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Alcoa *re*-revisited: Recycling, market power and environmental policy

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Abstract. This article incorporates an environmental dimension into the study of markets characterised by producers of a primary good in a position of market power over a sector of recycling. In the model used, production of the primary good by a monopolistic firm is polluting, whereas production of the recycled good is not. Taxing the monopolistic firm allows to reduce pollution, at the price of a reduction in the total quantity of good produced. The effect of a subsidy for recycling depends on the slopes of the demand curve and of the recycler's supply curve. It is ambiguous in terms of welfare, but it always encourages recycling.

JEL Classification: D42; D62; H23; Q53.
Keywords: Recycling; Market Power; Environmental Externalities; Environmental Policy.

Résumé. Cet article introduit une composante environnementale dans l'étude des marchés où des producteurs de produits primaires sont en position dominante par rapport aux acteurs du secteur du recyclage. Dans le modèle utilisé, la production de produit primaire par une firme monopolistique est polluante, contrairement à celle du bien recyclé. Taxer la firme monopolistique réduit la pollution au prix d'une diminution de la quantité totale de bien produite. L'effet d'une aide financière au recyclage est fonction des pentes respectives des courbes de demande et d'offre de l'entreprise de recyclage. Si le résultat est ambigu en termes de bien-être, il est toujours positif pour le recyclage.

Classification *JEL*: D42; D62; H23; Q53.
Mots-clefs: Recyclage; pouvoir de marché; externalités environnementales; politique environmentale.

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1. Introduction

Industrial organization has often approached the question of recycling through study of the Alcoa case (1945). Alcoa (Aluminum Company of America) applied to purchase the aluminium plants built by the US Federal Government for the war effort and operated by Alcoa on behalf of the Government during the War. The Supreme Court prohibited this acquisition on the grounds of antitrust law.[2] At the time, Alcoa totally dominated the extraction of bauxite, its transformation into aluminium oxide and the electrolysis of this latter to produce primary aluminium. It possessed more than 90 percent of aluminium production capacities in the United States, thus exceeding the legal threshold of monopolisation. In its defence, Alcoa argued that when primary and secondary aluminium were considered together, its production only represented 64 percent of the market. But the judge considered the firm's capacity to influence the supply of recycled products by a competitive fringe. Since Alcoa also produced recycled metal from scrap, it must have taken into account, in its production decisions, the effect of scrap recycling on future prices. It was because Alcoa also exercised monopolistic control over the supply of secondary (recycled) aluminium that it fell foul of antitrust laws.

The judge's ruling has been justified by theoretical works. By controlling the production of primary aluminium, Alcoa indirectly influenced the competitive production of recycled aluminium, and so maintained its rent. Gaskins (1974) proposed two results from data for the period 1939-1960: firstly, the existence of a secondary market encourages the monopolistic firm to set a higher initial price, and secondly, as demand for aluminium rises, the influence of the recycled aluminium market decreases.

This is because the monopolistic firm stockpiles some of its ore to make the most of an expected increase in demand (Amigues, Moreaux and Terreaux, 1990). Exploiting future demand to the full means restricting the potential scrap resources available to the recycling fringe. Tirole (1993, translated from the French) specifies that: "*growth of the aluminium market increases the profit margins of the monopolistic firm. (...) The basic idea is that during a period of market growth, recycled aluminium –which depends on the lower level of past demand rather than the higher level of current demand– obtains a smaller market share*." Swan (1980) and Suslow (1986) confirm that in the presence of a competitive fringe of recyclers, the price fixed by Alcoa is only slightly lower than the price it would have set in the absence of such a fringe, and well above the competitive price.[3]

Alcoa was compelled to divest its Canadian subsidiary Alcan, and its expansion was limited by the granting of new concessions to Reynolds and then Kaiser in 1946 to meet the demand

2. United States vs Aluminum Company of America, 148 F.2d. 416 (1945).

3. Grant (1999) shows that the difficulty of recovering and recycling certain goods containing aluminium sold by Alcoa is the primary source of its market power. He undermines the arguments of Gaskins, Swan and Suslow about the origin of the firm's market power; even if growth in the demand for aluminium is weak, the monopoly power remains practically the same, because it is not cost-efficient for the competitive fringe to recycle everything. For the same reason, there is less justification for any strategy limiting the production of primary aluminium during the first period.

for aluminium for armaments. The American aluminium market then became oligopolistic. At an international level, up until 1970, the six majors[4] controlled more than 75 percent of the primary aluminium market. The reference price for export was posted by Alcan. New companies were then formed. Industrial firms diversified their activities in the form of horizontal concentrations. Governments[5] participated in the creation or expansion of activities of bauxite extraction or aluminium oxide and aluminium production. Lastly, the collapse of the Soviet bloc in 1991 caused a surge in supply that halved the price of aluminium.

The market for aluminium gradually lost its oligopolistic nature, becoming very fragmented; since October 1978, the price of aluminium has been determined on the London Metal Exchange (LME). The introduction of primary aluminium into the LME was the result of increased competition on this market.

However, it may be that a certain degree of market power will again be exercised on the primary markets, with the trend towards concentration that we have seen over the last ten years (industrial reorganisation, mergers and acquisitions). The top five extracting companies control two thirds of the world market for metals, positioning themselves as leaders in zinc, lead, iron or aluminium, for example (Descôteaux, 2008). The antitrust authorities (in the United States, Canada and the European Union) keep a close eye on all operations that might lead to further concentration in the primary aluminium market (Chalmin, 2008).

The iron ore market is dominated by a mining oligopoly composed of the Brazilian corporation Vale and the Anglo-Australian groups BHP Billiton and Rio Tinto, which account for 75 percent of world production. A small number of steel firms are in monopolistic positions on their markets in Europe or Asia, so that we are in the presence of a bilateral oligopoly (Chalmin, 2009).

We propose to combine the theoretical problem of reducing the market power of a firm monopolising a primary resource *vis-à-vis* a competitive fringe of recyclers with an examination of the question of environmental policy. Under the hypothesis that primary production is more polluting than recycling, we analyse the impact of price instruments applied to the monopolistic firm (taxes) and to the recyclers (subsidies).

The literature on environmental policies concerning waste recycling have described the different instruments available to the public authorities. Among others, Palmer and Walls (1997), using a partial equilibrium model, show that it is possible to achieve the social optimum by combining an upstream tax (deposit) with a recycling subsidy (refund). Fullerton and Kinnaman (1995) and Dinan (1993) also conclude that it is best to combine the two price instruments: a recycling subsidy on its own allows to reach the optimal factor level for a given level of product, but this involves too high a level of product and of waste.

We shall show that efficient use of these instruments may be uncertain in the case of a monopoly over primary production faced with a competitive fringe of recyclers. The

4. Alcoa (USA), Alcan (USA-Canada), Kaiser (USA), Reynolds (USA), Péchiney (France) and Alusuisse (Switzerland).

5. For example in Norway, Brazil and Australia.

contribution of this article is that it incorporates an environmental dimension into the study of sectors characterised by producers of a the primary good who have market power, facing a competitive fringe of recyclers.[6]

Obviously, in the absence of recycling, a monopolistic firm pollutes less than a competitive sector. Solow (1974) shows that for a given demand function, a monopolist will exhaust a mine more slowly than a competitive fringe of mining companies. Under competition, the resource is exhausted after a finite time, whereas it is only exhausted asymptotically under a monopoly. If one associates mining activity with environmental damage, then, as Solow writes, monopoly is the friend of ecologists. It is less so when a technology of recycling exists.

From an empirical point of view, there is plenty of evidence to justify the difference in pollution levels between production of the virgin good and production of the recycled good:

- recycling reduces the production of waste;
- recycling avoids the pollution linked to mining;
- recycling avoids the pollution caused by the primary production of metal. In particular, the latter produces more greenhouse gases than secondary production, essentially because of the energy resources required to produce primary aluminium (D4E, 2007);
- lastly, recycling contributes to the conservation of a natural resource, even if, in the case of bauxite, known reserves are sufficient to meet demand for many centuries to come.

Section 2 presents a model similar to that proposed by Swan (1980). A monopolistic firm produces the primary good. A competitive recycling sector produces the secondary good. The two goods are assumed to be perfect substitutes[7] from the point of view of the consumers, whose demand function is taken as given. Production of the primary good by the monopolist causes negative externalities (pollution), whereas production of the secondary good does not. We shall introduce two different environmental policies into this situation, which can be considered as the modelling of policies that currently exist in France.

In Section 3, we assume that the government levies a tax on the polluting monopolist. Using comparative statics, we study the impact of this tax on the level of pollution and on the total production (and consumption) of the good (both primary and recycled). This tax takes the form of a fee τ that the monopolist must pay for each unit produced. It can be considered as the current obligation imposed on primary aluminium producers (and many other sectors of activity) in France to participate in the CO2 emissions trading scheme. There is an equivalence between tax and tradable emission allowances, provided the public authorities responsible for environmental policy know the reaction of the firm to a variation in the price of

6. Competition in the industry of recovery and recycling is easy to justify: in 2007, in France there were 2450 firms (Federec, 2008).

7. The substituability between primary and secondary aluminum depends on the purity of recycled metal and the use that is made.

pollution (measured by the tax or, equivalently, by the market price of emissions allowances).[8] We show that this tax does indeed reduce pollution, but at the price of a reduction in the total quantity of the good, and therefore with an ambiguous effect on welfare, assuming that welfare depends positively on consumption of the good and negatively on the level of pollution.

In Section 4 we assume that the government introduces a subsidy for the recycling sector. Still using comparative statics, we study the impact of this subsidy on the level of pollution and on the total level of production (and consumption) of the good (primary and recycled). This subsidy takes the form of a sum σ paid to the recycler for each unit produced. It can be considered as a modelling of the policy of financial support per ton sorted from which the recovery/recycling sector currently benefits in France. We show that the effect of this policy depends on the steepness of the recycler's demand and supply curves. It can either have the same effect as the tax (a rise in the price of the good, a fall in the total quantity produced and a fall in pollution), or it can cause a fall in the price of the good, a rise in the share of recycling and an indeterminate change in the level of pollution. The subsidy is therefore also ambiguous in terms of welfare, although it clearly encourages the activities of recovery and recycling. Section 5 concludes.

2. The model

2.1. The environmental issue

Independently of problems of imperfect competition, the fundamental difference between the sector of the secondary good and that of the primary good lies in their impact on the environment. As mentioned in the introduction, production of the primary good is clearly responsible for a whole series of negative externalities (waste, despoiling of landscapes, industrial pollution, depletion of natural resources). Formally, in a static model, these externalities can be encapsulated by assuming that a representative individual has preferences that take into account not only the total quantity of the good he consumes (whether primary or recycled), but also the quantity of primary good produced in the economy v. Consequently, the utility function of the representative individual takes the following form:

$$u(q,v)$$

We assume that:

$$\partial u/\partial q > 0$$
$$\partial u/\partial v < 0$$

8. In the case of a tax, the authorities fix the price of the externality and the polluter's behavior determines the level of externality. In the case of tradable emission permits, the authorities fix the externality and the polluter's behavior determines its price. If the authorities are fully aware of the behavior of the polluter, then the two policies are completely equivalent (same amount of externality, same price associated with this externality).

In the presence of this environmental externality, the competitive equilibrium is not optimal. Below, we shall examine the traditional solutions to this problem. A first environmental policy consists in taxing the activity that generates the externality, i.e. production of the primary good. Similarly, for any given total quantity, the recycling activity generates a positive externality. We shall therefore examine a second environmental policy consisting in subsidising this sector. Our aim is not to determine what policy achieves the optimal level of externality, but to study the effects of these policies in terms of levels of consumption and externality. Is there a policy that can reduce the level of the externality without reducing the level of consumption? We shall see that taking into account questions of imperfect competition can undermine the traditional effects of these policies.

2.2. The competitive sector of the secondary good

We start by presenting the competitive sector of the secondary good, before the monopolistic producer of the primary good. For decision-making purposes, the monopolist will consider the supply function of the secondary good as given. Consequently, we must first establish this supply function, which will allow the monopolist to know the residual demand for its product (defined as total demand minus the supply of the secondary good). Formally, the solution of the model is based on the fact that the monopolist producing the primary good is the leader, while the recyclers are considered as followers. They take the leader's price as given and decide on the quantity they will supply. The leader adjusts its price with the behaviour of the followers taken as given.

We adopt the hypotheses proposed by Swan (1980). The recoverer-recycler (RR) produces a quantity s of the secondary good, which will be sold at price p. Its production is a fraction γ of the total quantity produced in the previous period $q_{t-1} = \overline{q}$. As the formalisation used is static, the sector share of RR simply corresponds to a fraction of the total demand. This fraction γ depends on the spending on other inputs used in the production of the secondary good (labour, energy, etc.). These costs (per unit of waste recovered) are denoted by z. The fraction recycled is given by the function $\gamma(z)$, with $0 \leq \gamma(z) = s/\overline{q} \leq 1$. We make the following hypotheses about the function γ: $\gamma(0) = 0; \gamma'(z) > 0$ if $z < \bar{z}; \gamma''(z) < 0$. If it spends nothing, the RR recycles nothing; its production increases with the level of spending, but with decreasing returns.[9] In this general case, $\bar{z}$ is the level of spending required for total recycling (if the technology itself allows this: - see below). The total revenue of RR is therefore $p\gamma(z)\overline{q}$. As far as production costs are concerned, RR spends z per unit of waste recovered. It also pays the price ϕ for the waste that it is going to recover and recycle. The profit of RR can therefore be written:

$$\pi_{RR}(z) = (p\gamma(z) - z - \phi)\overline{q}$$

9. Decreasing returns in the recovery activity can be justified by the fact that it is a labor-intensive activity in which the extraction of a given unit of material in a waste stockpile reduces the density of this material in the latter. The marginal cost of recovery is growing with amounts recovered.

We define the function γ such that $\gamma(z) < 1$. This means that there is never a corner solution; there is never complete recycling of all available waste, whatever the amount spent on it. At equilibrium there is always a certain production of the primary good (and therefore always a certain level of pollution). This restriction seems to be realistic (presence of impurities in the aluminium, for example, technical limitations to recycling, etc.) and relevant to the problem of interest to us here. If total recycling was possible, then the question of environmental policy would be trivial: recycling would allow a constant level of consumption, the (polluting) monopolist would disappear, and with it would go the pollution. More interesting is the case where recycling exists, but is insufficient to satisfy equilibrium demand. More precisely, we adopt the following function:

$$\gamma(z) = 1 - e^{-kz}$$

The parameter k can be interpreted as a measure of the efficiency of the recycling sector. The higher this technological parameter, the larger the fraction that is recycled, for a given level of spending z. For the sake of simplicity, we have defined $k = 1$ in what follows.

The RR choose their level of spending z so as to maximise their profit. Their optimal spending is:

$$z^* = ln\, p$$

From this we can obtain the supply function of RR:

$$\begin{aligned} s(p) &= \gamma(z^*)\bar{q} \\ s(p) &= \left(1 - \frac{1}{p}\right)\bar{q} \end{aligned} \qquad (1)$$

The quantity supplied by the RR increases with the price ($s'(p) > 0$): - a simple verification of the law of supply. When the price of the good is high, the RR are prepared to spend more on production of the secondary good (z^* rises), thus increasing their production. The restriction on the function γ ensures that $s/\bar{q} < 100$ per cent.

2.3. The monopolistic producer of the primary good

The monopolistic producer of the primary good (hereafter referred to as Alcoa) sells its product at price p (as do the RR, since the virgin and secondary goods are assumed to be perfect substitutes). He supplies to the market an amount equal to the difference between total demand (market demand) and the quantity supplied by the secondary sector. Total demand is assumed to be known. It is given by the demand function[10] $q(p)$, with $q'(p) < 0$.

Production of the primary good is therefore determined by:

$$v = q(p) - s(p)$$

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10. Further, we specify a linear demand curve:

$$q(p) = -ap + b$$

The parameter $a = -q'(p)$ is then the slope of the demand curve. A high value means that the slope of the demand curve is low. Conversely, a low value means that the slope of the demand curve is high.

Alcoa has a constant unit cost c.[11] For a given period, its profit can therefore be written:

$$\pi_{Alcoa}(p) = (p-c)\big(q(p)-s(p)\big)$$

Alcoa chooses the price level p that allows it to maximise its profit. The first-order condition can be written:

$$p^{*} = c + \frac{q-s}{s'-q'} \qquad (2)$$

Unsurprisingly, $p > c$. The market power (Alcoa as price-maker) results in a price higher than the marginal production cost of the primary good. The monopoly rent depends fundamentally on the slope of the RR supply curve (s') and the slope of the total demand curve (q'):

- the monopoly rent is negatively related to s'. If s' is high, then the RR react strongly to variations in p: a small variation in p provokes a strong rise in the supply of the secondary good, leaving a low level of residual demand for the monopolist;
- the monopoly rent is negatively related to q' (in absolute terms). If q' is high (in absolute terms), then consumers react strongly to variations in p (shallow demand curve): a small rise in p provokes a strong fall in total demand, leaving little residual demand for the monopolist.

These two factors (high s' and high absolute value of q') naturally limit the market power.

Equation (2) implicitly gives the price (chosen by the monopolist), from which we can calculate total demand q, supply of the secondary good s and supply of the primary good v.

By considering a linear demand function, $q = -ap + b$, the model can be completely solved:

$$p = (bc/a)^{0.5}$$

3. Tax on the production of the primary good

Production of the primary good is assumed to be more polluting than production of the secondary good. Public policies are implemented in response to this negative externality, and we wish to explore the effects of these policies. The first environmental policy that we envisage is a tax on the production of the primary good (assumed to be polluting).[12] Here, the aim is to internalise a negative externality. The public authorities responsible for

11. In the production of primary aluminum, the elements of cost per tonne in 2009, are: alumina (31 percent), energy (29 percent), carbon (10 percent), other (14 percent) and labor (16 percent) (TCA Quebec, 2009). The weight of the first three elements can explain the existence of constant returns. Possibly increasing yields in logistics and transportation (other) probably outweigh the diminishing returns of labor. Similarly, Lesclous (1999) observes that in an aluminum plant in 1995, there was almost constant returns expressed as cost per tonne per year in the transition from two to three series of electrolytic cells.

12. In a partial equilibrium, we are not interested in the use of tax proceeds by the government.

environmental policy levy a tax τ per unit of primary good produced by the monopolist. We are interested in the impact of this tax on the welfare of consumers. We do not define a welfare function, but simply assume that welfare is affected positively by consumption of the good (whether it is primary or recycled, since they are assumed to be perfect substitutes) and negatively by pollution (and therefore by production of the primary good). Equation (2) becomes:

$$p = (c+\tau) + \frac{q(p)-s(p)}{s'(p)-q'(p)} \tag{3}$$

In the case of a linear demand function, the model can be completely solved:

$$p = \left(\frac{b(c+\tau)}{a}\right)^{0.5}$$

Without ambiguity:

$$\frac{dp}{d\tau} > 0$$

A rise in the tax has the effect of increasing the selling price (it is passed on to consumers by the monopolist). As a result, the total quantity consumed falls (through the law of demand), and the quantity of the secondary good increases (increasing supply of RR). Finally, we deduce that the quantity of the primary good (residual demand) falls, thus reducing pollution. To sum up, a tax increase does indeed reduce pollution, but it also reduces the total quantity of good available to consumers. The overall effect in terms of welfare is therefore ambiguous.

4. Subsidy on recycling

The second environmental policy that we envisage is a subsidy on production of the secondary good (assumed to be non-polluting or, with perfect equivalence less polluting than production of the primary good).[13] The unit price received by firms in the RR sector becomes $(p+\sigma)$. The supply function of the RR becomes:

$$s(p,\sigma) = \left(1 - \frac{1}{p+\sigma}\right)\overline{q} \tag{4}$$

From the point of view of the RR, all other things being equal, the subsidy σ plays an identical role to the selling price p. We also observe that the second derivative of the supply function is negative. The slope of the supply curve is steep if the the selling price is high / if the subsidy is high.

Equation (2) becomes:

$$p = c + \frac{q(p)-s(p,\sigma)}{s_p^*(p,\sigma)-q'(p)} \tag{5}$$

13. In a partial equilibrium, we are not interested in the financement of this subsidy.

In the case of a linear demand function, using the theorem of implicit functions[14], we can show that the effect of an increase in the subsidy ($d\sigma > 0$) depends in particular on the slope of the demand curve.

1) If the demand curve is steep, we obtain the same result as for the tax:

$$\frac{dp}{d\sigma} > 0$$

An increase in the subsidy will result in a rise in the selling price of the good, and therefore a fall in demand and, according to the supply function of the RR sector, an increase in production of the secondary good (the effects of the price rise and the subsidy increase combine, both working in favour of the recycling sector). Ultimately, this policy results in a fall in production of the primary good (and therefore of pollution). The effect is ambiguous in terms of welfare (reduction in pollution / fall in the total quantity of the good).

2) If the demand curve is shallow, we obtain:

$$\frac{dp}{d\sigma} < 0$$

A rise in the subsidy results in a fall in the price of the good, and therefore an increase in aggregate demand. At first sight, according to the supply function of the RR sector (4), the effect on this sector could be ambiguous. However, we have shown[15] that an increase in the subsidy always dominates the fall in price: the subsidy rise is always profitable to the RR sector. In other words, the share of the secondary good increases. Likewise, we can verify that the share of the primary good decreases. What about the absolute quantity of the primary good and therefore pollution)? At this stage, it remains ambiguous, as does the conclusion in terms of welfare: consumption clearly increases, but the variation in the level of negative externality is indeterminate.

How can this subsidy have different effects on the price level (and consequently on the total quantity produced and consumed)? The intuitive answer is that it is only when the demand curve is steep enough (from which one can deduce that the monopolist's residual demand curve is also steep) that the monopolist can increase its price, without losing too much residual demand. With steep residual demand, the price rise compensates for the (slight) reduction in quantity.

Conversely, when the demand curve is shallower (meaning that the monopolist's residual demand curve is also shallow), the monopolist has no interest in raising the price; it is even in the monopolist's interest to cut the selling price, which will discourage production of the secondary good, thereby leaving the monopoly with sufficient residual demand.

14. See Appendix A1.1.
15. See Appendix A1.2.

To put it another way, a rise in the subsidy paid to producers of the secondary good has the effect of shifting the monopolist's residual demand curve to the left (for any given price, residual demand is lower). In the case of a steep curve, despite the leftward shift of residual demand, the monopolist can raise the price because this more than compensates for the fall in quantity (linked to the increasing activity of the RR). In the case of a shallow curve, if the monopolist raises the price it will suffer too great a fall in quantity: its optimal response to a rise in the subsidy paid to RR (and the consequent reduction in residual demand) is then to cut the price.

Whether or not we find ourselves in case 1 or case 2 also depends on the slope of the RR supply curve:[16]

- We find ourselves in case 1 ($dp/d\sigma > 0$ - fall in quantity / fall in pollution) if the RR supply curve is relatively shallow. Study of the second derivative of the RR supply function shows that this is likely to happen if the initial price and the initial subsidy are relatively low. Intuitively, it is only when the price and the subsidy received by the RR are low that the monopolist can afford to raise its selling price.
- We find ourselves in case 2 ($dp/d\sigma < 0$ - rise in quantity / uncertain environmental impact) if the RR supply curve is relatively steep. This is likely to happen if the initial price and the initial subsidy are already high. Intuitively, a high initial equilibrium price / high subsidy limit the monopolist's room for manœuvre in terms of price increases. Its optimal response in the case of a rise in the subsidy will then be to cut the price, with the uncertain environmental impact described above.

5. Conclusion: in favour of a norm?

This article has presented a first attempt to incorporate the environmental dimension into a model where a polluting firm with market power faces a sector of (non-polluting) recyclers. In this context, we have studied the impact of different environmental policies.

The main conclusions are:
(i) An increase in the tax on the polluting monopolist raises the selling price of the good, reduces the total quantity of the good, reduces the quantity of primary good produced and reduces pollution. The effect on welfare is ambiguous.

(ii) An increase in the subsidy to the (non-polluting) recycling sector has an effect on the selling price of the good that depends on the slope of the demand curve for the good and on the slope of the recycler's supply curve. If the demand curve is steep / the RR supply curve shallow, the effect is the same as that of the tax on the polluting monopolist. If the demand curve is shallow / the RR supply curve steep, an increase in the subsidy leads to a fall in the selling price of the good, a rise in the total quantity of the good, an increase in the share of

16. See Appendix A1.1.

recycling (with a corresponding fall in the share of primary production) and an indeterminate change in the level of pollution. The effect on welfare is uncertain.

Policy-makers should therefore bear in mind that the first measure (tax), which directly affects the price-maker on this market, has a different impact to the second measure (subsidy), which indirectly affects the price-maker *via* a reduction in the residual demand for its product.

Furthermore, since the consideration of market power raises doubts about the implementation of public policy based on economic instruments (taxes and subsidies), this suggests that regulation may be appropriate. Price instruments alone are not enough, here, to ensure an acceptable outcome in terms of sustainable development (consuming the same amount but polluting less). One solution might be to combine the classic economic instrument (a subsidy on recycling, to increase the share of recycled product) with a norm (for example a maximum legal volume of primary production, so that a rise in the total quantity of the good does not lead to a rise in the absolute quantity of primary good produced).

The more general (and operational) message of this article is therefore a warning to environmental policy-makers, that cases of imperfect competition can strongly disrupt the use of economic instruments of environmental policy.

J. De B. & G. G.[17]

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Appendix A1.1
Effect of the subsidy on the selling price

With a linear demand function, the condition (5) can be written:

$$g(p,\sigma) \equiv p - c - \frac{q(p) - s(p,\sigma)}{s_p^*(p,\sigma) + a} = 0$$

Following to the theory of implicit functions:

$$\frac{dp}{d\sigma} = -\frac{\partial g/\partial\sigma}{\partial g/\partial p}$$

Firstly, we study the sign of $\partial g/\partial p$:

$$\partial g/\partial p = 2 + \frac{(q-s)s''}{(a+s')^2}$$

We use the supply function of the RR sector, the first and second derivatives of the function $s(\,.\,)$ and we change the variable as follows:

$$Y \equiv \frac{q}{(p+\sigma)^2} > 0$$

Here, Y is the slope of the RR supply curve.

It follows that:

$$\partial g/\partial p = \frac{2a^2 + 4aY}{a^2 + Y^2 + 2aY} > 0$$

$dp/d\sigma$ is therefore the opposite sign to $\partial g/\partial\sigma$.

We then study the sign of $\partial g/\partial\sigma$:

$$\partial g/\partial\sigma = \frac{s'(a+s') + (q-s)s''}{(a+s')^2}$$

By using the first and second derivatives of the function $s(\,.\,)$, we can therefore write:

$$\partial g/\partial\sigma = \frac{a\frac{q}{(p+\sigma)^2} - \frac{q^2}{(p+\sigma)^4}}{a^2 + \frac{q^2}{(p+\sigma)^4} + 2a\frac{q}{(p+\sigma)^2}}$$

With the above change of variable, we obtain:

$$\partial g/\partial\sigma = \frac{Y(a-Y)}{a^2 + Y^2 + 2aY}$$

Whence:

$$\alpha < Y \Leftrightarrow \partial g/\partial \sigma < 0 \Leftrightarrow dp/d\sigma > 0$$
$$\alpha > Y \Leftrightarrow \partial g/\partial \sigma > 0 \Leftrightarrow dp/d\sigma < 0$$

When α is below a certain threshold (relatively steep demand curve), an increase in the subsidy leads to a rise in the price of the good. Conversely, when α is above the same threshold (relatively shallow demand curve), a rise in the subsidy leads to a fall in the price of the good. The interpretation can also be made in terms of the slope of the RR supply curve: if Y is above a certain threshold (supply curve), then an increase in the subsidy leads to a rise in the price of the good. Conversely, when Y is below that threshold (relatively steep RR supply curve), then an increase in the subsidy leads to a fall in the price of the good.

APPENDIX A1.2
EFFECT OF THE SUBSIDY ON THE SUPPLY OF THE SECONDARY GOOD

In the case where an increase in the subsidy provokes a price rise ($a < Y$), the supply curve of the RR sector (4) shows that these two variables work in the same direction: without ambiguity, the share of recycling increases.

In the case where an increase in the subsidy causes a fall in price ($a > Y$), then we must determine which effect is dominant (positive effect of the subsidy increase versus negative effect of the fall in price). Firstly, we show that:

$$\frac{ds}{d\sigma} > 0 \Leftrightarrow \frac{dp}{d\sigma} > -1$$

$$\Leftrightarrow -\frac{dp}{d\sigma} < 1$$

$$\Leftrightarrow \left|\frac{dp}{d\sigma}\right| < 1$$

Naturally, for the recycling sector to benefit from the subsidy, the fall in price must be more than offset by the increase in the subsidy. Following APPENDIX A1.1, we have:

$$-\frac{dp}{d\sigma} = \frac{\partial g/\partial\sigma}{\partial g/\partial p}$$

$$(\partial g/\partial\sigma) - (\partial g/\partial p) = \frac{-Y^2 - 2a^2 - 3aY}{a^2 + Y^2 + 2aY} < 0$$

$$\partial g/\partial\sigma < \partial g/\partial p$$

$$\frac{\partial g/\partial\sigma}{\partial g/\partial p} < 1$$

$$-\frac{dp}{d\sigma} < 1$$

$$\frac{ds}{d\sigma} > 0$$

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