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To discard or to coproduce by recycling waste: An output constraint analysis

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To Discard or to Coproduce by recycling waste: an output constraint analysis

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Abstract:

This paper investigates a multi-market Cournot model where a particular firm may be present in a secondary market by recycling its waste as coproducts. We show the conditions under which the recycling strategy is optimal for the firm, thus creating coproduction and co-value. Unlike the usual models found in the literature based on costs and potential economies of scope, our model associates the relationship between the two goods as a new technological constraint for production. We show that an optimal percentage of recycling the waste as a new coproduct exists and depends on the structural conditions of the two markets.

Keywords: Multi-market Cournot Game; Waste management; recycling; Coproduction

JEL: C72, L13, Q5

1. Introduction

Multi-market corporate strategies have largely been analyzed in the literature through the concepts of economies of scope (Panzar and Willig 1977, Caves *et al.* 1980) and multimarket competition (Heggstad and Rhoades 1978, Bernheim and Whinston 1990). Concerning the latter, Harrington (1987) showed the potential collusion in multiproduct oligopoly games by assuming that, in each market, at least two firms also competing in another market can be found. Although the firm's production in one given market is independent from that of the other market, still the probability to collude increases due to the multiple contact effect. By being multi-market, one firm (e.g. a conglomerate) may create a strategic link between its decisions regarding the multiple products, and force other firms to consider all the decisions in every market of the conglomerate. This fact was first stated by Edwards (1955). Heggstad and Rhoades (1978) analyzed empirically such an impact of being multi-market in the banking industry. Although they show that "acquisition by dominant firms outside their traditional geographic and product markets is likely to be detrimental to competition and performance in the markets where they operate", they do not explain theoretically where such a link comes from. Bernheim and Whinston (1990) even consider that "when identical firms with identical constant-returns-to-scale technologies meeting identical markets, multimarket contact does not aid in sustaining collusive outcomes" (*Op. Cit.* p. 5).

Among the theoretical possibilities, Okuguchi and Szidarovszky (1999) and Ahmed and Eletteby (2014) assumed that a link may stem from economies of scope, where two or more commodities may be produced jointly at lower cost than if they were produced separately (Panzar and Willig 1981). As shown by Ahmed and Eletteby (2014) under this condition, the dynamic behavior of a Cournot multi-market game results in cycles and chaos.

In the present article, we assume a strategic link between the products sold in two different markets through a technical constraint within the production function. This link is well-known in the literature through the concept of jointness in production (Nadiri 1987). More specifically, intrinsic jointness refers to several goods being manufactured within a single production process, like wool and mutton. Usually, this property is associated with economies of scope and provides firms with cost advantages upon their single-product rivals. This is not the case in our approach where both multi-product and single-product firms compete exactly under the same cost conditions on every markets. Our study does not search to deal with the competition outcome of firms differentiated by their scope of products, but merely to address the problem of a firm which has to decide between recycling or discarding its intrinsic joint by-products or waste.

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At this stage, the vocabulary used for joint products needs to be clarified. A distinction is made by some authors between coproducts, by-products, and waste according to the level of revenues generated by the joint products, even though the revenue shares are not clearly defined (Horne and Matthews 2004). If this revenue is substantial and comparable to the main product, the side products will be called coproducts; if the revenue is significantly smaller, they become by-products, and if the revenue is negligible or null, the residues remain as simple waste. The problem then consists in recycling waste so as to convert it into by- or coproducts. Such a situation can be met when firms try to valorize on a secondary market the by-products and waste coming from the primary process. A first illustration is given by farmers producing milk for the food market and selling the methane generated by cattle farming on the energy market. The quantity of methane available for the secondary market is directly related to the level of milk production (e.g. the size of the farm and livestock). Assuming high value products (and/or inelastic demand) on the secondary market and low value products (and/or elastic demand) on the primary one, it becomes interesting for the multi-product firm to overproduce in the latter market in order to obtain a large quantity of profitable “waste” for the secondary market. The opposite statement is also true: if the secondary market is not profitable enough, for example because of stiff competition due to a large number of incumbent firms, incentives for recycling waste and by-products for the secondary markets disappear. As a recent example, the French project of a “farm of a thousand cows” has encountered high hostility from other cattle farmers¹. This new farm is supposed to produce up to 8.5 million liters of milk a year and run a huge methane power plant of 1.5 megawatts to be sold on the electricity market. Some of the critics said that this project would pull down the price of milk, resulting in a potentially non profitable market for every French farmers. This activity would only remain profitable for the multi-market farm only because of the methane production.

More than revenues, profits by type of products appear of far greater importance for firms since the coproducts sold on a separate market can compensate losses incurred by the main market, thus making the multi-market business profitable in overall. For example, in response to global warming and climate changes, microalgae is considered as a promising feedstock for biofuel production but the “fuel only” option is not economically viable (Williams and Laurens, 2010). With a current production of 15 000 ton of dry matter per year (Houdon and Gueudet, 2014), microalgae based biomass is mostly valorized as high-value products in relatively small markets such as human food, chemicals or cosmetics (Zhu, 2015). According to Houdon and Gueudet (2014), feed, human food and chemicals world-markets represent a potential of 55 billion euros compared with more than 1 000 billion

¹ News from Mediapart.fr (<http://www.mediapart.fr/journal/france/300913/opposition-grows-biggest-farm-ever-built-france>).

for biofuel market. Through biorefinery, multi-production is consequently a promising option for making microalgae biofuels economically (Zhu, 2015). A conventional definition is given by the International Energy Agency: “Biorefining is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, and chemicals) and energy (fuels, power, heat)”². According to Vanthoor-Koopmans et al., (2013), microalgae biofuel production requires using all produced compounds to reach economic viability. However, large-scale deployment of microalgae biorefineries may quickly saturate the high-value coproducts markets, i.e. generating market gluts that affect coproducts prices and biorefinery viability (Bobban G. Subhadra, 2011). Considering the technical constraint that links microalgae strains and conversion pathways (IEA 2013) to the range of coproduction possibilities, biorefineries may adapt their recycling strategy depending on the market structures and characteristics.

Considering this “coproduct market glut” paradigm (Bobban G. Subhadra, 2011), the rising concerns for sustainable waste management (Manfredi and Malgorzata, 2013; Zaman, 2014), and the technical constraints that links the different coproducts outputs, we propose addressing the following theoretical problem: *under which conditions does waste recycling become profitable for multi-market firms?* We show that the answer is not straightforward since it depends on the discarding cost, the technological link between the two productions, and the structure of the two markets in terms of competition intensity. Beyond the design of recycling/coproducts valorization strategies for multi-market firms, addressing such theoretical problem also provides new insights that may help to design sustainability policies for waste management such as zero-waste objectives.

Section 2 introduces the general Cournot oligopoly framework with firms facing waste management costs without any multi-market relationship. Section 3 analyzes the model with one multi-market firm competing with single-market firms on two different markets (e.g. energy and agriculture). Section 4 provides a sensitivity and risk analysis of the model based on numerical resolutions. Section 5 concludes the article by suggesting some policy implications of the results.

² International Energy Agency (IEA), Bioenergy Task 42, <http://www.ieabioenergy.com>

2. The standard Cournot game with no multi-market players

In order to develop the theoretical model, let's consider, for example, a microalgae biorefinery that produces algal biomass valorized as Biodiesel in market B and Algal based Omega 3 Fatty Acid (O3FA) in market A.

2.1. The game

Let N_B and N_A be respectively the number of players (firms) in the Biodiesel market (B) and in the O3FA market (A) market. Let $y_{i,k}$ be the level of production of a particular firm i in market k , with $k \in \{B, A\}$. Let $y_{-i,k}$ be the total level of production of the other firms in a particular market k .

Each firm aims to maximize its profit function:

$$\max_{y_{i,k}} P(y_{i,k}, y_{-i,k})y_{i,k} - C_k(y_{i,k}) - W_k(y_{i,k}) \quad (1)$$

With $C_k(\cdot)$ the cost function (production cost) and $W_k(\cdot)$ the discarding cost incurred by the management of waste from the primary production.

The price is supposed to be set as follows, with $Y = \sum_{i=1}^{N_k} y_{i,k} = y_{i,k} + y_{-i,k}$

$$P(y_{i,k}, y_{-i,k}) = A_k - B_k Y \quad (2)$$

The quantity of waste is assumed to be fully proportional to the output level for every firm, and in every market.

As a result, the quantity of waste will be $y_{i,k}^W = \gamma y_{i,k}$. For simplicity reason, we assume that $\gamma \equiv 1, \forall i, \forall k$ and that total costs are linear:

$$C_k(y_{i,k}) + W_k(y_{i,k}) = c_k y_{i,k} + w_k y_{i,k} \quad (3)$$

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With $c_k > 0$ and $w_k > 0$. c_k is the unitary variable cost of production and w_k the marginal cost of waste production. The sum $c_k + w_k$ defines the total marginal cost of production.

2.2. *The Cournot-Nash equilibrium solution*

Each firm aims to solve (1) given (2). The First Order Conditions (FOC) requires solving the following equation:

$$\frac{\partial P(y_{i,k}, y_{-i,k})}{\partial y_{i,k}} y_{i,k} + P(y_{i,k}, y_{-i,k}) - \frac{\partial C_k(y_{i,k})}{\partial y_{i,k}} - \frac{\partial W_k(y_{i,k})}{\partial y_{i,k}} = 0 \quad (4)$$

From (4) we obtain the standard reaction function:

$$y_{i,k} = \frac{A_K - c_k - w_k - B_K y_{-i,k}}{2B_k} \quad (5)$$

Assuming a symmetric Cournot-Nash equilibrium, i.e. $y_{i,k}^* = y_k^* \forall i$, the optimal level of production is given by:

$$y_k^* = \frac{A_K - c_k - w_k}{B_k (N_k + 1)} \quad (6)$$

The usual equilibrium level of output follows a positive function of the market size A_k and is negatively related to the unit costs and number of firms.

3. The multi-market firm's recycling-strategy: to discard or to coproduce?

3.1. *Coproduction and waste*

Let's now consider a multi-market firm, that is, for example, a microalgae biorefinery j which may participate in two different markets by using a specific coproduction function. For example, if the firm has an initial production of microalgae-biodiesel in market B, we assume it can recycle the waste as proteins for a secondary market A

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(Algal based O3FA for food market). Consequently, the number of firms in each market k will be $N_k + 1$, with N_k single-market firms and one multi-market firm.

The multi-market firm j must decide between recycling (or not) its waste as valuable coproducts for the secondary market, and, if it does, in which quantity. Reminding that the quantity of waste generated by firm j in market B will be $y_{j,B}^W = \gamma y_{j,b} \equiv y_{j,B}$, we assume that this firm j uses a processing technology θ that transforms the waste into a tradable coproduct in such a way that $y_{j,A} = \theta y_{j,B}^W = \theta y_{j,B}$. The technological parameter θ can be interpreted either as a productivity measure of the waste recycling process (i.e. microalgae strain constraint), or as a production (technical) constraint which implies that the level of output available for the secondary market is directly induced by the output quantity of the primary market (process productivity).

Let α be the proportion of waste generated by firm j per unit of output in market B that will be used to produce a unit of output for market A. We assume that the multi-market firm may decide to sell the recycled products ranging from none to totality:

- $\alpha = 1$: All the waste is used to produce at the maximum level in market A, with $y_{j,A} = \theta y_{j,B}$.
- $\alpha = 0$: No re-use of the waste: the firm discards everything. Then $y_{j,A} = 0$ and the cost of discarding in market B will be $w_{j,B} y_{j,B}$.
- $0 < \alpha < 1$: Only part of the by-products is recycled for market A. Then production in market A will be $y_{j,A} = \alpha \theta y_{j,B}$ and the cost of discarding in market B will be reduced to $w_{j,B} (1 - \alpha) y_{j,B}$.

As a consequence, the output levels of market A and B will be Y_A and Y_B , respectively, with

$$Y_B = \sum_i^{N_B+1} y_{i,B} = y_{i,B} + y_{-i,B} + y_{j,B} \quad \text{and} \quad Y_A = \sum_i^{N_A+1} y_{i,A} = y_{i,A} + y_{-i,A} + y_{j,A} \equiv y_{i,A} + y_{-i,A} + \alpha \theta y_{j,B}$$

For any firm $i \neq j$, the profit function is still defined by (1) but the price equation (2) is now given by:

$$P(y_{i,k}, y_{-i,k}, y_{j,k}) = A_k - B_k (y_{i,k} + y_{-i,k} + y_{j,k}) \quad (2')$$

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Because of its dual market position, the cost function of the multi-market Firm j will be different from the others and will be:

$$c_{j,B}y_{j,B} + w_{j,B}(1-\alpha)y_{j,B} + c_{j,A}\alpha\theta y_{j,B} + w_{j,A}\alpha\theta y_{j,B} \equiv \tilde{C}(y_{j,B}) + \tilde{W}(y_{j,B}) \quad (3')$$

where $C_{j,k}$ and $W_{j,k}$ may differ from c_k and w_k , the generic cost parameters of single-market firms.

Firm j thus creates a technological link between the two markets, and because it has only one degree of freedom (i.e. it cannot modify its technical constraint), its optimal multi-output level will be influenced by the discrepancy between the two markets in terms of number of players, price elasticity of demand, etc.

3.2. The Cournot Nash equilibrium with α given

We assume that the proportion of recycled waste α is given. It will be part of the maximization problem in the next section. We still assume that the single-market firms are symmetric firms (i.e. they will supply the same output level at equilibrium). Following the steps of the previous section (e.g. maximizing (1) given (2')), the reaction function of the N_k single-market firms will be:

$$y_{i,k} = \frac{A_K - c_k - w_k - B_K y_{-i,k} - B_K y_{j,k}}{2B_K} \quad (7)$$

The multi-product firm j will try to solve the following maximization problem, subject to (2'):

$$\max_{y_{j,B}, y_{j,A}} \sum_k P(y_{i,k}, y_{-i,k}, y_{j,k}) y_{j,k} - C_k(y_{j,k}) - W_k(y_{j,k}) \quad (8)$$

Given the technical constraint $y_{j,A} = \alpha\theta y_{j,B}$, we can rewrite (8) as the following maximization problem:

$$\max_{y_{j,B}} P(y_{i,B}, y_{-i,B}, y_{j,B}) y_{j,B} + P(y_{i,A}, y_{-i,A}, \theta y_{j,B}) \theta y_{j,B} - \tilde{C}(y_{j,B}) - \tilde{W}(y_{j,B}) \quad (8')$$

The resolution of (8') given (2') and (3') gives the reaction function for the multi-market firm:

$$y_{j,B} = \frac{A_B - c_{j,B} - w_{j,B}(1-\alpha) + \alpha\theta(A_A - c_{j,A} - w_{j,A}) - B_B(y_{i,B} + y_{-i,B}) - B_A\alpha\theta(y_{i,A} + y_{-i,A})}{2(B_B + B_A\alpha^2\theta^2)} \quad (9)$$

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As expected, any increase of the other firms' production on either market A or B will reduce the production of Firm j .

The impact of θ on the optimal level of production $y_{j,B}$ is more ambiguous. As we shall see numerically, a

nonlinear relationship exists, that is $\frac{\partial y_{j,B}}{\partial \theta} > 0$ for small values of θ , and $\frac{\partial y_{j,B}}{\partial \theta} < 0$ for higher ones.

The Cournot Nash problem requires solving simultaneously the following set of equations, $\forall i$ (i.e. $N_A + N_B + 1$ equations):

$$\begin{cases} y_{i,B} = \frac{A_B - c_B - w_B - B_B y_{-i,B} - B_B y_{j,B}}{2B_B} \\ y_{i,A} = \frac{A_A - c_A - w_A - B_A y_{-i,A} - \alpha \theta B_A y_{j,B}}{2B_A} \\ y_{j,B} = \frac{A_B - c_{j,B} - w_{j,B}(1 - \alpha) + \alpha \theta (A_A - c_{j,A} - w_{j,A}) - B_B (y_{i,B} + y_{-i,B}) - B_A \alpha \theta (y_{i,A} + y_{-i,A})}{2(B_B + B_A \alpha^2 \theta^2)} \end{cases} \quad (10)$$

Assuming a Nash symmetric solution for the i firms on the distinct markets, we shall have $y_{i,A}^* = y_A^*$ and

$y_{i,B}^* = y_B^*$, $\forall i \neq j$. This leads to solve:

$$\begin{cases} y_{i,B}^* = \frac{A_B - c_B - w_B - B_B y_{i,B}^* (N_B - 1) - B_B y_{j,B}^*}{2B_B} \\ y_{i,A}^* = \frac{A_A - c_A - w_A - B_A y_{i,A}^* (N_A - 1) - \alpha \theta B_A y_{j,B}^*}{2B_A} \\ y_{j,B}^* = \frac{A_B - c_{j,B} - w_{j,B}(1 - \alpha) + \alpha \theta (A_A - c_{j,A} - w_{j,A}) - B_B N_B y_{i,B}^* - B_A \alpha \theta N_A y_{i,A}^*}{2(B_B + B_A \alpha^2 \theta^2)} \end{cases} \quad (10')$$

Although the algebra to solve (10') is not difficult, the exact definition of the Nash equilibria is quite long and is not reproduced here.

It is possible to demonstrate numerically that profit is a non-linear function of θ . An increase of θ will first increase the profit of the multi-market firm which decreases thereafter. Its impact is more important when the number of competing firms on both markets is small. The next section discusses this result among others through a numerical application.

3.3. Numerical simulation.

In order to highlight the impact of θ we calculate the Cournot-Nash equilibrium as a function of θ with the following parameter values: $A_A = 50 = A_B, B_A = 1 = B_B, c_B = c_A = 1 = c_{j,A} = c_{j,B}, w_{j,B} = 1$ and $w_A = w_B = 0 = w_{j,A}$.

Except for small values of θ , Figures 1 and 2 show that the impact of α on profit for the multi-market firm is clearly nonlinear. There exists obviously an optimal value of α which may be different from 0 and 1, meaning that only part of the waste has to be recycled to be sold in the secondary market. A closer look at the two figures also indicates that this proportion is less important, *ceteris paribus*, when competition in the secondary market is stiffer (e.g. when N_A increases). The relationship between α and θ is also nonlinear. For small values of α , whatever the initial profit level of Firm j , an increase of θ seems to increase its multi-output profit, while higher θ values reduce it significantly.

An optimal couple (α, θ) can be found according to the market characteristics. Because θ is a parameter directly related to the technology used in market B (e.g. the strain of microalgae), this productivity parameter measures the capacity for Firm j to produce more goods A for a given amount of good B. Consequently, an increase of θ improves the efficiency (productivity) of the production process to supply the secondary market with more recycled waste becoming valuable coproducts. If the secondary market becomes more competitive and/or demand more flexible, prices can sharply decrease by any excess of supply. This will occur if the firm re-cycle a great proportion of its waste and, because of high productivity, overproduces for the secondary market. This will be better understood through a sensitivity analysis the next section.

Finally, it is possible to observe in Figure 3 that the multi-market firm may wish to recycle all its waste into additional output units for the secondary market even though the primary market is not profitable. The latter remains an important basis for providing inputs that can be highly valued on the secondary market. The core of the business may shift to the secondary market by offsetting the economic loss in the primary industry.

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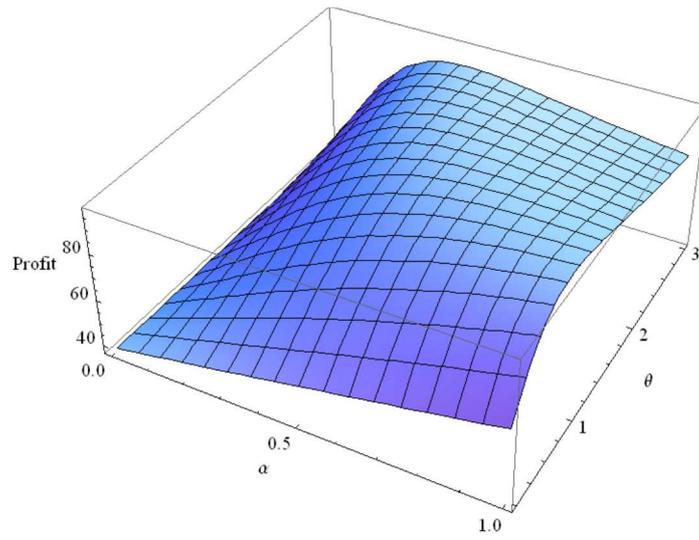


Figure 1 - Evolution of the overall profit of the multi-market firm
as a function of α and θ with $N_A=5$ and $N_B=5$

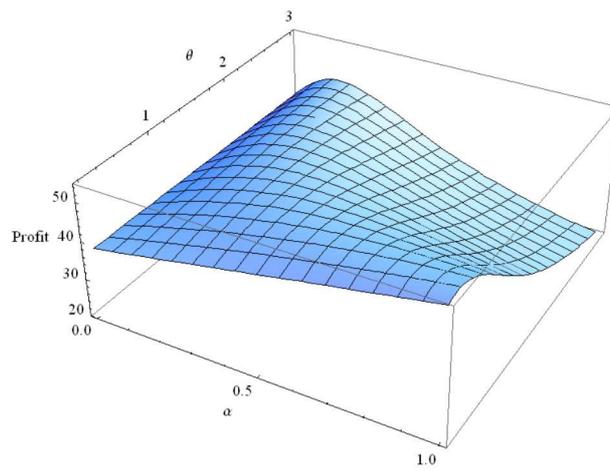


Figure 2 - Evolution of the overall profit of the multi-market firm
as a function of α and θ with $N_A=20$ and $N_B=5$

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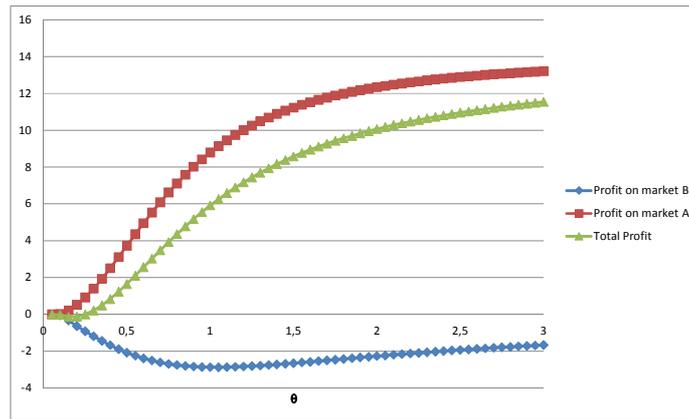


Figure 3 – Evolution of the profit, in market A, B and overall, as a function of θ with $N_A=5$ and $N_B=30$, $A_A=45$,

$A_B=40$, $B_A=B_B=1$, $c_{iA}=c_{iB}=c_{jA}=1$, $c_{jB}=3$, $w_{iA}=w_{iB}=w_{jA}=0$, $w_{jB}=2$, $C_{iB}=3$, and $\alpha=1$.

4. Sensitivity and multivariate analysis

4.1. Sensitivity analysis and the optimal proportion of waste

The Cournot-Nash equilibrium (10)' is defined for a given value of α . As highlighted by Figures 1-2, an optimal value for α exists. As a result, the multi-market firm, given (10)', should set α so as to maximize its overall profit. We solve the game in Excel³ and, using @Risk software, we run MonteCarlo sensitivity analysis by setting the possible range of values for the parameters as defined in Table I (e.g. the values of the parameters are drawn from independent uniform distributions).

What really matter for our study are causes of discarding waste on the B-market instead of valuing it on the A-market. It is worth noting that more than 60% of the Monte Carlo trials result in a zero or very close-to-zero waste rate (Fig. 4a), meaning that there is a strong incentive for a multi-market firm to recycle and sell by-products on the secondary market. More details about the driving factors of the waste rate are given in Figure 4b. The competitive degree on both markets, measured by the number of competing firms, has by far the greatest influence on the discarding strategy of the multi-market firm. But the technical parameter θ also changes significantly the waste rate which can vary between 6 and

³ Despite the simplicity of the model, a theoretical optimal value for α is not tractable.

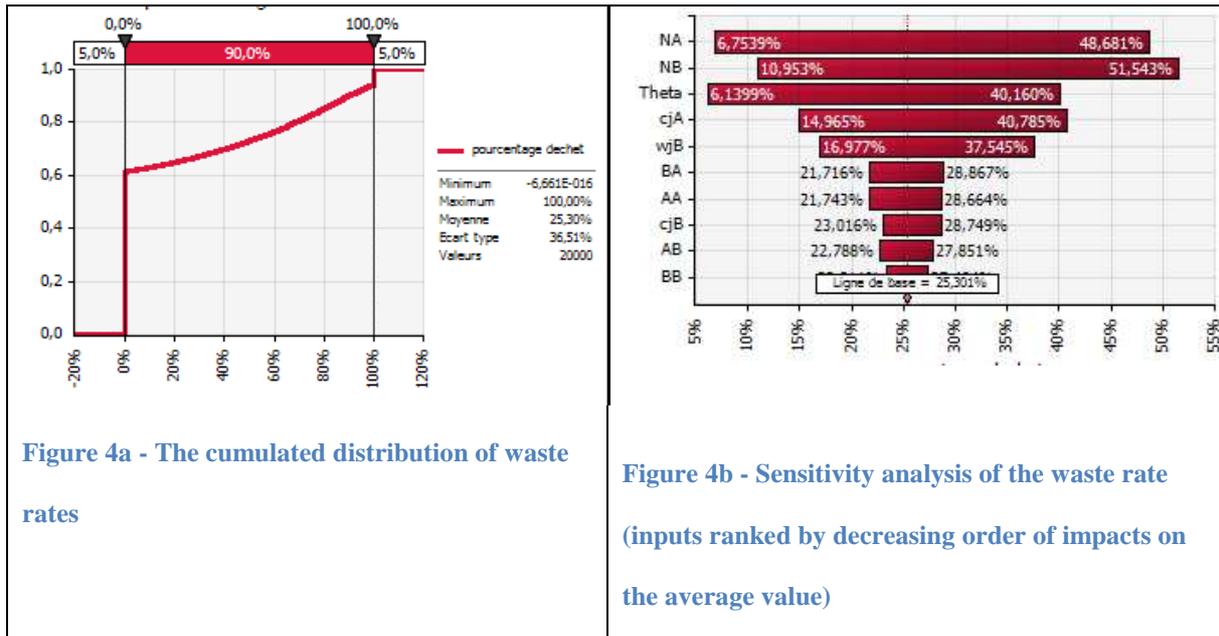
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40% when all other parameter values are kept constant. Finally, the cost conditions on the secondary market (c_{jA}) and the cost of waste destruction (w_{jB}) play a minor although significant role for the decision of discarding by-products.

Table I - Range of values for the Monte Carlo sensitivity analysis (uniform distribution)

Variables	Min value	Max value
A_A - Intercept of the market A demand curve	40	60
A_B - Intercept of the market B demand curve	40	60
B_A - Slope of the market A demand curve	0.8	1.2
B_B - Slope of the biofuel demand curve	0.8	1.2
N_A - Number of firms in market A	2	30
N_B - Number of firms in market B	2	30
P_A - Price in market A (calculated)	2.1	20.5
P_B - Price in market B (calculated)	2.0	17.2
C_{jB} - Marginal cost of goods in market B	0.5	4.0
C_{jA} - Marginal cost of goods in market A	0.5	4.0
w_{jB} - Marginal cost of discarding waste	0.1	3.0
θ - Technology parameter of waste processing	0.1	3.0

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4.2. Multivariate analysis and decision tree

A principal component analysis of variables (y_{iA} , P_A , P_B , c_{jA} , c_{jB} , N_A , N_B , w_{jB} , A_A , A_B , B_A , B_B , α , θ), explaining profits on both markets (profits and discards being used as illustrative variables, i.e. not included in the matrix reduction) shows a first principal component (23.3% of the Eigen Value sum) driven by the positive correlation between prices and quantity of all firms on market B, logically opposite on the factorial map to the number of firms competing on this market (Fig. 5).

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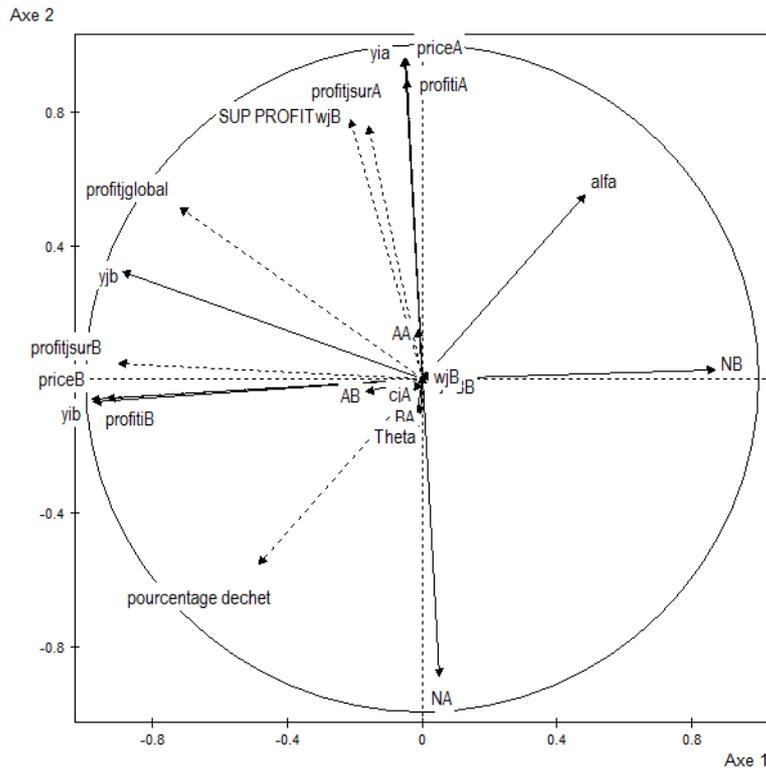


Figure 5 - Factorial map of the Monte-Carlo outcomes from the Cournot model

Profits issued from B-products are correlated with this first (horizontal) factor, but are found independent of profits achieved on the A-market which are positively correlated with factor 2 (concentrating 19.5% of total inertia). Not surprisingly, the number of competitors on the A market is negatively correlated with this second vertical axis. Note that the technical parameter θ is neither linked with factor 1 or 2, but rather with the third component (7.7% of EV sum) and negatively with α . The waste rate⁴, main variable of interest in our study, is negatively linked with the first three components (correlation coefficients are respectively -0.48, -0.55, -0.48). In other words, the proportion of waste on the B-market increases with market conditions on this primary market (prices, profits) and when θ is high, but decreases with market opportunities on the A-market. Other economic parameters, such as the demand parameters of the bioenergy market or the waste discarding cost, are correlated with more distant components and thus far less influential in the decision of co-producing or discarding.

⁴ Called *pourcentage déchets* ($= 1 - \alpha$) on the factorial map.

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To further scrutinize the incentives underlying a zero-waste strategy, the waste rate variable has been split into two discrete decisions: zero or close-to-zero (<0.001) waste (everything is valued on the second market = Decision 1), a positive up to full discard rate (= Decision 2)⁵. An Interactive Decision Tree (IDT) based on the CART approach⁶ highlights the most determining variables behind the choice of discarding vs valuing by-products (Fig. 6). First of all, the proportion of zero waste cases increases significantly (from 62% to 81%) if the B price is less than 7.247, and this proportion rises up to 93% of the sub-sample if the number of A-competitors is less than 15 (resulting in better price conditions on the secondary A-market). With more competitors, the proportion falls back to 62% but can improve still to 87% if the marginal cost on the A-market remains below a certain threshold (2.686) together with unattractive B-prices (<4.357). With higher B-prices, the probability of fully recycling by-products on the secondary market increases only if the technical constraint remains below 1.4, or even below 0.6 if the B-price is above 7.247 and A-price becomes less attractive ($P_A < 6.375$). In other words, market conditions, through price incentives and low competition, matter first, and thereafter only comes the productivity of the processing technology (or technical constraint of recycling).

⁵ Decision 1 = 62% of the sample; Decision 2 = 38% (of which 6% represent full discard observations).

⁶ Breiman L, Friedman J., Olshen R., Stone C. (1984), Classification and Regression Tree, California: Wadsworth International

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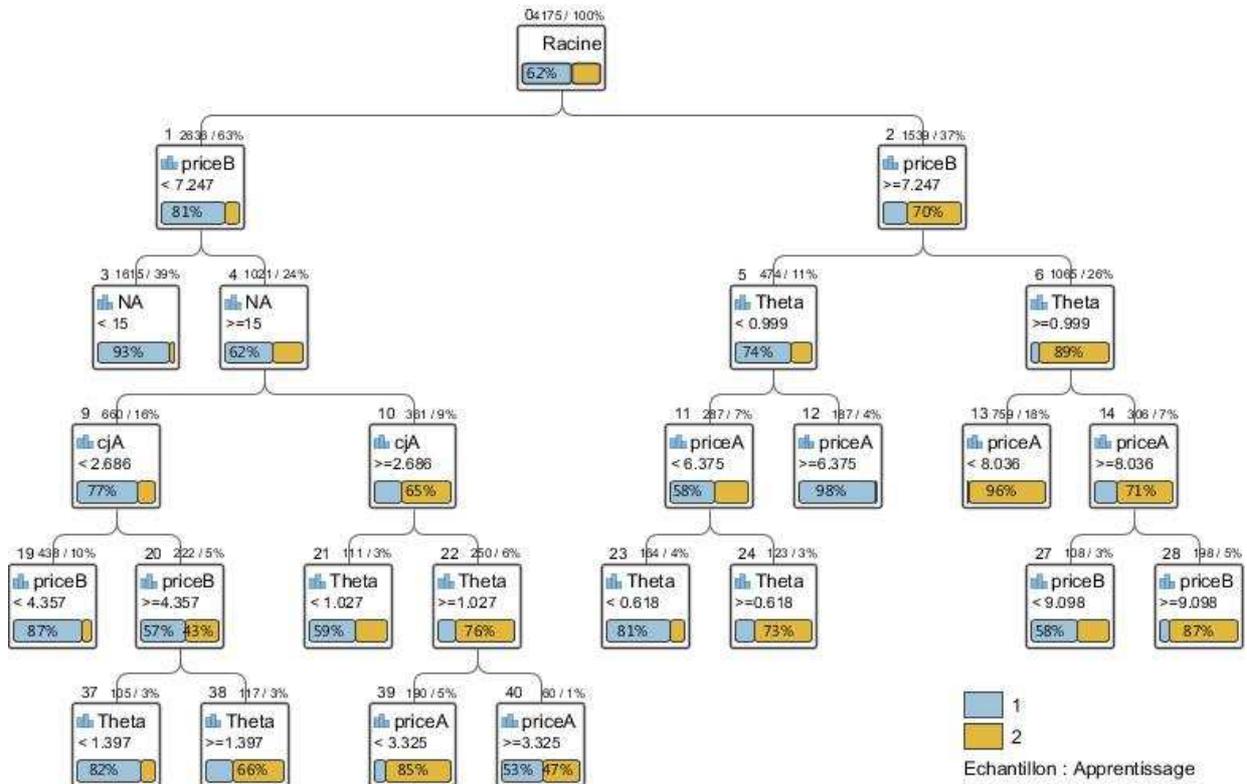


Figure 6 - Decision tree for the two (recycling/discarding) options (Decision 1 in Blue = zero waste)

A logit model has been applied through a stepwise procedure to the same set of variables to predict the probability of fully recycling Biofuel by-products:

$$\begin{cases}
 P(Y = zerowaste | X_1, \dots, X_k) = F(\beta_0 + \beta_1 X_1 + \dots + \beta_k X_k) \\
 P(Y = zerowaste | X_1, \dots, X_k) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \dots + \beta_k X_k)}}
 \end{cases} \quad (11)$$

The results are provided in Table II. All coefficients were found statistically significant and exhibit the expected theoretical sign, with the noticeable exception of the technological parameter θ whose relationship with the waste recycling rate $(1 - \alpha)$ is not straightforward. Confirming previous results given by the interactive decision tree and by decreasing order of khi-2 values, P_B , θ , N_A , c_{iA} and B_A reduce the probability of fully re-cycling (zero waste), whereas w_{jb} , P_A , c_{iB} , N_B , B_B ad A_A increase this probability. The higher the B-price, the lower the incentives to penetrate the secondary market. For instance, other things being equal, a twofold increase of B-prices from 3.6 to 7.2 would result in a 28% drop in the likelihood of full recycling (from 89 to 61%). On the other hand,

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the secondary market price has only a negligible attractive effect on recycling, unlike the slope of the demand curve on this market which affects substantially the recycling strategy. The sensitiveness of market A consumers to price changes hinders the likelihood of recycling waste on the primary market.

If price levels on the Biofuel market prevail, the processing technology on this market is far from being neutral. However, it influences the zero waste strategy in an unexpected way. Assuming that the conversion coefficient of waste into valuable A-market goods increases twofold (e.g. 2 units of A per unit of B instead of 1:1), the conditional probability of zero-waste would fall from 85 to 44%. This comes as a paradox since an improvement of the recycling technology would create a disincentive to recycle the B-market coproduct for the secondary market. As reported in section 3, the explanation comes from the quantity impact of being more productive in the A-industry (e.g. more output units for the A-market are obtained for a given quantity of waste inputs from the B-market). Because of the oligopoly regime on the secondary market, other single-product A-firms would respond to this increasing output from the multi-market firm in such a way that this market would face an excess of supply and a fall in prices and profits.

Finally, the Logit model confirms the results of the Monte Carlo analysis about the poor influence of production and discarding costs of both productions on the probability of full recycling. Neither the management cost of biofuel waste (w_{jb}) nor the marginal cost of producing bioenergy goods (C_{iB}) have a significant marginal effect on the recycling decision. The marginal effect of A-production costs, although small, appears even more influential than the latter two effects. The proportion of recycled waste would only decrease by 5% (from 95 to 90%) if producing for the agricultural market would double the marginal cost from 1 to 2 per unit of output. This result does not represent good news for any environmental policy targeting a full recycling rate of biofuel waste because a tax on discards and non-marketed by-products would only have a very limited impact on the recycling decision of the multi-market firm.

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Table II – Results of the Logit Model.

Variables	Coefficient	Std error	Wald Khi-2	P-value
P_A	0.233***	0.022	107.655	0.000
P_B	-0.464***	0.022	435.113	0.000
A_A	0.031***	0.008	16.120	0.000
C_{jA}	-0.761***	0.047	263.748	0.000
B_A	-1.962***	0.380	26.640	0.000
B_B	2.008***	0.374	28.795	0.000
C_{jB}	0.328***	0.044	54.473	0.000
N_A	-0.078***	0.008	91.638	0.000
θ	-2.015***	0.070	817.737	0.000
N_B	0.052***	0.008	40.426	0.000
w_{jB}	1.080***	0.057	353.029	0.000
Intercept	3.776***	0.725	27.098	0.000
Likelihood ratio	64.354			
Degrees of freedom	5.000			
p-value	0.000			
Indicators	Intercept	Model		
Akaike criterion	7941.027	3875.295		
BIC criterion	7947.721	3948.929		
Deviation	7939.027	3853.295		
Cox & Snell R ²	0.496			
Nagelkerke coef.	0.674			
McFadden Pseudo R ²	0.515			

* Significant at the 10%, ** 5% and *** 1% level

5. CONCLUSION

In this article, we address the issue of a potentially multi-producing firm which has to decide whether it should recycle its waste into a new coproduct sold on a secondary oligopoly market (e.g. coproduction). We demonstrate through an intrinsic joint production technological constraint and a Cournot-Nash setting that the profitability of a full recycling strategy depends first on the main market competitive characteristics, then on the secondary market conditions, along with the technological effectiveness of the recycling process and on the marginal discarding cost. We found that the most influential variables underlying the decision of fully recycling the waste and by-products of the primary market concern the demand and competitive conditions on the primary (main product) market, thus affecting the price of the main product (biofuel). As long as the price of the main product fetches high values, the incentive for recycling the waste and by-products for the secondary market remains weak. Should this price increase twofold that the likelihood of recycling would decline by 28%. The competitive conditions met in the secondary market also matter to a significant though lesser extent. Interestingly, profits on the secondary market may fall sharply if the recycling technology improves too fast and if the market is flexible in quantity, because single-product competitors may respond by increasing their own output and the price of coproducts may collapse due to a supply in excess on the secondary market. However, we show, for a given desirable value of α (=100%, i.e. zero waste), that overall profits of the multi-market firm may well increase with a more effective recycling technology as long as the discarding cost and the marginal cost of producing biofuel exceed a certain threshold.

This result gives room for public policies aiming at promoting green technologies which improve the recycling productivity. Such policies would only be effective if marginal discarding costs are increased by levying a tax on waste discards. Our results show that a tax policy on waste alone would not be successful because the recycling rate proved to be poorly sensitive to the cost levels on the main and secondary markets. Non-linearities between the recycling rate and the processing technology explain this need for a dual policy affecting both the recycling technology and waste management costs. On a theoretical ground, an optimal couple (θ, α) maximizing the multi-market profit has been found.

As an extension of the present research, we want to analyze the impact of a large number of multi-market firms adopting a recycling strategy on the market outcome, and the impact of public policy subsidizing the green technology or imposing a tax on waste discards so as to recycle more heavily the waste as a new input to be used for other markets.

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APPENDIX

Table III: Descriptive statistics on the continuous variables of the logistic regression model

Variable	Type	Mean	Standard-deviation	Minimum	Maximum
<i>priceA</i>	1	7.905	4.782	2.117	20.311
	2	4.966	3.214	2.107	16.415
	Total	6.781	4.485	2.107	20.311
<i>priceB</i>	1	4.894	3.104	2.007	16.746
	2	9.430	4.338	2.244	17.096
	Total	6.629	4.243	2.007	17.096
A_A	1	50.224	5.752	40.012	59.995
	2	49.560	5.747	40.008	59.994
	Total	49.970	5.759	40.008	59.995
A_B	1	49.634	5.764	40.002	59.971
	2	50.311	5.803	40.015	59.998
	Total	49.893	5.789	40.002	59.998
c_{jA}	1	2.132	0.993	0.502	4.000
	2	2.408	0.992	0.501	4.000
	Total	2.237	1.002	0.501	4.000
B_A	1	0.998	0.116	0.800	1.200
	2	1.009	0.115	0.800	1.200
	Total	1.002	0.115	0.800	1.200
B_B	1	1.003	0.117	0.800	1.200
	2	0.995	0.116	0.800	1.200
	Total	1.000	0.117	0.800	1.200
c_{jB}	1	2.302	0.990	0.501	3.999
	2	2.215	1.011	0.507	3.999
	Total	2.268	0.999	0.501	3.999
N_A	1	10.964	9.607	2.000	30.000
	2	17.262	10.242	2.000	30.000
	Total	13.372	10.319	2.000	30.000
<i>Theta</i>	1	1.305	0.826	0.100	2.999
	2	1.879	0.717	0.103	3.000
	Total	1.525	0.834	0.100	3.000
N_B	1	16.976	9.899	2.000	30.000
	2	7.495	8.033	2.000	30.000
	Total	13.350	10.316	2.000	30.000
w_{jB}	1	1.663	0.828	0.100	2.998
	2	1.392	0.832	0.101	2.999
	Total	1.559	0.840	0.100	2.999