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Corporate Social Responsibility and Firms Ability to Collude*

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Abstract

We examine a duopoly with polluting production where firms adopt a form of corporate social responsibility (CSR) to define their objective functions. Our analysis focusses on the bearings of CSR on collusion over an infinite horizon, sustained by either grim trigger strategies or optimal punishments. Our results suggest that assigning a weight to consumer surplus has a pro-competitive effect under both full and partial collusion. Conversely, a higher impact of productivity on pollution has an anti-competitive effect under partial collusion, while exerting no effect under full collusion. Under partial collusion, the analysis of the isoquant map of the cartel reveals that complementarity arises between the two weights.

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1 Introduction

A growing interest for Corporate Social Responsibility (CSR) is recently characterising the economic literature.[1] One strand identifies CSR with creation of public goods or curtailment of public bads (Bagnoli and Watts, 2003, Kotchen, 2006, Besley and Ghatak, 2010), generally showing that there is a close parallel between CSR so defined and the results obtained by the models of private provision of public goods. Other contributes study the desirability of CSR (Baron, 2001), the role of CSR in selecting motivated agents (Brekke and Nyborg, 2005) or the firm competition in the presence of "green" consumers (Arora and Gangopdhyay, 1995 and Garcia-Gallego and Georgantzís, 2009) or social pressure (Baron, 2009). Finally, Lundgren (2007), Lambertini and Tampieri (2010) and Manasakis *et al.* (2011) study the presence of a CSR firm in an oligopoly, and Lambertini and Tampieri (2011) examine the market stability in mixed oligopoly with CSR firms.

The presence of CSR is viewed by its supporters as a self-regulating tool, as it leads firms to internalise the environmental effects caused by production. The question we address in this paper is whether the adoption of CSR has an impact on firms ability to collude. *A priori*, CSR may have ambiguous welfare implications, since an output restriction driven by a CSR mandate shrinks the external effects but obviously intensifies collusion, the balance between the negative price effect and the positive environmental effect being unclear.

We model a duopoly supergame where production pollutes the environment, firms follow rules of Corporate Social Responsibility and compete *à la* Cournot. We define as CSR a firm that takes into account not only its profits but also internalises its own share of the externality and is sensitive to consumers' welfare. We examine both full and partial collusion using alter-

[1] For an overview, see Benabou and Tirole, 2010. For a series of articles on non-market strategy in the form of Corportate Social Responsibility, see the volume 16, issue 3 of the Journal of Economics & Management Strategy, 2007. For some empirical contribution, Chatterji *et al.* (2009) analyse the effectiveness of social ratings as a measure of CSR, while Fernández-Kranz and Santaló (2010) test whether Corporate Social Responsibility is driven by strategic considerations by empirically studying the link between competition and firms' social performance.

natively the punishment based on Friedman's (1971) grim trigger strategies and Abreu's (1986) optimal punishments.

Our results suggest that, irrespective of the specific nature of punishment, to assign a weight to consumer surplus has a pro-competitive effect both in full and partial collusion. Also, a higher impact of productivity on pollution has a pro-competitive effect in partial collusion, and no effect in full collusion.[2] We complement the analysis of cartel behaviour with a welfare appraisal based on the shape of the isoquant map associated with both types of punishment, finding out that the weights attached to the externality and consumer surplus are complements over the entire parameter range.

The remainder of the paper is organised as follows. Section 2 presents the model and the solution in full collusion. Section 3 analyses full and partial collusion, respectively, with grim trigger strategies. Section 4 examines full and partial collusion with optimal punishments. The welfare implications are illustrated in section 5. Section 6 concludes.

2 The model

We consider a supergame taking place over discrete time $t = 0, 1, 2, ..,$ during which firms 1 and 2 compete *à la* Cournot and supply a homogeneous good, whose market demand function is $p = a - q_1 - q_2$, a being a positive constant parameter measuring the reservation price and q_1 and q_2 being the quantity produced by firm 1 and 2, respectively. In each period t, production takes place at constant returns to scale with a marginal cost $c \in (0, a)$, common to both firms and time-invariant. Hence, the per-period individual firm's profit function is $\pi_i = (p - c) q_i$, $i \in \{1, 2\}$. Throughout the supergame, firms share the same time preferences, measured by the constant discount factor $\delta \in (0, 1)$. The production of the final output entails a negative

[2] To the best of our knowledge, there exists two contributions loosely related to our discussion, although neither incorporate CSR. The first is Damania (1996), using a Cournot supergame to show that firms' profitability is enhanced by environmental taxation. The second is Ecchia and Lambertini (1997), where the pro-competitive effects of a minimum quality standard regulation are illustrated in a vertically differentiated duopoly where firms collude in prices.

environmental externality $E = q_1 + q_2$. For simplicity, we assume that E does not accumulate over time.[3] Consumer surplus is measured by $CS = (q_1 + q_2)^2 / 2$. The resulting social welfare function is

$$SW = \pi_1 + \pi_2 + CS - E. \tag{1}$$

We assume firms follow rules of Corporate Social Responsibility. Oligopolies where all firm embrace CSR rules are common in the real world: an example is the energy market in Italy. According to the "European Union Paper on Corporate Social Responsibility",[4] CSR companies integrate social and environmental concerns in their business operations. Within the company, socially responsible practices primarily involve employees and relate to issues such as investing in human capital, health and safety, and managing change, while environmentally responsible practices relate mainly to the management of natural resources used in the production. Out of the company, CSR practices involve a wide range of stakeholders: business partners and suppliers, customers, public authorities and local communities, as well as the environment. Thus we need to assume a specific CSR objective structure. In this, we borrow from Lambertini and Tampieri (2010): for the environmental concern, we assume that the CSR firm internalises its own share of pollution. All the other social concerns can be interpreted in our model as part of consumer surplus, hence we assume that the CSR firm is sensitive to it. Thus the CSR objective function is:

$$\tilde{\pi}_i = \pi_i - gq_i + \frac{z (q_1 + q_2)^2}{2}, \text{ for all } i \in \{1, 2\}, \tag{2}$$

where $z \in [0, 1]$ denotes the weight that firm i assigns to consumer surplus, and $g \in [0, 1]$ measures the degree of environmental awareness of the firm. For simplicity, we assume z is common to both firms. Also, we assume that $a > c + g$ in order to ensure that the Cournot equilibrium quantities are

[3] This would turn our setup into a proper dynamic game with a state (the stock of pollution) evolving over time. There exists a large literature in this vein (see, e.g., Bencheckroun and Long, 1998; 2002; and Dockner *et al.*, 2000, ch. 12).

[4] See www.mallenbaker.net/csr/definition.php.

positive.

3 Grim trigger strategies

In this section we examine the standard solution of a supergame where deviations from the cartel path are deterred by grim trigger strategies (Friedman, 1971), i.e., after any defection firms revert forever to the Nash equilibrium of the constituent game.

3.1 Full collusion

To begin with, we examine the equilibrium in the case of *full collusion*, that is, we analyse the existence of a collusive subgame perfect equilibrium where the two firms jointly solve the following problem:

$$\max_{q_1,q_2} \widetilde{\Pi} = \tilde{\pi}_1 + \tilde{\pi}_2 \tag{3}$$

yielding:

$$q^* = \frac{a-c-g}{4(1-z)}, \tag{4}$$

$$\tilde{\pi}_i^* = \frac{(a-c-g)^2}{8(1-z)}. \tag{5}$$

A unilateral deviation q^* along one's own best reply function yields the following outcome:

$$q^D = \frac{3(a-c-g)}{4(2-z)}, q^* = \frac{a-c-g}{4(1-z)}, \tag{6}$$

$$\tilde{\pi}^D = \frac{(a-c-g)^2\left[9-8z(2-z)\right]}{32(2-z)(1-z)^2}, \tag{7}$$

$$\tilde{\pi}^{CH} = \frac{(a-c-g)^2\left[12-z(13+8z(1-z))\right]}{32(2-3z+z^2)^2}, \tag{8}$$

where the superscripts D and CH stand for "deviating" and "cheated", respectively. Finally, Cournot-Nash non-cooperative behaviour entails the following outputs and payoffs:

$$q^N = \frac{a-c-g}{3-2z}, \tag{9}$$

$$\tilde{\pi}^N = \frac{(a-c-g)^2}{(3-2z)^2}, \tag{10}$$

where N stands for "Nash equilibrium". Simple algebra shows that $\tilde{\pi}^D > \tilde{\pi}^*$, $\tilde{\pi}^N > \tilde{\pi}^{CH}$ and $\tilde{\pi}^* > \tilde{\pi}^N$. Therefore, the constituent game is indeed a prisoner's dilemma.

The condition for the stability of full collusion under grim trigger strategies is:

$$\frac{\tilde{\pi}^*}{1-\delta} \geq \tilde{\pi}^D + \frac{\delta\tilde{\pi}^N}{1-\delta}, \tag{11}$$

that is met by all

$$\delta \geq \delta^* = \frac{\tilde{\pi}^D - \tilde{\pi}^*}{\tilde{\pi}^D - \tilde{\pi}^N} = \frac{(3-2z)^2}{17-8z(3-z)}.$$

By deriving δ^* w.r.t. z, we obtain

$$\frac{\partial\delta^*}{\partial z} = \frac{4(3-2z)}{[17-8z(3-z)]^2} > 0.$$

Hence an increase in the firms' sensitivity to consumer surplus increases the critical threshold of the discount factor allowing for full collusion. This implies:

Lemma 1 *Under full collusion, increasing the weight attached to consumer surplus has a pro-competitive effect.*

On the other hand, since $\partial\delta^*/\partial g = 0$, internalising the environmental externality has no effect whatsoever on the sustainability of collusion.

3.2 Partial collusion

In the case that the discount factor is too high to allow full collusion, firms may nonetheless activate the highest degree of *partial collusion* compatible with their intertemporal preferences, rather than revert to Cournot-Nash competition. I.e., firms have to identify the lowest collusive quantity q^C, given a generic discount factor $\delta < \delta^*$.

Setting $q_1 = q_2 = q^C$, we may write the symmetric collusive payoff accruing to each firm as

$$\tilde{\pi}^C = q^C \left[a - c - g - 2q^C (1 - z)\right]. \tag{12}$$

The unilateral deviation along the best reply function yields:

$$q^{DP} = \frac{a - c - g - q^C (1 - z)}{2 - z}, \tag{13}$$

$$\tilde{\pi}^{DP} = \frac{\left(a - c - g - q^C\right)^2 + 2q^C z (a - c - g)}{2 (2 - z)}, \tag{14}$$

$$\tilde{\pi}^{CHP} = \frac{\left(a - c - g + q^C\right)^2 z}{2 (2 - z)^2} + \frac{q^C \left[(a - c) (1 - z) - g + q^C\right]}{2 - z} - gq^C, \tag{15}$$

where the meaning of superscripts is intuitive. The intensity of partial collusion is measured by the minimum level of q^C satisfying the inequality:

$$\frac{\tilde{\pi}^{CP}}{1 - \delta} \geq \tilde{\pi}^{DP} + \frac{\delta \tilde{\pi}^N}{1 - \delta}, \tag{16}$$

that gives:

$$q^C \in \left[\max \left(\frac{(a - c - g) \left[\delta \left(4z^2 - 10z + 5\right)^2 - (3 - 2z)^2\right]}{\left[\delta - (3 - 2z)^2\right] (3 - 2z)}, \frac{a - c - g}{4 (1 - z)}\right), \frac{a - c - g}{3 - 2z}\right], \tag{17}$$

with

$$\frac{(a - c - g) \left[\delta \left(4z^2 - 10z + 5\right)^2 - (3 - 2z)^2\right]}{\left[\delta - (3 - 2z)^2\right] (3 - 2z)} > \frac{a - c - g}{4 (1 - z)} \, \forall \, \delta < \delta^*. \tag{18}$$

Accordingly, for any $\delta \in (0, \delta^*)$, the most intense level of collusion takes place at

$$\widehat{q}_N^C = \frac{(a-c-g)\left[\delta\left(4z^2-10z+5\right)^2-(3-2z)^2\right]}{\left[\delta-(3-2z)^2\right](3-2z)} \tag{19}$$

with subscript N denoting the Nash reversion. We are now in a position to analyse the relationship between $\widehat{q}_N^C$ and both the sensitivity to consumer surplus, z, and the impact of productivity on pollution, g. The partial derivative of $\widehat{q}_N^C$ w.r.t. z yields:

$$\frac{\partial\widehat{q}_N^C}{\partial z} = \frac{2(a-c-g)\left[(3-2z)^4-2\delta^2\left(2z^2-6z+5\right)-\delta(3-2z)^2\left(4z^2-8z-1\right)\right]}{\left[\delta-(3-2z)^2\right]^2(3-2z)^2}. \tag{20}$$

To evaluate its sign, note first that $2z^2-6z+5>0$ for all $z\in[0,1]$. Moreover, the denominator of the above fraction is positive. Hence, $\partial\widehat{q}_N^C/\partial z$ is concave in δ, with $\partial\widehat{q}_N^C/\partial z=0$ at

$$\delta_{\pm} = \frac{(3-2z)^2\left(1+8z-4z^2\pm\sqrt{41-32z+72z^2-64z^3+16z^4}\right)}{4(5-6z+2z^2)} \tag{21}$$

with $\delta_- < 0$ and $\delta_+ > 1$ always. This proves that $\partial\widehat{q}_N^C/\partial z > 0$ over the entire admissible region of parameters $\{\delta, z\}$.

Lemma 2 *Under partial collusion, increasing the weight attached to consumer surplus has a pro-competitive effect.*

We turn now to the analysis of the impact of g on collusion. The partial derivative of $\widehat{q}_N^C$ w.r.t. g yields:

$$\frac{\partial\widehat{q}_N^C}{\partial g} = \frac{(3-2z)^2-\delta\left(4z^2-10z+5\right)}{(3-2z)\left(\delta-(3-2z)^2\right)}. \tag{22}$$

Since the denominator is surely negative, any $z\in((5-\sqrt{5})/4,1)$ suffices to yield $\partial\widehat{q}_N^C/\partial g<0$. Otherwise, for all $z\in\left(0,(5-\sqrt{5})/4\right)$, we have $\partial\widehat{q}_N^C/\partial g \gtreqless$

0 for all $\delta \gtreqless (3-2z)^2 / \left(4z^2 - 10z + 5\right)$. However,

$$\frac{(3-2z)^2}{4z^2 - 10z + 5} > \delta^* \, \forall \, z \in \left(0, \frac{5-\sqrt{5}}{4}\right). \tag{23}$$

Consequently, $\partial \widehat{q}_N^C / \partial g < 0$ over the entire admissible region of parameters $\{\delta, z\}$.

Lemma 3 *Under partial collusion, internalising the environmental externality has an anti-competitive effect.*

The intuition is clear. Both taking into account the environmental externality and colluding leads to a reduction of the output produced.

4 Optimal punishments

In this section we analyse Abreu's (1986, 1988) one-shot optimal punishments in the CSR duopoly, both for full and partial collusion. The stability of collusion and the implementability of the penal code require, respectively (see Abreu, 1986, Lemma 17, p. 204):

$$\tilde{\pi}^D - \tilde{\pi}^* \leq \delta \left(\tilde{\pi}^* - \tilde{\pi}^{OP}\right), \tag{24}$$

$$\tilde{\pi}^{DOP} - \tilde{\pi}^{OP} \leq \delta \left(\tilde{\pi}^* - \tilde{\pi}^{OP}\right), \tag{25}$$

where $\tilde{\pi}^{OP}$ denotes each firm's stage payoff when both firms play the optimal punishment q^{OP}, i.e.:

$$\tilde{\pi}^{OP} = q^{OP} \left[a - c - g + 2q^{OP} (1-z)\right], \tag{26}$$

whilst $\tilde{\pi}^{DOP}$ is the payoff from a one-shot best response against q^{OP}, i.e.:

$$\tilde{\pi}^{DOP} = \frac{\left(a - c - g - q^{OP}\right)^2 + 2q^{OP} z (a - c - g)}{2(2-z)}. \tag{27}$$

A third constraint must be taken into account, i.e., the so-called *security level*, stating that the discounted continuation payoff from the punishment period onwards must be non-negative in order for firms not to quit the supergame:

$$\tilde{\pi}^{OP} + \tilde{\pi}^* \sum_{t=1}^{\infty} \delta^t \geq 0. \tag{28}$$

4.1 Full collusion

We start from the case with full collusion. By solving the system (24-25), we obtain:

$$q^{OP} = \frac{(a-c-g)(5-6z)}{4(2z^2-5z+3)}; \tag{29}$$

$$\delta^{OP} = \frac{(3-2z)^2}{16(z^2-3z+2)}. \tag{30}$$

The denominator of (29) is positive for all $z \in [0,1]$, so that $q^{OP} > 0$ for all $z < 5/6$.

Now we have to check whether (28) is satisfied. Given $q_i = q^{OP}$, $\delta = \delta^{OP}$, and for all $z \in [0, 5/6)$, each firm's discounted profit flow from the punishment period onwards is:

$$\tilde{\pi}^{OP} + \sum_{t=1}^{\infty} \left(\delta^{OP}\right)^t \tilde{\pi}^* = \frac{(a-c-g)^2 \left[49 - 4z\left(19 + z\left(9 - 8z\left(3-z\right)\right)\right)\right]}{2(1-z)(3-2z)^2 \left(12z^2 - 36z + 23\right)}. \tag{31}$$

To evaluate its positivity, note first that the numerator is always positive since $(a-c-g)^2 > 0$ and $49 - 4z(19 + z(9 - 8z(3-z))) > 0$ for all $z \in [0,1]$. Moreover, $12z^2 - 36z + 23 > 0$ for all $z \in \left[0, \left(9 - 2\sqrt{3}\right)/6\right]$, where $\left(9-2\sqrt{3}\right)/6 > 5/6$. Therefore the security level condition is slack for all $z \in [0, 5/6)$.

We can now control how the sensitivity of consumer surplus affects collusion. By deriving δ^{OP} w.r.t. z, we obtain

$$\frac{\partial \delta^{OP}}{\partial z} = \frac{(3-2z)}{16\left(z^2-3z+2\right)^2} > 0. \tag{32}$$

Therefore, even with optimal punishment, an increase in the sensitivity to consumer surplus increases the minimum discount factor allowing for full collusion.

For all $z \in [5/6, 1)$ we have $q^{OP} = 0$, so that we obtain two values of δ^{OP} from (24-25), i.e.:

$$\delta_1^{OP} = \frac{(1-2z)^2}{4(z^2-3z+2)} \lor \delta_2^{OP} = \frac{4(1-z)}{2-z}. \tag{33}$$

Collusion is feasible for all $\delta > \max\left\{\delta_1^{OP}, \delta_2^{OP}\right\}$. Simple algebra shows that $\delta_1^{OP} > \delta_2^{OP}$ for all $z > 5/6$, so that collusion is feasible for all $\delta > \delta_1^{OP}$. Also within the range $z \in (5/6, 7/8)$, we have $\delta < 1$. For all $z \in (7/8, 1)$, since $\delta \geq 1$ collusion is impossible. Hence we can say that:[5]

Lemma 4 *Under optimal punishment and full collusion, any positive weight attached to consumer surplus has a pro-competitive effect.*

4.2 Partial collusion

We now turn to the case of partial collusion. We denote as $\widehat{q}_{OP}^{C}$ the quantity at which the most intense level of collusion takes place for any $\delta \in \left(0, \delta^{OP}\right)$. By solving (24-25) w.r.t. $\widehat{q}_{OP}^{C}$ and q^{OP}, we obtain:

$$\widehat{q}_{OP}^{C} = \frac{(a-c-g)\left[(3-2z)^2 - 4\delta\left(2z^2-5z+2\right)\right]}{(3-2z)^3}, \tag{34}$$

$$q^{OP} = \frac{(a-c-g)\left[(3-2z)^2 + 4\delta\left(2z^2-5z+2\right)\right]}{(3-2z)^3}. \tag{35}$$

We control for the nonnegativity of $\widehat{q}_{OP}^{C}$ and q^{OP}. Starting from $\widehat{q}_{OP}^{C}$, since the denominator is surely positive, any $z \in [1/2, 1]$ gives $4\delta\left(2z^2-5z+2\right) < 0$ and thus suffices to yield $\widehat{q}_{OP}^{C} > 0$. Otherwise, for all $z \in [0, 1/2)$, we have $\widehat{q}_{OP}^{C} \gtrless 0$ for all $\delta \lessgtr (3-2z)^2 / 4\left(2z^2-5z+2\right)$. However,

$$\frac{(3-2z)^2}{4(2z^2-5z+2)} > \delta^{OP} \,\forall\, z \in [0, 1/2). \tag{36}$$

[5] Trivially, in this case condition (28) is slack as $\tilde{\pi}^{OP} = 0$ while $\tilde{\pi}^{*} > 0$.

Consequently, $\widehat{q}_{OP}^{C} > 0$ over the entire admissible region of parameters $\{\delta, z\}$.

Turning to q^{OP}, any $z \in [0, 1/2)$ gives $4\delta\left(2z^2 - 5z + 2\right) > 0$ and thus suffices to yield $q^{OP} > 0$. Otherwise, for all $z \in [1/2, 1]$, we have $q^{OP} \gtreqless 0$ for all $\delta \lesseqgtr -(3-2z)^2 / 4\left(2z^2 - 5z + 2\right)$.

We can now examine whether the continuation payoff from the punishment onwards satisfies the security level constraint. For $q^{OP} > 0$, each firm discounted profit is:

$$\tilde{\pi}^{OP} + \sum_{t=1}^{\infty} (\delta)^t \tilde{\pi}^* =$$

$$\frac{(a-c-g)^2 \left[(3-2z)^4 + 8\delta^2 (2-z)(1-2z)^2 - 4\delta (2-z)(3-4z(2-z))^2\right]}{(1-\delta)(3-2z)^6}. \tag{37}$$

Being both $(a-c-g)^2$ and the denominator positive, we focus our attention on:

$$\Xi = (3-2z)^4 + 8\delta^2 (2-z)(1-2z)^2 - 4\delta (2-z)(3-4z(2-z))^2, \tag{38}$$

which is quadratic in δ. It can be easily shown (although we omit details for brevity) that $\Xi = 0$ has no real roots for any $z \in [0, 1]$. Therefore, (37) is positive, and the security level condition is slack. The same of course holds in the case in which $q^{OP} = 0$.

We are now in a position to determine whether z and g have a pro or anti-competitive effect. The partial derivative of q^{OC} w.r.t. z yields:

$$\frac{\partial \widehat{q}_{OP}^{C}}{\partial z} = \frac{2(a-c-g)\left[(3-2z)^2 - 2\delta\left(4z^2 - 8z + 3\right)\right]}{(3-2z)^4}. \tag{39}$$

To evaluate its sign, note first that $2(a-c-g)$, $(3-2z)^2$ and the denominator of the above fraction are positive, while $-2\delta\left(4z^2 - 8z + 3\right)$ is concave in z, with $4z^2 - 8z + 3 = 0$ at $z_{\pm} = \left(2 \pm \sqrt{7}\right)/2$ with $z_- < 0$ and $z_+ > 1$ always. This proves that $\partial \widehat{q}^{OC} / \partial z > 0$ over the entire admissible region of parameters $\{\delta, z\}$, implying:

Lemma 5 *Under partial collusion and optimal punishment, increasing the weight attached to consumer surplus has a pro-competitive effect.*

The impact of g on collusion remains to be analysed. The partial derivative of $\widehat{q}_{OP}^{C}$ w.r.t. g yields:

$$\frac{\partial \widehat{q}_{OP}^{C}}{\partial g} = \frac{4\delta \left(2z^2 - 5z + 2\right) - (3 - 2z)^2}{(3 - 2z)^3}. \tag{40}$$

Since the denominator is surely positive, any $z > 1/2$ suffices to yield $\partial \widehat{q}_{OP}^{C}/\partial g < 0$. Otherwise, for all $z \in [0, 1/2)$, we have $\partial \widehat{q}_{OP}^{C}/\partial g \gtreqless 0$ for all $\delta \gtreqless (3 - 2z)^2 / 4 \left(2z^2 - 5z + 2\right)$. However,

$$\frac{(3 - 2z)^2}{4\,(2z^2 - 5z + 2)} > \delta^{OP}\, \forall z \in [0, 1/2)\,. \tag{41}$$

Consequently, $\partial \widehat{q}_{OP}^{C}/\partial g < 0$ over the entire admissible region of parameters $\{\delta, z\}$, therefore an increase in g lowers the maximum quantity allowing for a partial collusion, implying:

Lemma 6 *With partial collusion and optimal punishment, to internalise the environmental externality has an anti-competitive effect on the market.*

Lemma 5 and 6 show that, with optimal penal code, the effect of z and g on competition are consistent to their effect with grim trigger strategies.

5 Welfare appraisal

The bottom line of the foregoing analysis is that the weights g and z attached to the environmental externality and consumer surplus have opposite effects on industry output under partial collusion. This, in turn, has to be assessed in combination with the fact that any increase (resp., decrease) in the output level causes a decrease (resp., increase) in profits and the externality, and an increase (resp., decrease) in consumer surplus. Hence, it is interesting to construct a measure telling how these two parameters should be combined so as to deliver a constant welfare level.

To this purpose, we write the total differential of the individual collusive output $\widehat{q}_J^C$, $J = N, OP$, w.r.t. g and z :

$$d\widehat{q}_J^C = \frac{\partial \widehat{q}_J^C}{\partial g} dg + \frac{\partial \widehat{q}_J^C}{\partial z} dz \tag{42}$$

and impose $d\widehat{q}_J^C = 0$ to obtain the marginal rate of substitution between z and g :

$$\frac{dz}{dg} = -\frac{\partial \widehat{q}_J^C}{\partial g} / \frac{\partial \widehat{q}_J^C}{\partial z} > 0 \tag{43}$$

always, as $\partial \widehat{q}_J^C / \partial g$ and $\partial \widehat{q}_J^C / \partial z$ have opposite sign irrespective of the type of punishment being used. Accordingly, g and z are complements, i.e., any increase in either one must go along with an increase in the other in order for the output to remain constant. In such a case, obviously, also the resulting welfare level remains constant at

$$SW = 2(a - \widehat{q}_J^C - c - 1)\widehat{q}_J^C. \tag{44}$$

Finally, observe that the slope of the associated isoquant is

$$\frac{\partial \left(dz/dg \right)}{\partial g} > 0, \tag{45}$$

again irrespective of the nature of punishment (the detailed proof of this result is in the appendix). This means that any increase in g must be accompanied by a more than proportional increase in z. This is seemingly due to the linear form of the externality function and the quadratic form of consumer surplus.

6 Concluding remarks

We have examined a duopoly with negative environmental externalities in which firms incorporate CSR into their objective functions, to investigate the effects of CSR on the stability/intensity of collusion. To do so, we have modelled a supergame alternatively allowing for both full or partial collusion, the deterrence being based either on grim trigger strategies or on optimal punishments. Our results suggest that, irrespective of the structure of the punishment phase, assigning a weight to consumer surplus has a pro-competitive effect, i.e., either increases the threshold level of the discount factor (under full collusion) or increases the output level (under partial collusion). On the contrary, the presence of the environmental externality in the objective function has an anti-competitive effect, again independently of the nature of the punishment, under partial collusion, and no effect at all under full collusion. The welfare analysis under partial collusion reveals the presence of complementarity between the weghts attached to consumer surplus and pollution.

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Appendix

Consider the Nash punishment. The partial derivative of

$$\frac{dz}{dg} = -\frac{\partial \widehat{q}_N^C}{\partial g} / \frac{\partial \widehat{q}_N^C}{\partial z} \tag{46}$$

w.r.t. g is:

$$\frac{\partial\left(dz/dg\right)}{\partial g}=\frac{\left(3-2z\right)\left[\left(3-2z\right)^{2}-\delta\right]\left[2z\left(6-5\delta\right)-9+5\delta-4z^{2}\left(1-\delta\right)\right]}{2\left(a-c-g\right)^{2}\left\{2\delta^{2}\left[5-2z\left(3-z\right)\right]-\left(3-2z\right)^{4}-\delta\left(3-2z\right)^{2}\left[4z\left(2-z\right)+1\right]\right\}}. \tag{47}$$

Take the numerator first:

$$\left(3-2z\right)\left[\left(3-2z\right)^{2}-\delta\right]>0 \tag{48}$$

always, while:

$$2z\left(6-5\delta\right)-9+5\delta-4z^{2}\left(1-\delta\right)<0 \tag{49}$$

over the admissible parameter range, because the roots the above expression are:

$$z=\frac{6-5\delta\pm\sqrt{\delta\left(5\delta-4\right)}}{4\left(1-\delta\right)} \tag{50}$$

which are imaginary for $\delta\in(0,4/5)$ and larger than one for $\delta\in(4/5,1)$. As to the denominator, observe that the coefficient of δ^2 is always positive, and then solve

$$2\delta^{2}\left[5-2z\left(3-z\right)\right]-\left(3-2z\right)^{4}-\delta\left(3-2z\right)^{2}\left[4z\left(2-z\right)+1\right]=0 \tag{51}$$

to obtain

$$\delta=\frac{\left(3-2z\right)^{2}\left(1+8z-4z^{2}\pm\sqrt{41-32z+72z^{2}-64z^{3}+16z^{4}}\right)}{4\left(2z^{2}-6z+5\right)}, \tag{52}$$

both outside the unit interval. This proves that the isoquant is convex w.r.t. g when the infinite Nash reversion is used to stabilise the cartel.

We turn now to optimal punishments. The partial derivative of

$$\frac{dz}{dg}=-\frac{\partial\widehat{q}_{OP}^{C}}{\partial g}/\frac{\partial\widehat{q}_{OP}^{C}}{\partial z} \tag{53}$$

w.r.t. g is:

$$\frac{\partial\left(dz/dg\right)}{\partial g}=-\frac{\left(3-2z\right)\left[4\delta\left(2-z\right)\left(1-2z\right)-\left(3-2z\right)^{2}\right]}{2\left(a-c-g\right)^{2}\left[2\delta\left(3+4z\left(2-z\right)\right)+\left(3-2z\right)^{2}\right]}. \tag{54}$$

The denominator is clearly positive, while the numerator has

$$4\delta\left(2-z\right)\left(1-2z\right)-\left(3-2z\right)^{2}<0$$

for all $z\in\left(1/2,1\right]$. If instead $z\in\left(0,1/2\right]$, the above condition is satisfied for all

$$\delta<\frac{\left(3-2z\right)^{2}}{\left(2-z\right)\left(1-2z\right)} \tag{55}$$

but the RHS is always higher than one. Therefore the isoquant is convex w.r.t. g also when optimal punishments are adopted.

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