does not affect the extractor's first period market power but increases its second period market power. (2) When the recycling sector is competitive, the extractor's second period market power increases with the recycled output but becomes lower (compared to the non-competitive case), while its first period market power can be lower or higher (compared to the non-competitive case). Then, it can increase or decrease with the recycled output. (3) In either case, the extractor's first period market power further increases when the resource constraint is binding. (4) We also show that the extractor's market power can increase or decrease over time.

The present paper contributes to the earlier literature in the following way. First, to the best of our knowledge, it is one of the few, if it is not the only, which shows that recycling does not affect the monopolist's first period market power. This occurs, here, when the whole scrap collected in the first period is not recycled, i.e. when the recycling sector is not competitive. This finding implies that the monopolist ignores recycling because this is the best strategy for it, and preventing recycling will be costly for it. Second, we show that, when the resource constraint is binding, the first period market power futher increases. Third, allowing the recycling market to be competitive or not affects the results. When it is competitive, Alcoa's second period market power increases with the recycled output but becomes lower (compared to the non-competitive case), while its first period market power can be lower or higher, in comparison with the market power under a non-competitive recycling sector case, and then can increase or decrease with the recycled output. To our knowledge, this comparison has not been done before, and the result whereby the first period market power can decrease with the recycled output has not been highlighted by the previous literature.

The remainder of the paper is structured as follows. The next section constructs the two-period model. The dynamic of the extractor's market power is established in section 3. The main conclusions and some further research lines are given in section 4. The proof of some calculations is relegated to the appendix in section 5.

2 The two-period model

We consider a two-period model where an extractor, which has some degree of market power on the market of aluminum, extracts this resource. Its extraction cost function is denoted

$C_t(Q_t)$, where $t = 1, 2$ is an index over time periods. We assusme that $\sum_{t=1}^{2} q_t \leq S$, where $q_t > 0$ is the quantity of aluminum extracted over each period, and $S > 0$ the stock of aluminum held by the extractor. In the second period, the extractor faces the entry of a recycling sector that can be competitive or not. The recycled aluminum is denoted r. We assume that the aluminum consumed in the first period is collected and given to the recycling sector at price zero. The recycling sector incurs only a recycling cost given by $C_r(r)$. The recycled aluminum is viewed by consumers as a perfect substitute for the extracted aluminum. Consumers's preferences for aluminum are captured by the inverse demand function $P(Q_t)$, where $Q_t = q_t + r$ stands for the total output produced over each period, and $P^{'}(Q_t) < 0$. Note that $Q_1 = q_1$ in the first period and $Q_2 = q_2 + r$ in the second period. The last equation indicates that recycling increases the quantity of the available aluminum by the amount r. Then, the market clears at the price $P(q_2 + r)$ in the second period. For purposes of simplification, we assume that the common discount factor is normalized to one. We will relax the latter assumption in section 3.

The timing of the game between the extractor and the recycling sector can be precisely described as follows. At time $t = 1$, the extractor produces q_1. This quantity becomes a scrap which is exactly recycled at time $t = 2$. In this period, the recycling and the extraction activities occur simultaneously. Accordingly, the extractor and the recycling sector compete à la Cournot at time $t = 2$. Notice that we will use backward induction in order to obtain the Subgame Perfect Nash Equilibrium of the game. In the following, we will analyze the recycling sector's behavior before switching to the extractor's behavior.

2.1 The recycling market

In the second period, the optimal recycling problem is the following:

$$\underset{r}{Max}\ \Pi^r = P(q_2 + r)r - C_r(r) \tag{1}$$

$$\text{S.t. } r \leq \beta q_1, \text{ with } \beta \in [0, 1] \tag{2}$$

Where βq_1 is the scrap from the first period extraction. The parameter β can be interpreted as the efficiency of the recycling technology. Since $\beta < 1$, equation (2) says that recycling cannot exceed the scrap collected in the first period. This equation illustrates the phenomenon of depreciation that occurs during the recycling process or the loss[2] of extracted resources before the recycling process. The Lagrangian from the above programme is:

$$L^r = P(q_2 + r)r - C_r(r) + \mu(\beta q_1 - r) \tag{3}$$

Where μ is the Lagrange multiplier associated with the recycling constraint. The first-order conditions that maximize (3) writes:

$$P(q_2 + r) + P^{'}(q_2 + r)r - C_r^{'}(r) - \mu = 0 \tag{4}$$

$$\mu(\beta q_1 - r) = 0 \tag{5}$$

In the sequel, we will distinguish two cases:

Case 1: the output of the recycling sector is lower than the scrap collected in the first period, i.e. $r < \beta q_1$. Since the recycled output is low, this case can be considered to be non-competitive. In the present case, we will use the term "monopolist" to designate the extractor. The case where the recycling constraint is binding will be reserved for the term "Alcoa". From (5), we get $\mu = 0$ and (4) becomes:

$$P(q_2^r + r) + P^{'}(q_2^r + r)r - C_r^{'}(r) = 0 \tag{6}$$

From (6), we get the following best response function:

$$r(q_2^r) = -\frac{P(q_2^r + r) - C_r^{'}(r)}{P^{'}(q_2^r + r)} \tag{7}$$

Where q_2^r is the quantity extracted by the monopolist in the *second period* provided that $r < \beta q_1$. Since the monopolist has some degree of market power, we have $P(q_2^r + r) - C_r^{'}(r) > 0$.

[2] Several reasons can explain this loss. For the case of aluminum cans in the beverage industry, for example, it is hard to collect all the used cans due to the sparsity of consumption and disposal. For high-tech devices like mobile phones an computers, many of them stay in garages or drawers for years without attention of their owners (Ha, 2017).

Then, $r(q_2^r) > 0$ because $P^{'}(q_2^r+r) < 0$. The best response function $r(q_2^r)$ shows how recycling reacts in response to the second period extracted quantity. Since extracted and recycled products are considered as perfect substitutes, the increase of the second period extraction decreases the recycled output[3].

Case 2: all the scrap collected in the first period is recycled. This case corresponds to the Alcoa case since it can be associated with a competitive recycling sector. Said differently, the higher the recycled output, the more it tends to a competitive output. In this case, we get:

$$\tilde{r}(q_1) = \beta q_1 \tag{8}$$

Equation (8) is an another best response function. It shows that the prior extraction increases the recycled output. So, in this case, Alcoa would be better off reducing its first period extraction in order to limit recycling.

2.2 The extraction market

The extractor will choose q_1 and q_2 to maximize its profit over the two periods. Then, its optimal programme runs as follows:

$$\underset{q_1,q_2}{Max}\ \Pi^e = P(q_1)q_1 - C_1(q_1) + P(q_2 + r) - C_2(q_2) \tag{9}$$

$$\text{S.t. } q_1 + q_2 \leq S \tag{10}$$

Equation (10) indicates that the stock of aluminum is consumed over the two periods and can be exhausted or not during this planning horizon. The Lagrangian associated with this programme is:

$$L^e = P(q_1)q_1 - C_1(q_1) + P(q_2 + r)q_2 - C_2(q_2) + \lambda(S - q_1 - q_2) \tag{11}$$

[3] This result can be mathematically proved. Indeed, we have $\frac{\partial r(q_2^r)}{\partial q_2^r} = -\left\{ \frac{[P^{'}(.)]^2 - P^{"}(.)\overbrace{[P(.) - C_r^{'}(.)]}^{+}}{[P^{'}(.)]^2} \right\}$.

The numerator is positive only and only if $P^{"}(.) < 0$, which holds for the Lagrangian to be concave. In fact, we get $\frac{\partial^2 L^r}{\partial (L^r)^2} = 2P^{'}(.) + P^{"}(.)r - C_r^{"}(.) < 0$ if $P^{"}(.) < 0$. Then, $\frac{\partial r(q_2^r)}{\partial q_2^r} < 0$.

Where λ is the Lagrange multiplier associated with the resource constraint. Depending on whether the whole scrap collected in the first period is recycled or not, the extractor can choose to ignore recycling or to limit it. Assume that it chooses to ignore recycling when the whole scrap collected in the first period is not recycled, i.e. $r < \beta q_1$. Said differently, it decides to reduce its first period extraction when the whole scrap is recycled, i.e. $\tilde{r} = \beta q_1$. These two cases will be treated separately when analyzing the extractor's behavior.

Case 1: $r < \beta q_1$. As mentioned above, this situation does not correspond to the Alcoa case.

Let us analyze the monopolist's behavior in the second period. For simplicity, we will only focus here on the case where the stock of aluminum is not exhausted over the two periods, i.e. $q_1 + q_2 < S$ and $\lambda = 0$. In this context, the maximization problem in (11) yields the following first-order condition:

$$P(q_2^r + r) + P'(q_2^r + r)q_2^r - C_2'(q_2^r) = 0 \tag{12}$$

Conditions (6) and (12) constitute a Subgame Perfect Nash Equilibrium provided that $r < \beta q_1$. They say that each firm will charge a price higher than its marginal cost in the second period. In order to investigate the effect of recycling on the monopolist's second period market power, which is conventionally measured by the Lerner measure, let us rewrite equation (12) in the following way:

$$L_2^{r^{nc}} \equiv \frac{P(q_2^r + r) - C_2'(q_2^r)}{P(q_2^r + r)} = \frac{1}{\varepsilon_2(Q_2^r)} \tag{13}$$

Where the superscript "r" refers to the case where $r < \beta q_1$, the term "nc" means that the monopolist is not constrained by the exhaustion of the primary aluminum and $\varepsilon_2(Q_2^r) = -\frac{P(Q_2^r)}{P'(Q_2^r)q_2^r}$ is the second period elasticity of demand for the extracted output when all the scrap is not recycled. Notice that $Q_2^r = q_2^r + r$ is the industry production at time $t = 2$, where q_2^r and r are the Nash-Cournot outputs produced by the two producers in the second period. Unsurprisingly, equation (13) tells us that the higher the elasticity of demand, the less the price set by the monopolist will be. The intuition is that a slight increase in price reduces drastically the demand. When the elasticity of demand is infinite, i.e. $\varepsilon_2(Q_2^r) \to +\infty$, the price charged by the monopolist equals its marginal cost of extraction.

To analyze the effect of recycling on the monopolist's second period market power, we will compare its market power in the benchmark case where recycling is absent to its market power when recycling exists. In the first case, its extraction q_2^b satisfies the following optimal condition:

$$P(q_2^b) + P^{'}(q_2^b)q_2^b - C_2^{'}(q_2^b) = 0 \tag{14}$$

The superscript "b" refers to the term benchmark. Here, the extractor behaves as a standard monopoly[4]. Its market power is given by:

$$L_2^{b^{nc}} \equiv \frac{P(q_2^b) - C_2^{'}(q_2^b)}{P(q_2^b)} = \frac{1}{\varepsilon_2(q_2^b)} \tag{15}$$

Where $\varepsilon_2(q_2^b) = -\frac{P(q_2^b)}{P^{'}(q_2^b)q_2^b}$ is the second period elasticity of demand for the extracted output in the absence of recycling.

Now, let us compare the left-hand side of (13) to the left-hand side of (15). Straightforward calculations shows that $\frac{1}{\varepsilon_2(Q_2^r)} > \frac{1}{\varepsilon_2(q_2^b)}$ (see appendix 1 for the detail of calculations). Then, we conclude that $L_2^{r^{nc}} > L_2^{b^{nc}}$, which means that recycling increases the monopolist's second period market power.

Now, let us turn into the *first period*. Since $r < \beta q_1$, the monopolist behaves as if recycling were irrelevant and produces a standard monopoly quantity. Then, the first-order condition in this period is:

$$P(q_1^b) + P^{'}(q_1^b)q_1^b - C_1^{'}(q_1^b) - \lambda = 0 \tag{16}$$

► First, assume that the resource constraint is not binding, i.e. $q_1 + q_2 < S$ and $\lambda = 0$. Then, (16) rewrites:

$$P(q_1^b) + P^{'}(q_1^b)q_1^b - C_1^{'}(q_1^b) = 0 \tag{17}$$

[4] By this term, we mean that the extractor does not face a recycling sector.

From (17), we get the following Lerner measure in the first period:

$$L_1^{r^{nc}} = L_1^{b^{nc}} \equiv \frac{P(q_1^b) - C_1^{'}(q_1^b)}{P(q_1^b)} = \frac{1}{\varepsilon_1(q_1^b)} \tag{18}$$

In this case, recycling does not affect the market power of the monopolist in the first period since its behavior matches that of a standard monopoly.

► Now, assume that the resource constraint is binding, i.e. $q_2^b = S - q_1^b$. This means that the resource becomes worthless after the second period. This formulation is inspired by Gaudet et al. (1995). As it is never optimal to exploit the resource beyond the second period, the monopolist sells all remaining resource stock, $S - q_1^b$, in the second period. Given the fact that the first period extraction determines what is left to be sold in the second period, the size of the stock constrains the monopolist, which thus takes no strategic decision in the second period. Then, its first period market power is:

$$L_1^{r^c} \equiv \frac{P(q_1^b) - C_1^{'}(q_1^b)}{P(q_1^b)} = \frac{1}{\varepsilon_1(q_1^b)} + \underbrace{\frac{P^{'}(S - q_1^b + r)(S - q_1^b) + P(S - q_1^b + r) - C_2^{'}(S - q_1^b)}{P(q_1^b)}}_{\textbf{Resource constraint effect}} \tag{19}$$

Where the superscript "c" means that the monopolist is constrained by the exhaustion of the primary aluminum. Equation (19) shows that recycling does not affect the monopolist's first period market power. Nevertheless, in comparison with (18), equation (19) presents an additional effect called "Resource constraint effect". It represents the monopolist's marginal profit in the second period. Thus, it must be positive for the monopolist to extract the resource in this case. Accordingly, the "Resource constraint effect" increases the monopolist's first period market power. Notice that this effect appears because there is a direct link between the two extracted quantities.

Case 2: the recycling sector is so efficient that it recycles the whole scrap collected in the first period. Then, we get:

$$\tilde{r}(\tilde{q}_1) = \beta \tilde{q}_1 \tag{20}$$

Since the recycling market is competitive here, this situation corresponds to the Alcoa case. Notice that $\tilde{q}_1$ is the quantity extracted by Alcoa in the first period. We use this notation in order to distinguish this quantity to the benchmark quantity q_1^b. Let us mention that conditions (12) and (20) constitute another Subgame Perfect Nash Equilibrium. Anticipating (20) and assuming that the resource constraint is not binding, Alcoa maximizes its *second period* profit with respect to q_2. Then, (13) rewrites:

$$L_2^{\tilde{r}^{nc}} \equiv \frac{P(\tilde{q}_2 + \beta\tilde{q}_1) - C_2^{'}(\tilde{q}_2)}{P(\tilde{q}_2 + \beta\tilde{q}_1)} = \frac{1}{\varepsilon_2(\tilde{Q}_2)} \tag{21}$$

Where $\varepsilon_2(\tilde{Q}_2) = -\frac{P(\tilde{Q}_2)}{P^{'}(\tilde{Q}_2)\tilde{q}_2}$, with $\tilde{q}_2$ the new quantity extracted by Alcoa and $\tilde{Q}_2 = \tilde{q}_2 + \beta\tilde{q}_1$ the global production of the industry when $\tilde{r}(\tilde{q}_1) = \beta\tilde{q}_1$. It is easy to show that $q_2^1 = q_2^b < \tilde{Q}_2$ (see appendix 2). Then, $\frac{1}{\varepsilon_2(\tilde{Q}_2)} > \frac{1}{\varepsilon_2(q_2^b)}$. This concludes that Alcoa's second period market power increases also when the whole scrap is recycled (i.e. when the recycling market is competitive).

Let us now investigate the effect of recycling on Alcoa's *first-period* market power. Since $\tilde{r}(\tilde{q}_1) = \beta\tilde{q}_1$, the recycled output increases mechanically with the first period extraction. Then, Alcoa can have the incentive to reduce its first period extraction in order to limit the possibility of recycling. Hence, we must have $\tilde{q}_1 < q_1^b$.

▶ Assume, first, that the resource is not exhausted over the two periods. Then, Alcoa's first period extraction satisfies the following first-order condition:

$$P(\tilde{q}_1) + P^{'}(\tilde{q}_1)\tilde{q}_1 - C_1^{'}(\tilde{q}_1) + P^{'}(\tilde{q}_2 + \beta\tilde{q}_1)\tilde{q}_2\beta = 0 \tag{22}$$

Equation (22) can be rewritten in the following way:

$$L_1^{\tilde{r}^{nc}} \equiv \frac{P(\tilde{q}_1) - C_1^{'}(\tilde{q}_1)}{P(\tilde{q}_1)} = \frac{1}{\varepsilon_1(\tilde{q}_1)} - \underbrace{\frac{P^{'}(\tilde{q}_2 + \beta\tilde{q}_1)\tilde{q}_2}{P(\tilde{q}_1)}\beta}_{\textbf{Recycling effect}} \tag{23}$$

Notice that $\varepsilon_1(\tilde{q}_1) = -\frac{P(\tilde{q}_1)}{P^{'}(\tilde{q}_1)\tilde{q}_1}$ is the elasticity of demand for the extracted aluminum in the first period when $\tilde{r}(\tilde{q}_1) = \beta\tilde{q}_1$. Since $P^{'}(\tilde{q}_2 + \beta\tilde{q}_1)\tilde{q}_2 < 0$ and $\frac{1}{\varepsilon_1(\tilde{q}_1)} < \frac{1}{\varepsilon_1(q_1^b)}$ [because $\tilde{q}_1 <_1^b$ (see appendix 2)], equation (23), incomparison with (18), says that the prospect of recycling may increase or decrease Alcoa's first period market power. Its right-hand side indicates that recycling the whole scrap affects Alcoa's first period market power in two different ways. First, it increases this market power by decreasing its first period extraction. This effect is captured by the term $\frac{1}{\varepsilon_1(\tilde{q}_1)}$. Second, it reduces Alcoa's second period market power (in comparison with the case where it would behave as a standard monopoly, which would be equivalent to the case where the whole scrap is not recycled given by (18)). This effect is captured by the term $-\frac{P'(\tilde{q}_2+\beta\tilde{q}_1)\tilde{q}_2}{P(\tilde{q}_1)}\beta$. The net effect depends on whether the sum of the intertemporal market power (when the whole scrap is recycled) outweighs its first period market power when it behaves as a standard monopoly or not. Formally, we have:

(i) $L_1^{\tilde{r}^{nc}} > L_1^{r^{nc}}$ when $\frac{1}{\varepsilon_1(\tilde{q}_1)} - \frac{P'(\tilde{q}_2+\beta\tilde{q}_1)\tilde{q}_2}{P(\tilde{q}_1)}\beta > \frac{1}{\varepsilon_1(q_1^b)}$. In this case, Alcoa's first period market power is greater in the case where the whole scrap is recycled than in the case where it is not recycled. Then, its first period market power increases with the recycled output.

(ii) $L_1^{\tilde{r}^{nc}} < L_1^{r^{nc}}$ when $\frac{1}{\varepsilon_1(\tilde{q}_1)} - \frac{P'(\tilde{q}_2+\beta\tilde{q}_1)\tilde{q}_2}{P(\tilde{q}_1)}\beta < \frac{1}{\varepsilon_1(q_1^b)}$. Alcoa's first period market power is lower in the case where the whole scrap is recycled than in the case where it is not recycled. Consequently, its first period market power decreases with the recycled output.

Equation (23) states also that the standard result whereby the Lerner index is equal to the inverse of the elasticity of demand is obtained in the absence of recycling.

► Let us now turn into the case where the stock of aluminum is exhausted, i.e. the resource constraint is binding. Then, Alcoa's first period extraction satisfies the following first-order necessary condition:

$$P(\tilde{q}_1)+P'(\tilde{q}_1)\tilde{q}_1-C_1'(\tilde{q}_1)-P(S-\tilde{q}_1+\beta\tilde{q}_1)+P'(S-\tilde{q}_1+\beta\tilde{q}_1)(\beta-1)(S-\tilde{q}_1)+C_2'(S-\tilde{q}_1)=0 \quad (24)$$

After some rearrangements, equation (24) writes:

$$L_1^{\tilde{r}^c} \equiv \frac{P(\tilde{q}_1)-C_1'(\tilde{q}_1)}{P(\tilde{q}_1)} = \frac{1}{\varepsilon_1(\tilde{q}_1)} + \overbrace{\frac{P'(S-\tilde{q}_1+\beta\tilde{q}_1)(S-\tilde{q}_1)+P(S-\tilde{q}_1+\beta\tilde{q}_1)-C_2'(S-\tilde{q}_1)}{P(\tilde{q}_1)}}^{\textbf{Resource constraint effect}} \underbrace{-\frac{P'(S-\tilde{q}_1+\beta\tilde{q}_1)(S-\tilde{q}_1)}{P(\tilde{q}_1)}\beta}_{\textbf{Recycling effect}} \quad (25)$$

In the following subsection, we will explore whether the extractor's (Alcoa's or the monopolist's) second period market power is greater in the case where the whole scrap is recycled or not.

2.3 Some comparisons

This part investigates whether the extractor's per-period market power is affected by the capacity constraints or not. Let us analyze what happens in the *first period*:

• The comparison of (18) and (19), and that of (23) and (25) show that $L_1^{r^c} > L_1^{r^{nc}}$ and $L_1^{\tilde{r}^c} > L_1^{\tilde{r}^{nc}}$ since the resource constraint effect is positive. We conclude that the capacity constraint that faces the extractor increases its first period market power.

• In what follows, we will investigate whether the extractor's *second period* market power is greater when the whole scrap is recycled or not. For this, we will compare (13) and (21). If $\tilde{Q}_2 > Q_2^r$, we will conclude that the extractor's second period market power is greater in the case where all the scrap is recycled. Otherwise, a non-competitive recycling market would yield a greater second period market power. Since it is difficult to provide a clearer insight with the general functional forms, let us make the following assumption: $P(Q_t) = a - Q_t$, with $t = 1, 2$ and Q_t stands for the global production of the industry over each period. Straightforward comparisons show that $Q_2^r > \tilde{Q}_2$ (the detail of calculations is relegated to the appendix 2). This condition implies $\frac{1}{\varepsilon_2(Q_2^r)} > \frac{1}{\varepsilon_2(\tilde{Q}_2)}$, resulting then in $L_2^{r^{nc}} > L_2^{\tilde{r}^{nc}}$. This inequality says that the extractor's second period market power is greater in the case where the whole scrap is not recycled than in the case where it is recycled.

3 Dynamic of Alcoa's market power

In contrast to section 2 where we have analyzed the extractor's (Alcoa's and monopolist's) per-period market power, this section aims at investigating how the market power evolves over time. Notice that $q(t)$ and $q(t+1)$ are respectively the quantities extracted by the extractor in the periods t and $t+1$. Let $c(t)$ and $c(t+1)$ denote the marginal costs of extraction.

Assume that recycling occurs at time $t+1$ and depends on the prior extraction $q(t)$. For simplicity, assume that a fraction of $q(t)$ is recycled at time $t+1$, i.e. the recycled quantity is given by $r = \beta q(t)$. Recall that this situation corresponds to the Alcoa case. Let $\delta = \frac{1}{1+\alpha}$ be the discount factor, where α is the rate of interest.

Knowing the recycled output, Alcoa faces the following programme over the two periods:

$$\underset{q(t),q(t+1)}{Max}\ \Pi^e = P[q(t)]q(t) - c(t)q(t) + \delta\left\{P[q(t+1) + \beta q(t)]q(t+1) - c(t+1)q(t+1)\right\} \quad (26)$$

$$q(t) + q(t+1) \leq S \quad (27)$$

The Lagrangian associated with this programme is:

$$L^e = P[q(t)]q(t) - c(t)q(t) + \delta\left\{P[q(t+1) + \beta q(t)]q(t+1) - c(t+1)q(t+1)\right\} + \lambda[S - q(t) - q(t+1)] \quad (28)$$

We get the following first order conditions:

$$P[q(t)] + P^{'}[q(t)]q(t) - c(t) + \delta\left\{\beta P^{'}[q(t+1) + \beta q(t)]q(t+1)\right\} - \lambda = 0 \quad (29)$$

$$\delta\left\{P[q(t+1) + \beta q(t)] - c(t+1) + P^{'}[q(t+1) + \beta q(t)]q(t+1)\right\} - \lambda = 0 \quad (30)$$

$$\lambda[S - q(t) - q(t+1)] = 0 \quad (31)$$

► First, assume that the resource constraint is not binding, i.e. $q(t)+q(t+1) < S$ and $\lambda = 0$. Then, substituting $\delta = \frac{1}{1+\alpha}$ into the system of equations, combining (29) and (30) due to the intertemporal optimization principle[5] and rearranging some terms yield:

$$\frac{\Delta P - \Delta c}{P(t)} = \alpha[1 - \frac{c(t)}{P(t)} + \frac{P^{'}[q(t)]q(t)}{P(t)}] + \frac{P^{'}[q(t)]q(t)}{P(t)} - \frac{(1-\beta)P^{'}[q(t+1) + \beta q(t)]q(t+1)}{P(t)} \quad (32)$$

Where $\Delta P = P[q(t+1)+\beta q(t)] - P[q(t)]$ and $\Delta c = c(t+1) - c(t)$ are respectively the changes in the price and the cost from one period to another period. Equation (32) shows that Alcoa's market power increases over time when $\alpha[1 - \frac{c(t)}{P(t)} + \frac{P^{'}[q(t)]q(t)}{P(t)}] > \frac{(1-\beta)P^{'}[q(t+1)+\beta q(t)]q(t+1)}{P(t)} -$

[5] It states that discounted marginal revenues should be equalized across periods (Liski and Montero, 2014).

$\frac{P^{'}[q(t)]q(t)}{P(t)}$. Otherwise, it decreases over time. Notice that when recycling is absent, we obtain the standard optimal condition for a monopoly, i.e. $\frac{\Delta P-\Delta c}{P(t)} = \alpha[1-\frac{c(t)}{P(t)}+\frac{P^{'}[q(t)]q(t)}{P(t)}] - \frac{P^{'}[q(t+1)]q(t+1)}{P(t)}+\frac{P^{'}[q(t)]q(t)}{P(t)}$. In the case where the firm behaves as a price-taker[6], the distortions due to the imperfect competition disappear and we get $\frac{P[q(t+1)]-P[q(t)]}{P(t)} = \alpha(1-\phi)+\frac{c(t+1)-c(t)}{c(t)}\phi$, where $\phi = \frac{c(t)}{P(t)}$. This is similar to Stiglitz (1976)'s finding. Since $\phi < 1$, the sign of the previous equation depends on whether the extraction cost is increasing $[c(t+1)-c(t)>0]$ or decreasing $[c(t+1)-c(t)<0]$. In the first case, the price increases over time. In the second case, it increases when $\alpha(1-\phi) > -\frac{c(t+1)-c(t)}{c(t)}\phi$ and decreases when $\alpha(1-\phi) < -\frac{c(t+1)-c(t)}{c(t)}\phi$. It is worth noting that when the extraction cost is zero, in addition, we have $\frac{P[q(t+1)]-P[q(t)]}{P(t)} = \alpha$, i.e. the price of the resource grows at the rate of interest. This was Hotelling (1931)'s prediction.

► Now, assume that the resource constraint is binding, i.e. $q(t+1) = S - q(t)$ and $\lambda > 0$. Then, substituting $\delta = \frac{1}{1+\alpha}$ and $q(t+1) = S-q(t)$ into the system of equations, combining (29) and (30) and rearranging some terms yield:

$$\frac{\Delta P-\Delta c}{P(t)} = \alpha[1-\frac{c(t)}{P(t)}+\frac{P^{'}[q(t)]q(t)}{P(t)}]+\frac{P^{'}[q(t)]q(t)}{P(t)}-\frac{(1-\beta)P^{'}[(S+(\beta-1)\,q(t)](S-q(t))}{P(t)} \tag{33}$$

Equations (32) and (33) are almost[7] identical. Then, we conclude that the resource constraint does not affect the dynamic of Alcoa's market power.

4 Conclusion

This paper has explored the effects of recycling and capacity constraints on an extractor's per-period market power. For this, we have used a two-period Cournot model where the extractor produces aluminum over the two periods. In the second period, it competes with a recycling sector that can be competitive or not. Our results run as follows. (1) When

[6] As stated by Hotelling (1931), the difference between the monopolist and the competitive firm optimization appears in ther term $P^{'}[q(.)]q(.)$.

[7] The term "almost" means that there is a small change in the way of writing the equations since $q(t+1)$ into (32) is replaced by $S-q(t)$ into (33).

the recycling sector is not competitive, recycling does not affect the extractor's first period market power but increases its second period market power. (2) When the recycling sector is competitive, the extractor's second period market power increases with the recycled output but becomes lower (compared to the non-competitive case), while its first period market power can be lower or higher (compared to the non-competitive case). Then, it can increase or decrease with the recycled output. (3) In either case, the extractor's first period market power further increases when the resource constraint is binding. (4) We also show that the extractor's market power can increase or decrease over time.

The present paper can be extended into several directions:

(i) First, it is based on the assumption that the recycled and the extracted resources are strategic substitutes. Another natural extension would consist in considering that these two types of resources exhibit strategic complementarity. The emergence of other potential market effects may influence the results established in the present paper.

(ii) Second, in the present setting, we have taken the demand as a parameter that does not vary over time. Since the demand can change due to technological evolutions, it would be important to propose a model that captures this aspect. Specifying the inverse demand function, it could take the following simple linear form: $P(Q_t) = (a - Q_t) \exp^{\beta t}$ (when demand increases over time:) or $P(Q_t) = (a - Q_t) \exp^{-\beta t}$ (when demand decreases over time). In this specification, β represents the rate of growth of the linear demand curve.

5 Appendix

Appendix 1: Comparison of $L_2^{r^{nc}}$ and $L_2^{b^{nc}}$.

We will proceed as Gaudet and Long (2003) have done. We will, first, show that the global production of the industry with the existence of recycling is higher than the production of the monopolist in the absence of recycling, i.e. $Q_2^r > q_2^b$. To do so, assume, on the contrary, that $Q_2^r < q_2^b$. This yields the following conditions: (a): $P(Q_2^r) > P(q_2^b)$, and (b): $\varepsilon_2(Q_2^r) > \varepsilon_2(q_2^b)$, since it follows from $P^{'}(Q_2^r) < 0$ that $\varepsilon_2^{'}(Q_2^r) < 0$ for all $Q_2^r > 0$. Hence, we have the following relationship:

$$\frac{P(Q_2^r) - C_2^{'}(q_2^r)}{P(Q_2^r)} < \frac{P(q_2^b) - C_2^{'}(q_2^b)}{P(q_2^b)} \tag{34}$$

The inequality (34) implies:

$$\frac{C_2^{'}(q_2^r)}{C_2^{'}(q_2^b)} > \frac{P(Q_2^r)}{P(q_2^b)} \tag{35}$$

From (a), we have $\frac{P(Q_2^r)}{P(q_2^b)} > 1$. Taking this inequality into account in (35) yields:

$$\frac{C_2^{'}(q_2^r)}{C_2^{'}(q_2^b)} > \frac{P(Q_2^r)}{P(q_2^b)} > 1 \tag{36}$$

In what follows, we will show that (36) cannot hold. As Gaudet and Long (2003), assume that $C_2^{'}(.)= 0$ identically. Then (36) implies that $1 > 1$, which is a contradiction. Accordingly, we obtain $Q_2^r > q_2^b$. Taking into account this inequality, we get:

$$\frac{1}{\varepsilon_2(Q_2^r)} > \frac{1}{\varepsilon_2(q_2^b)} \tag{37}$$

Hence, we conclude that recycling increases the monopolist's second period market power, i.e. $L_2^{r^{nc}} > L_2^{b^{nc}}$.

Appendix 2: the model with a linear inverse demand function

We will use backward induction in order to obtain the Subgame Perfect Nash Equilibrium of the game. Then, we have:

Period 2: the programmes are:

For the extractor:

$$\underset{q_2}{Max}\ \pi_2^e = (a - q_2 - r)q_2 - c_2 q_2 \qquad q_1 + q_2 \leq S \tag{38}$$

The Lagrangian associated with the extractor's second period programme is:

$$L_2^e = (a - q_2 - r)q_2 - c_2 q_2 + \lambda(S - q_1 - q_2) \tag{39}$$

For the recycling sector:

$$\underset{r}{Max}\ \pi^r = (a - q_2 - r)r - c_r r \qquad r \leq \beta q_1 \tag{40}$$

Notice that c_2 and c_r are, respectively, the marginal costs of extraction and recycling. The Lagrangian associated with (40) is:

$$L^r = (a - q_2 - r)r - c_r r + \mu(\beta q_1 - r) \tag{41}$$

The first-order conditions that maximize (39) and (41) are respectively:

$$a - r - c_2 - 2q_2 - \lambda = 0 \tag{42}$$

$$\lambda(S - q_1 - q_2) = 0 \tag{43}$$

And:

$$a - 2r - \mu - q_2 - c_r = 0 \tag{44}$$

$$\mu(\beta q_1 - r) = 0 \tag{45}$$

(*i*) When $\mu = 0$, i.e. $r < \beta q_1$, (44) rewrites in the following way:

$$a - 2r - q_2 - c_r = 0 \tag{46}$$

Assuming $\lambda = 0$, the intersection of (42) and (46) yields the Nash-Cournot outputs given by: $q_2^r = \frac{1}{3}(a - 2c_2 + c_r)$ and $r = \frac{1}{3}(a + c_2 - 2c_r)$. The global production of the industry is then $Q_2^r = \frac{1}{3}(2a - c_2 - c_r)$.

(*ii*) When $\mu > 0$, we get $\tilde{r}(\tilde{q}_1) = \beta\tilde{q}_1$. Since $\tilde{q}_1$ determines $\tilde{r}(\tilde{q}_1)$, let us go back to the first period in order to compute the quantity extracted in this period.

Period 1: in this period, the extractor produces q_1 in order to maximize its profit over the two periods. In the first case (point (i)), the extractor (the monopolist) ignores recycling and extracts a standard monopoly quantity given by $q_1^b = \frac{1}{2}(a - c_1)$.

In the second case (point (ii)), Alcoa takes the entry of the recycling sector as a threat and maximizes its following profit over the two periods:

$$\begin{array}{c} \Pi^e = (a - q_1 - c_1)q_1 + (a - q_2 - \beta q_1 - c_2)q_2 \\ q_1 + q_2 \leq S \end{array} \tag{47}$$

And the Lagrangian is:

$$L^e = (a - q_1 - c_1)q_1 + (a - q_2 - \beta q_1 - c_2)q_2 + \lambda(S - q_1 - q_2) \tag{48}$$

The first-order conditions are:

$$a - \lambda - c_1 - 2q_1 - \beta q_2 = 0 \tag{49}$$

$$a - \lambda - c_2 - 2q_2 - \beta q_1 = 0 \tag{50}$$

$$\lambda(S - q_1 - q_2) = 0 \tag{51}$$

Assume that $\lambda = 0$, i.e. $q_1 + q_2 < S$, the intersection of (49) and (50) gives: $\tilde{q}_1 = \frac{\beta(a-c_2)-2(a-c_1)}{\beta^2-4}$, $\tilde{q}_2 = \frac{\beta(a-c_1)-2(a-c_2)}{\beta^2-4}$, $\tilde{r} = \frac{\beta(a-c_2)-2(a-c_1)}{\beta^2-4}\beta$, and $\tilde{Q}_2 = \frac{\beta(-a+c_1+\beta(a-c_2))-2(a-c_2)}{(\beta-2)(\beta+2)}$. In order to make the analysis more tractable, assume that $c_1 = c_2 = c_r = 0$. Then $\tilde{q}_1 = \frac{a}{\beta+2}$, $\tilde{q}_2 = \frac{a}{\beta+2}$, $\tilde{r} = a\frac{\beta}{\beta+2}$, $\tilde{Q}_2 = a\frac{\beta+1}{\beta+2}$, $q_1^b = \frac{1}{2}a$ and $Q_2^r = \frac{2}{3}a$. Simple mathematical computations show that $\frac{\partial \tilde{q}_1}{\partial \beta} < 0$[8], $\frac{\partial \tilde{q}_2}{\partial \beta} < 0$ and $\frac{\partial \tilde{r}}{\partial \beta} > 0$.

Let us verify that $\tilde{q}_1 < q_1^b$. This holds when $\beta > 0$, which is true under our framework.

Straightforward comparisons show also that $Q_2^r > \tilde{Q}_2$ when $\beta < 1$, which holds. Since $\varepsilon_2'(.) < 0$, the condition $Q_2^r > \tilde{Q}_2$ implies $\frac{1}{\varepsilon_2(Q_2^r)} > \frac{1}{\varepsilon_2(\tilde{Q}_2)}$, resulting then in $L_2^{r^{nc}} > L_2^{\tilde{r}^{nc}}$.

Notice that, in the absence of recycling (with zero extraction cost), the extractor's second period extraction is $q_2^b = \frac{1}{2}a$. Simple comparisons show that $\tilde{Q}_2 > q_2^b$ when $\beta > 0$, which is

[8] This result corroborates the idea whereby Alcoa reduces its first period extraction when the recycling constraint is binding.

true. Then, with the condition $\varepsilon_2^{'}(.) < 0$, this inequality implies $\frac{1}{\varepsilon_2(\tilde{Q}_2)} > \frac{1}{\varepsilon_2(q_2^b)}$, resulting in $L_2^{\tilde{r}^{nc}} > L_2^{r^b}$. We conclude that recycling the whole scrap increases the extractor's (Alcoa's) second period market power.

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