Vertical Control in the Circular Economy

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Abstract

We argue that the possibility to recycle a product may induce a loss of vertical control in a production channel where one upstream monopolist sells an input to two downstream firms, which transform it into two differentiated products. We set up and solve a two-period game. In each period the upstream firm makes secret take-it-or-leave-it offers to the downstream firms. One downstream firm can recycle a part of its output and sell it in the second period. If the recycled product is homogeneous to the product of the *other* firm then recycling creates a cross-product inter-temporal externality that cannot be fully internalized. This entails that the whole surplus of the supply channel is reduced by recycling. The ultimate consequence is that the upstream firm, selling the input, has no incentive to make it recyclable at all.

Keywords: Vertical relationships; Circular economy; Recycling.

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1 Introduction

The Circular Economy (CE, henceforth) has risen as a new production and consumption paradigm, in which the once linear life-cycle of a product turns into a closed loop by virtue of actions such as reusing, repairing and recycling the product itself (see, e.g. Reike et al., 2018). The contribution of the CE is crucial to develop a more sustainable society. In fact, on the one hand it reduces the depletion of non-renewable resources, and on the other hand it lowers the emission of pollution and accumulation of waste. As a further benefit, CE practices contribute to mitigate climate change, see e.g. Yang et al. (2023) and the references therein.

Recycling, one of the main practices of the CE, is tightly related to the dynamics of production channels. The possibility to replace a new input with a recycled one, and to collect and (re-)sell a recycled product, profoundly influence the trade of factors within the production chain. On the one hand, the possibility to use a recycled input clearly affects the supply contracts for new production factors between upstream and downstream firms. On the other hand, the presence of a recycled product increases the total quantity of final output, thus influencing the total quantity of goods available for consumption, hence the profit generated in the channel.

The relevance of such issues for antitrust policy, starting from the famous ALCOA (1945) case, has stimulated an economic debate on the effects of recycling within production channels. The early contributions by Swan (1980) and Martin (1982) point out that a monopolist manufacturer restricts its supply of a recyclable product to downstream firms in order counter the cannibalization effect that the recycled products exert on the new ones. More recently, Giardino-Karlinger (2016) shows that in chain of monopolies where the upstream manufacturer can make take-it-or-leave-it (TIOLI) offers and the downstream producer is not credit constrained, the profit-maximizing level of output can be achieved through two-part tariffs.[1] By contrast, downstream competition for the recycled product can result in a reduction of the channel profits, siphoned off by the recycling sector, which in turn, leads the upstream firm either overproduce in the second period or underproduce in the first period. Giardino-Karlinger (2016) develops her analysis of downstream competition under the assumption of public and simultaneous offers by the upstream firm.

In this paper, we depart from this literature by focusing on the role of secret contracts in the supply of recycled products. It is well-known (see e.g. McAfee and Schwartz, 1994) that public contracts are a commitment device that allows the firms to set the trade terms so that the industry profits are maximized. If contracting is instead secret, this outcome no longer holds. Indeed, under the common assumption of passive beliefs, the monopolist and each downstream firm have an incentive to behave opportunistically, and to re-negotiate the

[1] Furthermore, even if the presence of a recycled product creates an outside option for the downstream firm, the upstream one is able to extract, intertemporally, all the industry surplus.

two-part tariff supply contract, *given* the contracts that have been offered to the other firms. This results in a loss of control within the production channel: the firms fails to replicate the full integration outcome, with a consequent reduction of the industry profit (see, e.g. Hart and Tirole, 1990; O'Brien and Shaffer, 1992; Rey and Vergé, 2004), even if one party (the upstream monopolist) it is endowed with complete bargaining power. The present paper points out that recycling can lead to a further loss of vertical control depending on the characteristics of the recycling process itself

To make our point, we set-up and solve a vertical relationship model where the interaction among firms unravels around two periods. Two downstream firms, h and l, produce substitutable goods by means of an input sold by an upstream monopolist. In each period, the upstream monopolist makes secret take-it-or-leave-it offers to the downstream firms. A fraction of the quantity of firm h's first period output can be recycled and sold in the second period. As an instance instance, imagine two companies that procure new lithium for producing batteries of different generations or designed for specific applications and that they also use lithium from recycled batteries. We show that if the recycled product shares the same characteristics of the original one, the upstream firm can always control the total quantity of good h (new plus recycled) through an appropriate unit price, so as to neutralize the presence of recycling. By contrast, if the recycled product becomes a perfect substitute of good l, then the upstream firm loses control of the total quantity of good l in period 2, reducing the industry surplus. Recycling adds then a further source of loss of vertical control to the well-known opportunism-related one.

Finally, because of these features, the present paper is also connected to the literature on Closed Loop Supply Chains –CLSC– (ee e.g. Savaskan et al., 2004; Savaskan and Van Wassenhove, 2006; Shulman et al., 2011; Agliardi and Kasioumi, 2023; De Giovanni and Zaccour, 2014). As pointed out by the De Giovanni and Zaccour (2019)'s literature review, two main elements inform these contributions, namely the *return function* and the *coordination mechanism*. The former determines the way the product is returned to a member of the supply chain to be recycled. The latter is the set of contractual clauses that allow to align the individual interests within the supply chain.

The remainder of the paper is organized as follows, Section 2 outlines the model, and Section 3 finds its equilibrium. Finally, Section 4 provides a short conclusion.

2 The Model

2.1 Industry and firms

An upstream firm u sells an input to two downstream firms, h and l, which transform it into two final, substitute, products (denoted, with a slight notational abuse, h and l, respectively) on a one-to-one basis. Both the upstream production and the downstream transformation of the input are costless, so that the only production costs borne by the downstream firms are due to the payments stipulated in the supply contracts.

The inverse demands, in each period, are

$$p_l^t(Q_l^t, Q_h^t) = 1 - Q_l^t - \gamma Q_h^t, \quad p_h^t(Q_h^t, Q_l^t) = 1 - Q_h^t - \gamma Q_l^t; \tag{1}$$

where Q_i^t is the total quantity of good $i = h, l$ available for consumption at period $t = 1, 2$, and $\gamma \in [0, 1]$. If $\gamma = 0$ both products are independent in demand, as γ approaches 1, products increasingly substitute one another, and they are perfect substitutes for $\gamma = 1$.

2.2 Timing

The interaction among firms unravels along two periods, 1 and 2. In both periods firm u makes simultaneous, interim-unobservable take-it-or-leave-it (TIOLI) contract offers to the downstream firms, based on two-part tariffs. As the contracts are contracts are interim-unobservable, downstream firms does not know the terms of their rivals even after the contract has been finalized. Moreover we assume that firms' conjectures on their competitors' contracts are characterized by passive beliefs.[2] Conditional on accepting the contracts, the firms maximize their profits by simultaneously choosing their output levels. At the end of period 1 firm h collects its first-period output and recycles a fraction θ of it into product l, which it sells along with a new batch of product h. Accordingly, in period 2 firm h is a multi-product firm if it accepts firm u's offer; if it does not, it can only sell the recycled product.

3 Equilibrium

We solve the game by backward induction, to find Perfect Bayesian Equilibria.

3.1 Second Period

3.1.1 Quantity setting

In the second period the total quantities of the goods are $Q_l^2 = q_l^2 + \theta q_h^1$ and $Q_h^2 = q_h^2$, where θq_h^1 is the quantity of good h produced in the first period that is recycled into good l in the

[2] Under passive beliefs, when a firm receives an offer different from what it expects, it does not revise its beliefs about the offers made to others firms (McAfee and Schwartz, 1994). Passive beliefs are natural when the downstream competition is Cournot-like as assumed in this work (see Hart and Tirole, 1990 and Rey and Vergé, 2004).

second one. Accordingly, the demands are

$$p_l^2(q_h^1, q_l^2, q_h^2) = 1 - (q_l^2 + \theta q_h^1) - \gamma q_h^2, \quad p_h^2(q_h^1, q_l^2, q_h^2) = 1 - q_h^2 - \gamma(q_l^2 + \theta q_h^1); \tag{2}$$

The upstream firm offers a contract (w_i^2, t_i^2) to firm $i = h, l$. If both downstream firms accept the contractual offer, their profits in the second period of the game are

$$\pi_l^2(q_h^1, q_l^2, q_h^2) = [p_l^2(\cdot) - w_l^2]q_l^2 - t_l^2, \quad \pi_h^2(q_h^1, q_l^2, q_h^2) = [p_h^2(\cdot) - w_h^2]q_h^2 + p_l^2(\cdot)\theta q_h^1 - t_h^2. \tag{3}$$

The profit of firm h includes the term $p_l^2(\cdot)\theta q_h^1$, which comes from the sales of the recycled product in period 2. The underlying assumption is that, given the exogenous recycling rate θ, firm h sells all of the recycled product in period 2.[3]

Standard profit maximization leads to the following period-2 best replies (contracts are interim-unobservable):

$$q_l^2(q_h^2; w_l^2, q_h^1) = \frac{1}{2}(1 - w_l^2 - \gamma q_h^2 - \theta q_h^1), \quad q_h^2(q_l^2; w_h^2, q_h^1) = \frac{1}{2}[1 - w_h^2 - \gamma(q_l^2 + \theta q_h^1)]. \tag{4}$$

Compared to the case of absence of recycling ($\theta = 0$) recycling increases the quantity of good l sold in period 2. The immediate consequence is that firm l is lead to reduce the period-2 output of good l. Because of strategic substitutability, also firm h reduces its second-period output. We now move to the definition of the downstream firms' outside options in the negotiations with the upstream firm; that of firm l is easily dealt with, because if this firm rejects the contractual offer, it cannot be active on the market, thus its outside option is zero. By contrast if firm h rejects the offer, it can still sell the recycled product. In this case its profit is

$$\pi_h^O(q_l^2, q_h^1) = p_l^{O2}(.)\theta q_h^1, \tag{5}$$

where $p_l^{02}(q_h^1, q_l^2) = 1 - (q_l^2 + \theta q_h^1)$. Here we are assuming that the contract proposed by firm u are non-contingent on the acceptance of the contract by firm l (see, e.g. Bacchiega et al., 2018).

With this in mind, we are now in a position to derive the optimal contracts offered by firm u in the second period.

3.1.2 Optimal contract offers

Firm u offers secretly contract (w_i^2, t_i^2) to firm i. Contracts are interim-unobservable: their terms remain undisclosed after the contract has been signed. Because the upstream firm is entitled to propose TIOLI offers, it extracts all the net surplus originating from the transactions.

[3]Clearly, in period 1 firm h anticipates that it will recycle and sell that fraction of its first-period product, and will account for it.

Its profit is

$$\pi_u^2(w_l^2, t_l^2, w_h^2, t_h^2) = w_l^2 q_l^2(\cdot) + t_l^2 + w_h^2 q_h^2(\cdot) + t_h^2. \tag{6}$$

In Appendix A we prove the following

Lemma 1. *In the second period, firm u offers the contract*

$$w_l^2 = 0, \quad t_l^2(q_h^1) = \frac{[2 - \gamma - 2q_h^1(1-\gamma^2)]^2}{(4-\gamma^2)^2} \tag{7}$$

to firm l, and the contract

$$w_h^2 = 0, \quad t_h^2(q_h^1) = \frac{(2-\gamma-3\gamma\theta q_h^1)^2}{(4-\gamma^2)^2} \tag{8}$$

to firm h.

Because contracts are interim unobservable the unit input price is set to marginal cost (zero), as expected. The fixed fees are negatively affected by on the quantity of recycled good. This is intuitive: a larger quantity of recycled good directly reduces the demand of good l in period 2, thus lowering the l-firm's profits and eventually the surplus the fixed fee extracts. The presence of the recycled quantity also impacts the profit of firm h. On the one hand, this firm now sells two products, which increases its profit. On the other hand, the presence of a larger quantity of good l lowers the price of good h, which reduces the stream of profits from the latter good. As for firm l a rate of recycling increases the quantity of good l that is sold on the market by firm h, which directly reduces its profits.

At the contractual terms of Lemma 1, the quantities produced by firms h and l are, respectively

$$q_l^2(q_h^1) = \frac{2-\gamma-2\left(1-\gamma^2\right)\theta q_h^1}{4-\gamma^2}, \quad q_h^2(q_h^1) = \frac{2-\gamma-3\gamma\theta q_h^1}{4-\gamma^2}. \tag{9}$$

Both second-period quantities decrease with the recycled quantity, q_l^2 because of the direct substitution effect, and q_h^2 because of the resulting increases in competitive pressure. The associated profits

$$\pi_l^2(q_h^1) = 0, \quad \pi_h^2(q_h^1) = \frac{\theta q_h^1\{2+\gamma[1-\gamma(1+\theta q_h^1)] - 2\theta q_h^1\}}{4-2\gamma^2}. \tag{10}$$

Because of TIOLI offers, the upstream firm appropriates all the profit exceeding the outside options of the downstream ones, which are zero for firm l and the value of the sales of the recycled product for firm h. Finally, the profit reaped by the upstream firm is

$$\pi_u^2(q_h^1) = \frac{\left[2-\gamma-2\left(1-\gamma^2\right)\theta q_h^1\right]^2 + (2-\gamma-3\gamma\theta q_h^1)^2}{\left(4-\gamma^2\right)^2}. \tag{11}$$

3.2 First Period

Obviously, in period 1 $Q_i^1 = q_i^1$, so that he product demands are

$$p_l^1(q_h^1, q_l^1) = 1 - q_l^2 - \gamma q_h^2, \quad p_h^1(q_h^1, q_l^1) = 1 - q_h^2 - \gamma q_l^2; \tag{12}$$

and the corresponding downstream firms period-1 profits:

$$\pi_l^1(q_l^1, q_h^1) = [p_l^1(\cdot) - w_l^1]q_l^1 - t_l^1, \quad \pi_h^1(q_l^1, q_h^1) = [p_h^1(\cdot) - w_h^1]q_h^1 - t_h^1. \tag{13}$$

Firms take the first-period production decisions anticipating the effect they will have on their present and future profits. As for the downstream firms, they are:

$$\pi_l^I(q_l^1, q_h^1) = \pi_l^1(q_l^1, q_h^1) + \pi_l^2(q_h^1), \quad \pi_h^I(q_l^1, q_h^1) = \pi_h^1(q_l^1, q_h^1) + \pi_h^2(q_h^1), \tag{14}$$

where $\pi_l^I(q_l^1, q_h^1) = \pi_l^1(q_l^1, q_h^1)$ because the second-period profits of firm 2 are completely extracted by the upstream firm. The usual maximization techniques yield the following first-period beat replies:

$$q_l^1(q_h^1; w_l^1) = \frac{1}{2}(1 - \gamma q_h^1 - w_l^1), \quad q_h^1(q_l^1, w_h^1) = \frac{(2-\gamma)[(2+\gamma)(1-\gamma q_l^1 - w_h^1) + (1+\gamma)\theta]}{2\,(2+\gamma^2)\,\theta^2 - 2\gamma^2 + 8} \tag{15}$$

Firm-l's best reply reflects the fact that its intertemporal profit in period 1 coincides with period 1 profit, because of the absence of outside options in the period-2 negotiation. Accordingly, its best reply only accounts for the effect of q_l^1 on $\pi_l^1(\cdot)$. By contrast, firm h anticipates that a fraction of the quantity it markets in period-1 will be recycled and sold in period 2, which provides this firm with an outside option in the second-period negotiation with firm-u. With this in mind, we proceed to solve the first period contracting stage.

3.2.1 Optimal contractual offers

In period 1 neither firm h, nor firm l have outside options in the negotiation. In appendix B we prove

Lemma 2. *In the first period, firm u offers the ensuing contract*

$$w_l^1 = 0, \quad t_l^1 = \frac{1}{4}\left\{1 - \frac{(2-\gamma)^2\gamma\left[2(1-\gamma)\gamma\theta - (2-\gamma)(2+\gamma)^2\right]}{(4-\gamma^2)^3 - 4\,(4+\gamma^2-5\gamma^4)\,\theta^2}\right\}^2 \tag{16}$$

to firm l, and the contract

$$
\begin{aligned}
w_h^1 &= \frac{2\theta\left\{\left(16-4\gamma^6+15\gamma^4\right)\theta-2(1-\gamma)\{\gamma\{\gamma[4\gamma(\gamma+3)+7]+12\}+4\}\theta^2-(2-\gamma)^2(1+2\gamma)(2-\gamma)^3\right\}}{4(1-\gamma)(1+\gamma)\left(4+5\gamma^2\right)(2+\gamma)\theta^2+(2-\gamma)^3(2+\gamma)^4}, \\
t_h^1 &= \frac{(2-\gamma)^3\left[(2-\gamma)(2+\gamma)^2-2(1-\gamma)\gamma\theta\right]^2\left[\left(\gamma^2+2\right)\theta^2-\gamma^2+4\right]}{(\gamma+2)\left[\left(4-\gamma^2\right)^3-4\left(4+\gamma^2-5\gamma^4\right)\theta^2\right]^2}
\end{aligned}
\tag{17}
$$

to firm h.

The apparent difference with period 2 contracts is that in period 1 the per unit price charged on firm h is positive, the unobservability of contracts notwithstanding. The intuition is that firm u anticipates that the supply of recycled products in the second period will encourage firm h's to increase its supply in the first period. To reduce this incentive, firm u sets a positive w_h^1, i.e. higher than the marginal cost.[4]

With the contracts reported in Lemma 2, the optimal first-period quantities are:

$$
\begin{aligned}
q_l^1 &= \frac{2\left(4+\gamma^2-5\gamma^4\right)\theta^2+(2+\gamma)^2(2-\gamma)^3-(1-\gamma)\gamma^2(2-\gamma)^2\theta}{\left(4-\gamma^2\right)^3-4\left(4+\gamma^2-5\gamma^4\right)\theta^2}, \\
q_h^1 &= \frac{(2-\gamma)^2\left[2(1-\gamma)\gamma\theta-(2-\gamma)(2+\gamma)^2\right]}{\left(4-\gamma^2\right)^3-4\left(4+\gamma^2-5\gamma^4\right)\theta^2}.
\end{aligned}
\tag{18}
$$

Tedious algebra returns the second period quantities:

$$
\begin{aligned}
q_l^2 &= \frac{4\left(2-\gamma^2-\gamma^4\right)\theta^2+(2+\gamma)^2(2-\gamma)^3-2(1-\gamma)(1+\gamma)(2+\gamma)(2-\gamma)^2\theta}{\left(4-\gamma^2\right)^3-4\left(4+\gamma^2-5\gamma^4\right)\theta^2} \\
q_h^2 &= \frac{(4-\gamma^2)(2-\gamma)-(4-\gamma)\{3\gamma(2-\gamma)^2\theta\left[(2-\gamma)(2+\gamma)^2+2(1-\gamma)\gamma\theta\right]\}}{(4-\gamma^2)\left[\left(4-\gamma^2\right)^3-4\left(4+\gamma^2-5\gamma^4\right)\theta^2\right]}
\end{aligned}
\tag{19}
$$

A similar procedure yields the firms' equilibrium profits. As for firm l, the combination of TIOLI offers and absence of an outside option implies that in both periods (hence intertemporally) its equilibrium profits are nil:

$$\pi_l^{1*} = \pi_l^{2*} = 0. \tag{20}$$

The intertemporal profits of firm h are zero as well, even in the presence of an outside option in period 2 coming from the recycled product. Indeed, because firm u is endowed with full bargaining power, it sets the contractual terms in period 1 so that the outside option of period 2 is completely extracted in period 1. Therefore the inter-temporal profit of fitm h is

[4] $w_h^1 > 0$ for all $\theta \in]0,1[$ and $\gamma \in [0,1[$, $w_h^1 > 0$ for all $\theta = 1$ and $\gamma \in [0,1[$, and as expected $w_h^1 = 0$ for $\theta = 0$.

nil, because

$$\begin{aligned}\pi_h^{1^*} &= \\ &= \frac{(2-\gamma)^2\theta\left\{4(1-\gamma)^2\gamma\{\gamma[\gamma(4+9\gamma)+8]+4\}\theta^3-\Delta\theta^2+(2-\gamma)^3(2+\gamma)^2\{4+\gamma[4+(2-\gamma)\gamma]\}\theta-[(1+\gamma)\left(\gamma^2-4\right)^4]\right\}}{\left[(4-\gamma^2)^3+4(4+\gamma^2-5)\theta^2\right]^2} = \\ &= -\pi_h^{2^*},\end{aligned} \tag{21}$$

where $\Delta \equiv 4(2-\gamma)(1-\gamma)(2+\gamma)\{\gamma\{\gamma[4\gamma(3+\gamma)+7]+12\}+4\}$. Finally, the inter-temporal profits of the upstream firm are

$$\pi_u^{I^*} = \frac{8(1-\gamma)^2(1+\gamma)\left(4+5\gamma^2\right)\{\gamma[\gamma(7+2\gamma)+2]+6\}\theta^4-8(1-\gamma)^3\gamma(1+\gamma)(4+5\gamma^2)(2-\gamma)^2\theta^3+\Psi-2(1-\gamma)\gamma(2+\gamma)^2(2-\gamma)^6\theta+4(2+\gamma)^4(2-\gamma)^6}{\left[(4-\gamma^2)^3+4(4+\gamma^2-5)\theta^2\right]^2} \tag{22}$$

where $\Psi \equiv 2\{112+\gamma\{72+\gamma\{36+\gamma\{-130+\gamma\{\gamma[-95+\gamma(2\gamma-3)]\}\}\}\}\}(2-\gamma)^3\theta^2$.

3.3 Recycling and loss of vertical control

We are now in a position to analyze the effects or recycling on the industry's surplus. The following lemma characterizes the effect of recycling on industry profits, and shows that recycling reduces the industry's surplus whenever the products h and l are differentiated. The above observations allow us to state

Lemma 3. *The inter-temporal industry's surplus is given by the inter-temporal profit of the upstream firm, $\pi_u^{I^*}$, with $\frac{\partial \pi_u^{I^*}}{\partial \theta} < 0$ $\forall \theta \in]0,1]$ and $\forall \gamma \in [0,1[$, and $\frac{\partial \pi_u^{I^*}}{\partial \theta} = 0$ $\forall \theta \in]0,1]$ and $\gamma = 1$.*

Before detailing the effects of recycling on the vertical relationship, it is worth stressing that the averse effect of recycling on the industry's surplus cannot be imputed to costs to operate the recycling technology or to payments to a "recycling sector" outside the industry under scrutiny.

In our setup, recycling has a twofold implication on the vertical relationship:

(i) As already pointed out by Giardino-Karlinger (2016), recycling allows firm h to build a positive outside option in the second period. The larger the recycling rate, θ, the larger that outside option. We label this effect the *outside-option* effect.

(ii) Recycling generates a cross-externality on the downstream market in the second period. The recycled good (θq_h^1) adds to the output of firm l to define the total quantity of good l produced. We call this the *cross-externality* effect.

Before proceeding, it is worth analyzing, as benchmark the case where there is no cross externality, which is obtained under the alternative assumption that the recycled product is homogeneous to good h instead of good l. In this case the total quantity of good h in the second period is $Q_h^2 = \theta q_h^1 + q_h^2$. It is apparent that, in this case, by setting w_h^2, *given* q_h^1, the upstream firm controls the total quantity of good h available in period 2.[5] Indeed, irrespective of the value of θ, in period 2 we have $Q_h^2 = \frac{\alpha}{2+\gamma}$, which is the optimal quantity in the absence of recycling. The essential difference in this case is that recycling into the same product only generates the outside-option effect, which can however be internalized. Recycling does not lead to a loss of vertical control. The ensuing Lemma summarizes.

Lemma 4. *If in period 2 good h is recycled into itself, recycling has no effect on the industry profits.*

We can analyze the outside-option effect separately from the cross-externality one, by setting $\gamma = 1$. In this case products h and l are homogeneous, which implies that the cross-externality effect vanishes *de facto*. By Lemma 3, the outside-option effect has no impact on industry's surplus either. As pointed by Giardino-Karlinger (2016) in a bilateral monopoly, the upstream firm anticipates that firm h wants to purchase more input in the first period in order to increase its outside option in period 2. As a consequence, firm u increases the input price in period 1 causing a reduction in firm h output so as to counter the incentive of firm h to expand its period-1 output. Furthermore, provided that firm h is not credit-constrained in the first period, the upstream firm sets the terms of trade so as to extract, in period 1, the the value of firm h's period-2 outside option. All in all, recycling in the presence of more than one downstream producer does not affect the ability of the upstream firm to control the vertical channel, with the well-known limitations due to secret contracting, as long as the cross-externality effect is absent.

We are now in a position to analyze the loss of control due to recycling in the presence of the cross-externality effect. Like the outside-option effect, the cross-externality effect also encourages firm h's to expand its output in the first period. Unlike the outside-option effect, though, the cross-externality one cannot be fully internalized by firm u due to the passive beliefs and the contract non-observability. Firm u sets the contractual terms so as to maximize the aggregate industry profit, by regulating the downstream competitive pressure through the unit input prices w_i^t, which, in turn, determine the downstream firms' output levels q_i^t. In period 1 the upstream firm offers contracts to the downstream firms so that w_h^1 determines q_h^1 and w_l^1 determines q_l^1, but in the second period w_h^2 still determines q_h^2 and w_l^2 determines q_l^2, yet, the recycled quantity q_h^1 is now homogeneous to product l, and is not determined by w_l^2. Stated differently, firm u cannot completely control the quantity of good l in period

[5] Needless to say, w_l^2 determines q_l^2.

2. The upstream monopolist anticipates this issue and thus increases w_h^1 in order to reduce the quantity of good h in the first period (and thus that of the recycled good in the second period). Because of strategic substitutability, this increases the production of good l in the first period, relative to the no-recycling case. In the second period the recycled product is homogeneous to good l, thus firm l reduces its second-period output to counter the price drop due to the presence of the recycled product. This notwithstanding, the total quantity of good l on the market in period 2, namely $q_l^{2^*} + \theta q_h^{1^*}$ is larger than the quantity of that good that would be sold without recycling. As a consequence, firm h also reduces the quantity of good h to sustain its price, because of the presence of a larger quantity of good l. Overall, the presence of the recycled good increases the total quantity of goods available in period 2, thus lowering the industry profits. The ultimate consequence is that the upstream firm, which captures the whole industry profits prefers the recycling rate to be as low as possible.

The following Proposition summarizes our main results.

Proposition 1. *If, in period 2 good h is (partially) recycled into good l, recycling has an averse effect on the industry profits. As a consequence, the upstream firm prefers the lowest possible recycling rate.*

Our result points to a new force that acts against recycling at the individual firm level, which adds to the ones already described in the literature. The intriguing characteristic of the cross-externality effect is that it does not originate from the technical characteristics of the recycling technology, nor to a change in the relative bargaining positions of the firms due to the presence of recycled material. The cross-externality generated by recycling a good into a substitute one results in a loss of vertical control along the production channel which entails a reduction of the profit generated by the channel itself.

4 Conclusion

In this paper we have explored the effects of recycling in a supply chain where an upstream monopolist sells an input to two differentiated downstream firms. We consider a dynamic, two-period model, at each period the upstream firm makes two-part tariff, TIOLI secret offers to the downstream ones. In the second period Downstream firm h recycles and re-sells a fraction of its first-period output into a product that is homogeneous to product l. Recycling has a twofold effect on the production channel. On the one hand the presence of the recycled good guarantees an outside option to firm h, which will improve its bargaining position relative to the upstream firm in the second period. Yet, the upstream firm anticipates this and, in the first period, it increases the value of the fixed fee to firm h so as to neutralize the effect of the second-period outside option. Second, the fact that the recycled good h is now homogeneous to good l generates a loss of control in the production channel. The upstream firm cannot fully control the degree of competition in the downstream market. This leads to a reduction of the producer surplus, which is larger the larger the recycling rate. As a consequence, the upstream firm has no incentive in making it input recyclable at all.

Our result is robust to various specifications of the model. In particular, if we allow both downstream firms to recycle, the upstream firm retains the control of downstream competition as long as every product is recycled into itself. By contrast, if recycling is such that, after recycling, product h becomes homogeneous to product l, and viceversa, firm U is not able to set the contractual terms so fully internalize the presence of recycling. The same outcome obtains if the products are vertically differentiated *à la* Mussa and Rosen (1978). Finally, assuming secret negotiations, but interim observable contracts only affects the results quantitatively, but not qualitatively.

A Proof of Lemma 1

Consider now u choice of input prices and fixed fees at the first stage of period 2. To derive u's objective function, note first that, each downstream firm i does never observe the offer (w_j^2, t_j^2), made to its rival, such as t_i^2 cannot depend on (w_j^2, t_j^2),$\forall i, j \in h, l$ and $j \neq i$. Moreover, as each downstream firm i anticipates that its rival receives the equilibrium offer (passive beliefs) and thus puts the equilibrium quantity $q_j^{2^e}$ on the market, then in response to a contract (w_i^2, t_i^2), the firm i sets the quantity $q_i^2(q_j^{2^e}, w_i^2, q_h^1)$ given by the equation 4, with q_h^1 the quantity produced at the first period. Therefore the upstream firm's objective function is of the form:[6]

$$\pi_u^2(w_l^2, t_l^2, w_h^2, t_h^2) = w_l^2 q_l^2(q_h^{2^e}, w_l^2, q_h^1) + t_l^2 + w_h^2 q_h^2(q_l^{2^e}, w_h^2, q_h^1) + t_h^2. \tag{23}$$

Each downstream firm accepts the contract if and only if the terms provide it a net surplus equal to its outside option, i.e. 0 for the firm l, and $\pi_h^O(q_l^{2^e}, q_h^1)$, given by equation 5, for the firm h. The fixed tariffs (t_l^2) and (t_h^2) set by the upstream firm are therefore:

$$\begin{aligned}
t_l^2 =& \left(p_l^2\left(q_h^1, q_l^2(q_h^{2^e}, w_l^2, q_h^1), q_h^{2^e}\right) - w_l^2\right) q_l^2(q_h^{2^e}, w_l^2, q_h^1)\\
=& \frac{(1 - w_l^2 - \gamma q_h^{2^e} - \theta q_h^1)^2}{4},\\
t_h^2 =& \left(p_h^2\left(q_h^1, q_l^{2e}, q_h^2(q_l^{2^e}, w_h^2, q_h^1)\right) - w_h^2\right) q_h^2(q_l^{2^e}, w_h^2, q_h^1)\\
&+ p_l^2\left(q_h^1, q_l^{2e}, q_h^2(q_l^{2e}, w_h^2, q_h^1)\right)\theta q_h^1 - \pi_h^O(q_l^{2e}, q_h^1)\\
=& \frac{(1 - w_h^2 - \gamma q_l^{2^e} - 2\gamma\theta q_h^1)^2}{4}
\end{aligned} \tag{24}$$

According to equations 23 and 24 the input prices (w_l^2) and (w_h^2) are set so as to maximize:

$$\begin{aligned}
\max_{w_l^2, w_h^2} \quad & p_l^2\left(q_h^1, q_l^2(q_h^{2^e}, w_l^2, q_h^1), q_h^{2^e}\right) q_l^2(q_h^{2^e}, w_l^2, q_h^1)\\
&+ p_h^2\left(q_h^1, q_l^{2e}, q_h^2(q_l^{2^e}, w_h^2, q_h^1)\right) q_h^2(q_l^{2^e}, w_h^2, q_h^1) + p_l^2\left(q_h^1, q_l^{2e}, q_h^2(q_l^{2^e}, w_h^2, q_h^1)\right)\theta q_h^1\\
&- \pi_h^O(q_l^{2e}, q_h^1)
\end{aligned} \tag{25}$$

which we can write as:

$$\max_{w_l^2, w_h^2} \quad \frac{(1 + w_l^2 - \gamma q_h^{2^e} - \theta q_h^1)(1 - w_l^2 - \gamma q_h^{2^e} - \theta q_h^1) + (1 - \gamma q_l^{2^e} - 2\gamma\theta q_h^1)^2 - {w_h^2}^2}{4} \tag{26}$$

Note that w_l^2 affects the upstream firm's objective function only through $p_l^2\left(q_h^1, q_l^2(.), q_h^{2^e}\right) q_l^2(.)$

[6] See e.g. Rey and Vergé, 2004.

which is maximized for $q_l^2(.)$ (see subsection 3.1.1). In the same way w_h^2 affects the upstream firm's objective function only through $p_h^2\left(q_h^1, q_l^{2^e}, q_h^2(.)\right)q_h^2(.) + p_l^2\left(q_h^1, q_l^{2^e}, q_h^2(.)\right)\theta q_h^1$ which is maximized for $q_h^2(.)$. Therefore, at equilibrium the upstream firm sets the input prices equal to marginal cost and the corresponding fixed tariffs:

$$\begin{aligned} w_l^2 = 0, \quad t_l^2(q_h^1) &= \frac{(1-\gamma q_h^{2^e} - \theta q_h^1)^2}{4} \\ w_h^2 = 0, \quad t_h^2(q_h^1) &= \frac{(1-\gamma q_l^{2^e} - 2\gamma\theta q_h^1)^2}{4} \end{aligned} \tag{27}$$

From the best responses functions, given by equation 4, we obtain the equilibrium quantities:

$$q_l^{2^e} = \frac{2-\gamma-2\left(1-\gamma^2\right)\theta q_h^1}{4-\gamma^2}, \quad q_h^{2^e} = \frac{2-\gamma-3\gamma\theta q_h^1}{4-\gamma^2}. \tag{28}$$

such as the equilibrium fixed fee are given by:

$$t_l^2(q_h^1) = \frac{[2-\gamma-2q_h^1(1-\gamma^2)]^2}{(4-\gamma^2)^2}, \quad t_h^2(q_h^1) = \frac{(2-\gamma-3\gamma\theta q_h^1)^2}{(4-\gamma^2)^2} \tag{29}$$

Finally, it is easy to check that multilateral deviations are not profitable. As shown in Rey and Vergé (2004), this is due to Cournot competition and passive beliefs with interim unobservable contracts.

B Proof of Lemma 2

Consider now u choice of input prices and fixed fees at the first stage of period 1. As in period 2, t_i^1 cannot depend on (w_j^1, t_j^1),$\forall i, j \in h, l$ and $j \neq i$, and in response to a contract (w_i^1, t_i^1), each firm i sets the quantity $q_i^1(q_j^{1^e}, w_i^1)$ given by the equation 15, with $q_j^{1^e}$ the equilibrium quantity putted on the market by its rival. Therefore the upstream firm's objective function is of the form:

$$\pi_u^1(w_l^1, t_l^1, w_h^1, t_h^1) = \pi_u^2(q_h^1(q_l^{1^e}, w_h^1)) + w_l^1 q_l^1(q_h^{1^e}; w_l^1) + t_l^1 + w_h^1 q_h^1(q_l^{1^e}, w_h^1) + t_h^1. \tag{30}$$

with $\pi_u^2(.)$ given by equation 11.

Each downstream firm accepts the contract if and only if the terms provide it a net surplus equal to its outside option. This one is given by its profit of second period if it refuses the first period contract i.e. 0 due to the TIOLI strcture of contract. The fixed tariffs (t_l^1) and

(t_h^1) set by the upstream fim are therefore:

$$\begin{aligned}
t_l^1 =& \pi_l^2({q_h^1}^e) + \left(p_l^1\left({q_h^1}^e, q_l^1({q_h^1}^e, w_l^1)\right) - w_l^1\right) q_l^1({q_h^1}^e, w_l^1), \\
=& \frac{(1 - w_l^1 - \gamma {q_h^1}^e)^2}{4}, \\
t_h^2 =& \pi_h^2\left(q_h^1({q_l^1}^e, w_h^1)\right) + \left(p_h^1\left(q_h^1({q_l^1}^e, w_h^1), q_l^1\right) - w_h^1\right) q_h^1({q_l^1}^e, w_h^1) \\
=& - \frac{(\gamma - 2)\left((\gamma + 2)(\gamma {q_l^1}^e + w_h^1 - 1) - (\gamma + 1)\theta\right)^2}{4(\gamma + 2)\left((\gamma^2 + 2)\theta^2 - \gamma^2 + 4\right)}
\end{aligned} \tag{31}$$

with $\pi_l^2(.)$ and $\pi_h^2(.)$ given by the equation 10

According to equations 30 and 31 the input prices (w_l^1) and (w_h^1) are set so as to maximize:

$$\begin{aligned}
\max_{w_l^1, w_h^1} \quad & \pi_u^2(q_h^1({q_l^1}^e, w_h^1)) + \pi_l^2({q_h^1}^e) + p_l^1\left({q_h^1}^e, q_l^1({q_h^1}^e, w_l^1)\right) q_l^1({q_h^1}^e, w_l^1) + \\
& \pi_h^2\left(q_h^1({q_l^1}^e, w_h^1)\right) + p_h^1\left(q_h^1({q_l^1}^e, w_h^1), q_l^1\right) q_h^1({q_l^1}^e, w_h^1)
\end{aligned} \tag{32}$$

Note that w_l^1 affects the upstream firm's objective function only through $p_l^1\left({q_h^1}^e, q_l^1(.)\right) q_l^1(.)$ which is maximized for $q_l^1(.)$ (see subsection 3.2). Therefore at equilibrium the upstream firm sets w_l^1 equal to marginal cost. Conversely w_h^1 affects the upstream firm's objective function not only through $\pi_h^2\left(q_h^1({q_l^1}^e, w_h^1)\right) + p_h^1\left(q_h^1({q_l^1}^e, w_h^1), q_l^1\right) q_h^1({q_l^1}^e, w_h^1)$, which is maximized for $q_h^1(.)$, but also $\pi_u^2(q_h^1({q_l^1}^e, w_h^1))$ which is not maximized for $q_h^1(.)$. Therefore, at equilibrium the upstream firm sets w_l^1 above marginal cost in order to reduce the quantity q_h^1 and thus maximize its objective function. The input prices the corresponding fixed tariffs are given by:

$$\begin{aligned}
w_l^1 =& 0, \quad t_l^1 = \frac{(1 - \gamma {q_h^1}^e)^2}{4} \\
w_h^1 =& \frac{\theta\left((\gamma - 1)(\gamma(\gamma(4\gamma(\gamma + 3) + 7) + 12) + 4)\theta^2 - 2(\gamma + 2)(2\gamma + 1)(\gamma - 2)^2\right)}{(\gamma + 2)\left((5\gamma^4 - \gamma^2 - 4)\theta^2 - (\gamma^2 - 4)^2\right)} + \\
& \frac{\theta\left(-(\gamma + 2)\left(4\gamma^4 + \gamma^2 + 4\right)\theta(\gamma {q_l^1}^e - 1)\right)}{(\gamma + 2)\left((5\gamma^4 - \gamma^2 - 4)\theta^2 - (\gamma^2 - 4)^2\right)} \\
t_h^1 =& - \frac{(\gamma - 2)^3\left((\gamma^2 + 2)\theta^2 - \gamma^2 + 4\right)\left((\gamma + 2)^2(\gamma {q_l^1}^e - 1) - (\gamma - 1)\gamma\theta\right)^2}{4(\gamma + 2)\left((\gamma^2 - 4)^2 + (-5\gamma^4 + \gamma^2 + 4)\theta^2\right)^2}
\end{aligned} \tag{33}$$

From the best responses functions, given by equation 15, we obtain the following equilibrium quantities:

$$q_l^{1\,e} = \frac{2\left(4+\gamma^2-5\gamma^4\right)\theta^2+(2+\gamma)^2(2-\gamma)^3-(1-\gamma)\gamma^2(2-\gamma)^2\theta}{\left(4-\gamma^2\right)^3-4\left(4+\gamma^2-5\gamma^4\right)\theta^2},$$
$$q_h^{1\,e} = \frac{(2-\gamma)^2\left[2(1-\gamma)\gamma\theta-(2-\gamma)(2+\gamma)^2\right]}{\left(4-\gamma^2\right)^3-4\left(4+\gamma^2-5\gamma^4\right)\theta^2}. \tag{34}$$

This gives us the equilibrium contracts:

$$w_l^1 = 0, \quad t_l^1 = \frac{1}{4}\left\{1-\frac{(2-\gamma)^2\gamma\left[2(1-\gamma)\gamma\theta-(2-\gamma)(2+\gamma)^2\right]}{\left(4-\gamma^2\right)^3-4\left(4+\gamma^2-5\gamma^4\right)\theta^2}\right\}^2,$$
$$w_h^1 = \frac{2\theta\left\{\left(16-4\gamma^6+15\gamma^4\right)\theta-2(1-\gamma)\{\gamma\{\gamma[4\gamma(\gamma+3)+7]+12\}+4\}\theta^2-(2-\gamma)^2(1+2\gamma)(2-\gamma)^3\right\}}{4(1-\gamma)(1+\gamma)\left(4+5\gamma^2\right)(2+\gamma)\theta^2+(2-\gamma)^3(2+\gamma)^4},$$
$$t_h^1 = \frac{(2-\gamma)^3\left[(2-\gamma)(2+\gamma)^2-2(1-\gamma)\gamma\theta\right]^2\left[\left(\gamma^2+2\right)\theta^2-\gamma^2+4\right]}{(\gamma+2)\left[\left(4-\gamma^2\right)^3-4\left(4+\gamma^2-5\gamma^4\right)\theta^2\right]^2}. \tag{35}$$

Finally, as for the equilibrium contracts of period 2 (see Appendix A) it is easy to check that multilateral deviations are not profitable.

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