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What if Cartel Fines are not high enough? Implications on Deterrence and Productive Efficiency

¿Qué pasa cuando las multas por colusión no son suficientemente elevadas? Implicancias en la disuación del delito y la eficiencia productiva

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Abstract

I develop a model in which cartel firms allocate costly effort to activities related to productive efficiency and concealment: the higher the fine or the probability of inspection, the more biased the firms' effort allocation towards concealment. In this context, a fine increase can improve welfare through fewer cartels, but also reduce it through more inefficient surviving ones. The analysis suggests a carefully design of policy such that achieving a level of deterrence and productive (in)efficiency socially accepted. Within this framework, I also consider the implications of leniency programs. I show that leniency enhances incentives on deviation more that in standard models of collusion.

Keywords: collusion, productive efficiency, antitrust policy, deterrence, leniency programs, social welfare.

JEL Code: D21, K21, K42, L41.

Resumen

En este artículo se desarrolla un modelo en el que las empresas de un cártel asignan esfuerzo costoso a actividades vinculadas a la eficiencia productiva

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y a actividades propias de la ocultación del delito de colusión. Particularmente, mientras mayor es la multa por colusión o la probabilidad de inspección, más sesgada es la distribución de esfuerzo de las firmas hacia la ocultación del acto delictivo. En este contexto, un incremento de la multa a la vez que puede mejorar el bienestar social por su poder de disuasión del delito, también puede reducirlo a través de cárteles más ineficientes. El análisis sugiere un diseño cuidadoso de la política de defensa de la competencia, que permita combinar un nivel de disuasión del delito con un nivel de ineficiencia productiva socialmente aceptado. Finalmente, al considerar las implicancias de programas de clemencia demuestro una mayor eficacia en la disuasión del delito con respecto a modelos estándares de colusión.

Palabras Clave: colusión, eficiencia productiva, política de defensa de la competencia, disuasión, programas de clemencia, bienestar social.

Código *JEL*: D21, K21, K42, L41.

I. Introduction

To succeed cartels concentrate on two targets: profit maximization and concealment. And to this end, member firms devote resources to productive efficiency and to conceal evidence. Costly resources face firms with the challenge to allocate them optimally, sacrificing productive efficiency in favor of concealment, or vice versa. In this decision, the antitrust policy has a key role, as it affects expected detection costs, and through it the relative importance of the targets. In this context this paper sheds light to the effect of fines and inspections on cartel deterrence and on cartel firms' decision to allocate effort among productive efficiency and concealment. This last issue takes special interest when fines are not high enough, as cartels might not only imply a welfare loss derived from less production and a higher price, but also an inefficiency loss derived from devoting costly effort to an unproductive activity as concealment.

In this paper I develop a model in which cartel firms devote effort to productive activities and to concealment: effort devoted to production reduces marginal costs and effort devoted to concealment reduces the probability of detection. Effort is costly and limited, thus firms have to decide on how to allocate it among productive efficiency and concealment. The intuition goes as follows: cartel survival depends on the success of each of its member firms, not only as firms that play in a cartelized market, but also as firms that individually operate in complex (legal) markets. Thus, within a cartel senior executives have to be cautious on how to allocate their time, effort and attention among the own productive efficiency and the cartel organization, in order to guarantee a balanced success on both.[1] For simplicity purposes, among the activities related to the cartel organization, I focus on concealment activities. These include the attendance to secret meetings all over the world and the conduct of a joint sales agency, among other activities.[2] For further simplification, I reduce the three dimensions of care (effort, time and attention) to one: effort.

In this setup, cartel firms' effort allocation depends on fines and inspections. When fines are low and/or the probability of inspection is low, firms find it profitable to allocate all effort to productive efficiency. However, as fines or inspections go up, firms substitute effort from productive efficiency to concealment. This reallocation of effort makes collusion sustainable in industries where it wouldn't be otherwise and create inefficiencies not considered in standard models of collusion. In the light of these results, a fine increase can have two opposite effects on welfare, while it can improve welfare through fewer cartels, it can also reduce it through more inefficient surviving ones. Particularly, for intermediate fine levels, a fine increase implies a welfare gain from fewer cartels that does not compensate the welfare loss from more inefficient surviving ones. This analysis suggests a carefully design for the antitrust policy, as deterrence is not monotonic in the level of the fine. Indeed, a fine increase may enhance collusion sustainability and a welfare loss rather than deterrence if inspections are not set accordingly.

In the analysis I also consider the effectiveness of leniency programs. These programs reduce sanctions against the cartel firm that reports evidence of the cartel to the antitrust authority (AA) and cooperates with it along the prosecution phase.[3] The effectiveness of these programs to improve deterrence lies in enhancing the temptation to deviate. In terms of my model, the prospect of an amnesty enhances deviation incentives more than in models

1. Aware of how time and effort-consuming are cartel activities (not only concealment), cartel members create complex hierarchical structures that set the role of each member in the cartel, as well as the rules to follow in case of eventual problems. In this way, the cartel is intended to be conducted as efficiently as a legal organization. For evidence on the hierarchical operativeness of cartels, see Baker & Faulkner (1993), Griffin (2000), Levenstein & Suslow (2006) and Harrington (2006).

2. Using data from 19 discovered cartels, Levenstein & Suslow (2006) show that cartels that used joint sales agencies were among the more successful cartels in terms of their long- lastingness and fewer coordination problems. They find evidence on the use of a joint sales agency to conceal cartel practices in the following cartels: bromine (1885-1895), cement (1922-1962), diamonds (1870s-1970s), ocean shipping (1870-1924), oil (1871-1874), potash (1877-1897), and European steel (1926-1939).

3. Spagnolo (2008) provides an extensive review of literature on leniency in collusion.

without effort on concealment, as the firm that deviates saves effort costs associated to concealment (a deviant that applies for leniency has no incentives to devote costly effort to concealment).

The paper continues as follows. In Section 2, I provide a brief description of the related literature. In Section 3, I set up the model. In section 4, I solve it without effort on concealment (benchmark case), and in Section 5, I solve it with effort on concealment. In Section 6, I discuss the implications of a fine increase on deterrence and on firms' productive efficiency. In Section 7, I analyze the welfare implications of using leniency programs. Finally, Section 8 concludes.

II. Related Literature

This paper is closely related to studies on collusion that analyze productive inefficiencies created by antitrust policies. Aubert, Kovacic & Rey (2006) show that whistle-blowing programs improve the deterrence effect of high fines, but that, however, may induce (i) cartel firms to bribe informed employees and hold their under-performance to avoid possible crime reports, and (ii) non-cartelized firms to deter good cooperation between them when this can not be distinguished from the type of communication involved in price-fixing agreements. Therefore, although these programs can improve deterrence, they can also reduce the productive efficiency of surviving cartels and of non-cartelized firms.

Within a principal-agent model, Aubert (2009) achieves this result for individual leniency programs. Under the assumption that competition requires less managerial effort than collusion, and this, in turn, less than deviation, a manager that privately chooses market conduct and productivity-enhancing effort may opt for an anti-competitive conduct to save costly effort. With the same logic, a manager that fixes price is highly tempted to deviate from the price agreement. Thus, to avoid cartelization or, under collusion, to prevent deviation, shareholders provide the manager with weak incentives to exert effort. In this context, individual leniency raises the costs of inducing collusion; but also makes it more likely the payment of informational rents and the request of inefficient effort levels when it is desired to induce competition. Therefore, while individual leniency contributes to deterrence, it also tempts competition-prone shareholders to induce collusion rather than competition. Regardless of the market conduct, productive efficiency is not achieved.

Similar to Aubert (2009), I also get into the firm's 'black-box' to analyze how the antitrust policy distorts the decision problem of those who decide on the behavior of the firm. However, the mechanism in this paper is different to that in Aubert. While Aubert focuses the analysis on how the antitrust policy can distort the agency problem of a principal and its subordinate, I focus the analysis on how the antitrust policy can distort firms' interest in productive efficiency with respect to that in concealment.

A key element in my framework is the possibility of destroying evidence of collusion. Aubert et al. (2006) suggest that firms keep evidence of the cartel if they fear that rivals will apply for leniency. Jellal & Souam (2004) point to firms' interest in keeping evidence taking into consideration that concealment is costly and negatively related to the inspector's performance. The higher the cost of effort devoted to concealment or the lower the inspector's effort devoted to discovering evidence, the more the evidence that firms prefer to keep. Following Jellal et al. (2004), I consider costly concealment as the driving force behind the keeping of evidence of the cartel. However, I assume that concealment can create productive inefficiencies by making use of effort previously devoted to production. This trade-off explains why firms keep cartel evidence in the absence of leniency programs or underperformance of the inspectors.

Other key element in my framework is the endogeneity of the probability of detection. Jellal et al. (2004) consider the probability of detection endogenous to the firms' and the inspector's efforts devoted to hide and discover collusion, respectively. Harrington (2004 and 2005) considers the probability of detection endogenous to current and previous periods' prices, since he assumes that anomalous price movement make customers and the AA suspicious that a cartel is operating. Harrington & Chen (2005) extends these works to leniency programs. Similar to the probability of detection, the probability of paying penalties is endogenous to the cartel firms' perception regarding the severity of the antitrust policy, Harrington & Chang (2009), and on the AA's resources devoted to prosecute and convict discovered cartels, Harrington (2011).

This paper is in line with those that consider the probability of detection endogenous to the firm's behavior, and not to that of the AA. The novelty of my work lies in the productive inefficiencies associated to concealment and, through this, to the antitrust policy. This is captured in the fact that firms' willingness to sacrifice productive efficiency in favor of concealment increases with the severity of the antitrust policy.

This paper is also related to the literature on the impact of leniency programs in antitrust enforcement. Two main results stand out in this literature. First, high amnesties, and particularly total amnesty, improve deterrence by making self-reporting attractive and, therefore, inducing cartel members to defect and report, Motta & Polo (2003), Aubert et al. (2006), Chen & Rey (2007), Harrington (2008), among others. Second, low and intermediate amnesties may have a perverse effect on deterrence: when self-reporting becomes attractive, the threat of self-reporting to punish an agent that did not behave as agreed upon by the cartel may also become credible, and can be used by smart wrongdoers to enforce cartels that would not be sustainable in the absence of this threat, Spagnolo (2000), Buccirossi & Spagnolo (2001 and 2006). Regarding leniency, my paper has a very specific objective: whether a generally accepted leniency program distorts cartel firms' effort allocation, and if so, what implication does it have on firms' productive efficiency. To the best of my knowledge, this question has not been explored in the literature before.[4]

Finally, this paper also addresses the issue of antitrust policies with perverse effects, i.e., antitrust policies that contribute to cartel sustainability rather than to deterrence. Spagnolo (2000) and Buccirossi & Spagnolo (2001 and 2006) emphasis the perverse effect of leniency programs in deterrence. Harrington (2004, 2005) shows how a fine increase can (negatively) affect profits from deviation more than the net value of future profits from collusion, facilitating collusion (i.e., relaxing the incentive compatibility constraint of the cartel). Similarly, I show perverse effects from an antitrust policy that distorts profits from deviation more than those from collusion, facilitating collusion.

III. The Model

Consider an economy with a continuum of industries. In each industry, there are two firms producing perfect substitutes and there is an inelastic demand for two units with reservation price v I assume $v \sim U\ [\underline{v},\ \overline{v}]$. Firms maximize profits over an infinite time horizon with constant discount parameter δ. To this end, they compete or collude on prices.

4. For a generally accepted leniency program I consider a program that offers amnesty to the first informant firm for its full collaboration in the detection of the cartel.

To produce, firms have a fixed marginal cost β, which can be privately reduced for the current period through effort devoted to productive efficiency $a_i \geq 0$, $i = 1,\ 2$. I set firm's marginal cost $c_i = \beta - a_i$.

The market demand goes to the lowest priced firm or, in case of a price tie, to the firm with the lowest production cost. Under a price tie and equal production costs, firms equally split demand.

Collusion requires communication, which constitutes hard evidence for cartel detection. Evidence lasts for one period and can be discovered by the AA during an inspection. However, firms can privately destroy some of evidence through costly effort and, consequently, reduce the likelihood of finding evidence in an inspection.

To model this, I set the probability of finding cartel evidence in an inspection to firm i: e^{-z_i} , $i = 1,\ 2$, where $z_i \geq 0$ is firm i's effort devoted to concealment. The higher is this effort, the lower is the probability of finding cartel evidence in an inspection to a firm.

Effort is costly. I set the firm's effort disutility function as $(a_i + z_i)^2 / 2$. This specification for the disutility of effort follows Holmstrom & Milgrom (1991) and is common in multitask analyses. It is consistent with the view that efforts are technological substitutes and that disutility depends on total effort (not on the firm's effort allocation).[5]

To fight cartels, the AA has two instruments, fines and inspections. Both instruments are specific to firms, which implies: (i) in a single period, the AA can inspect either firm i, or firm j, or both firms, and (ii) under detection, each firm pays a fine F.

I assume that the probability of an inspection to a firm, denoted by $\rho \in [0,\ 1]$, is exogenously given. Hence, the cartel probability of detection is:

$$h\ (z_1, z_2\ \mid \rho) = \rho\ (e^{-z_1} + e^{-z_2}) - \rho^2\ e^{-z_1}\ e^{-z_2})$$

There is cartel detection if the AA finds evidence after inspecting one or both of the firms.

5. For the effort allocation to be also relevant, one can introduce a weighting parameter $\mu \in \Re_0^+$ such that $[(a_i + \mu z_i)^2]/2$. The assumption of $\mu = 1$ affects the degree of substitution between efforts, but in no case restricts the results of the paper.

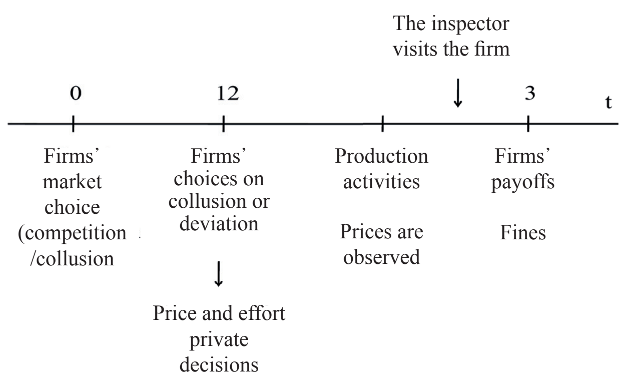
Note that each firm's effort devoted to concealment creates a positive externality to rivals by reducing the cartel probability of detection. The lower is z_i, the higher is the externality that firm i perceives from and additional unit of z_j $(\frac{\partial^2 h}{\partial z_i \partial z_j} < 0)$.

The timing of the game is as follows. At stage 0, firms choose whether to collude or compete. If one firm chooses to compete, competition takes place and the game ends. If, instead, there is an agreement on collusion, at stage 1, firms decide whether to follow the price agreement or to deviate. Under deviation, the deviant either slightly reduces price, or increases effort devoted to productive efficiency, or both. In this way, it gets all demand.

At stage 2, effort, production and price decisions are executed and the rival's price is observed. Also, inspections take place. At stage 3, firms get their payoffs from sales. Under cartel detection, firms pay a fine F and the game starts again from stage 0. If the cartel is not detected, but one firm has deviated, a punishment phase takes place. Finally, if none of the firms have deviated and the cartel is not detected, the game repeats itself from stage 1.

In this setup, firms make simultaneous pricing and effort decisions in every period t. With an infinite horizon, firm i, $i = 1, 2$, chooses prices $p_{it} \in [0, v]$ and efforts a_i, $z_i \in [0, 1]$, in every t, $t = 1, 2, ..., \infty$.[6]

Figure 1: Time-structure of the model



6. Latter in the model it is shown how effort z_i is particularly relevant under deviation: since under deviation the deviant produces more units than under collusion, it has incentives to substitute effort devoted to concealment for effort devoted to production. The firm that follows the cartel agreement, instead, faces no distortion on its effort decision rule. Hence, under deviation the probability of cartel detection can be higher than under collusion; this issue will be a key issue for cartel sustainability. This is explained in detail in next sections.

Under collusion, price choices at date t depend on the history of previous sales, so that p_{it} depends on $Hit = (q_{i1} ; q_{i2} ; . . . ; q_{i,t\text{-}1}), i = 1, 2$. The rational behind this rule goes as follows: under collusion firms charge the same price and split the demand in halves, $q_i = 1, i = 1, 2$.[7] Thus, for a firm, no sales implies that the rival deviated (in price, in effort or in both). Therefore, the strategy under collusion for firm i is to initially price at the agreed price p^c (the price under collusion) in period 1 and to continue pricing according to:

$$p_{it} = p^c \qquad if: \; q_i^{\tau} = 1 \quad \forall \tau \in \{1, ..., t-1\}, \; j = \{1, 2\}$$

as long no firm has deviated from this path. If a firm has deviated, there is a reversion to the single-period Nash equilibrium strategy of pricing, since Nash reversion can assure zero profits for the deviant.

In the one-shot game, firms choose price and effort devoted to productive efficiency to maximize current profits:

$$\Pi_i = [p_i - (\beta - a_i)]\, q_i - \frac{a_i^2}{2}$$

Proposition 1: *There exists a one-shot game Nash equilibrium in which one firm obtains zero profits.*

In the one-shot game there is a pure strategy equilibrium in weakly dominated strategies that yields zero profits for both firms. Also, there are undominated mixed-strategy equilibria that yield zero profits for one firm and positive profits for the other. Since at the static Nash equilibrium there is at least one firm that obtains zero profits, Nash reversion in which the deviant obtains zero profits constitutes an optimal penal code.

IV. Collusion without Effort on Concealment

Without effort on concealment, the probability of finding cartel evidence in an inspection to a firm is 1. Therefore, the cartel probability of detection is exogenously determined as a function of ρ: $h^B = 2\rho - \rho^2$.

The firm's problem is to chose price and effort to maximize:

$$\Pi_i = [p_i - (\beta - a_i)]\, q_i - \frac{a_i^2}{2} - F\rho\,(2 - \rho)$$

7. The decision rule of splitting the market in halves is standard in models of collusion with asymmetric firms and without transfers in the price agreement.

The first term is the firm's payoff from production and the second and third ones its costs associated to effort and to detection, respectively.

Taking partial derivative with respect to a_i and solving: $a_i = q_i, i = 1, 2$.

Regarding price, under collusion firms charge the same price and split the demand in halves: $p_i = p^c$ and $q_i^c = 1,\ i = 1, 2$. Thus, in each period, firms make one unit of effort $(a_i^c = 1)$ and obtain profits:

$$\Pi_i^c = p^c - \beta + \frac{1}{2} - F\rho\,(2-\rho)$$

If a firm decides to deviate, it either slightly reduces its price, or increases its effort devoted to productive efficiency (to reduce marginal costs), or both. In this way, it gets all demand. A price reduction does not have side effects on firm's efficiency, however the increase of effort on productive efficiency does it. Thus, to maximize profits, a deviant always reduce its price slightly and chooses the effort level a^d that maximizes the current value of profits from deviation. Assuming firm i deviates:[8]

$$a_i^d = \arg\max\left\{2\ \left[\,p^c - (\beta - a_i)\,\right] - \frac{a_i^2}{2} - F\rho\,(2-\rho)\right\} = 2$$

Under deviation, the firm behaves as an efficient monopolist: it devotes two units of effort to produce the two units of the good that the market demands. Profits from deviation are:

$$\Pi_i^d = 2\,(p^c - \beta) + 2 - F\rho\,(2-\rho)$$

in the current period, and zero thereafter.

IV.1 Cartel's Sustainability

Collusion is sustainable as long as firms have no incentives to deviate, i.e., when the current gains from deviation (G) are no greater than the present value of net future profits from collusion.

$$(ICC) \qquad G = \Pi^d - \Pi^c \ \leq\ \frac{\delta}{1-\delta}\,\Pi^c \qquad (1)$$

8. Since the optimal penal code yields zero profits for the deviant forever after deviation, the current value of total profits from deviation equates current profits from deviation:

$$\pi_i^d + \delta\,0 + \delta^2\,0 + \delta^3\,0 + \ldots = \pi_i^d$$

In this model:

$$p^c - \beta + \frac{3}{2} \leq \frac{\delta}{1-\delta} \left[p^c - \beta + \frac{1}{2} - F\rho\,(2-\rho) \right]$$

For $\delta > \frac{1}{2}$, a price increase relaxes ICC, which implies that firms always charge the reservation price under collusion, $p_c = v$.[9] Prices lower than v make collusion harder to sustain, and prices higher than v would imply no sales. So, collusion is sustainable if and only if it is sustainable at price v. Along the paper I assume $\delta > \frac{1}{2}$.[10]

Solving for v in ICC:

$$v \geq v_1 = \beta + \frac{\frac{3}{2} - 2\delta + \delta\rho\,(2-\rho)\,F}{(2\delta - 1)} \qquad v_1 \in [\underline{v}, \overline{v}]$$

Proposition 2: *(Without effort on concealment) There exists* $v_1 \in [\underline{v}, \overline{v}]$ *such that collusion is sustainable in all industries with high enough reservation price,* $v \geq v_1$. v_1 *is increasing in* F *and* ρ.

From the AA's point of view, v_1 states the efectiveness of the antitrust policy to deter cartels: an increase in the fine and/or in the likelihood of an inspection raises the threshold parameter v_1, making collusion harder to sustain.

V. COLLUSION WITH EFFORT ON CONCEALMENT

Allowing for effort on concealment, the firm's problem is to choose price and effort levels that maximize:

$$\Pi_i = [p_i - (\beta - a_i)]\,q_i - \frac{(a_i + z_i)^2}{2} - F\;\rho\left[\left(e^{-z_i} + e^{-z_j}\right) - \rho e^{-z_i - z_j}\right]$$

Taking partial derivative with respect to efforts, at the interior solution it holds:

$$a_i + z_i = q_i \qquad (2)$$

$$q_i = F\rho e^{-zi}(1\text{-}\rho e^{-zj}) \qquad (3)$$

9. The partial derivative of G (LHS of equation (1)) with respect to p^c is given by: $\partial G/\partial p^c = 1$. On the other hand, the partial derivative of the present value of net future profits from collusion (RHS of equation (1)) with respect to p^c is: $\delta/1\text{-}\delta$. For a price increase ($\Delta p^c > 0$) to relaxes ICC it must be true that $\partial G/\partial p^c{=}1 \leq \delta/(1\text{-}\delta) = \partial[\delta/(1\text{-}\delta).\Pi^c]/\partial p^c$, which is true for $\delta \geq 1/2$.

10. Otherwise, collusion is not profitable. $\delta > 1/2$ is the standard level of patient assumed in models of collusion.

Equations (2) and (3) characterize firm's optimal behavior under both collusion and deviation. Equation (2) states that, for the same level of production, an increase in effort devoted to productive efficiency must be compensated with an equal reduction in effort devoted to concealment. Equation (3) states that z_i's marginal benefits to i's profits (LHS) must equate its marginal costs in terms of changes in the cartel probability of detection (RHS). The latter should be interpreted as follows: a reduction in z_i implies additional benefits for firm *i* due to more effort devoted to productive activities (higher a_i) equal to q_i, however it also implies a reduction in benefits of $F\rho e^{-zi}(1\text{-}\rho e^{-zj})$ due to a higher cartel probability of detection.

Rewriting (3): $$R_i(z_j) = -\ln\left[\frac{q_i}{F\rho\,(1-\rho e^{-z_j})}\right] \qquad (4)$$

Equation (4) is an effort reaction curve. It represents each firm's effort devoted to concealment in terms of the rival's effort devoted to concealment.[11] Particularly, the higher is the rival's effort devoted to concealment, the higher is the own effort devoted to this activity too. To see this, assume that j increases its effort on concealment. Immediately, the cartel probability of detection decreases distorting i's equilibrium condition: now, i's marginal utility from effort devoted to concealment is lower than its marginal cost. Hence, to restore equilibrium, i increases its effort devoted to concealment.[12]

Regarding antitrust parameters: $R_i(z_j)$ is upward sloping in F and in ρ. The more severe is the antitrust policy, the more incentivized is the firm to conceal evidence, and thus the higher is the firm's effort devoted to this activity. Regarding firm's market share: $R_i(z_j)$ is downward sloping in q_i. The higher is the level of production, the lower is the firms's willingness to devote effort to concealment, as higher market shares makes concealment relatively less important with respect to productive efficiency.

Under collusion, firms charge the same price and split demand in halves. Setting $q_i^c = 1$ in equations (2) and (4), reaction curves $R_1(z_2)$ and $R_2(z_1)$

11. Using equation (2), one can rewrite equation (4) in terms of efforts devoted to productive efficiency.

12. Analytically, for the same level of production ($dq_i = 0$), an increase in z_j ($dz_j > 0$) implies:

$$dq_i = -F\rho e^{-zi}\,[(\,1-\rho e^{-zj}\,)dz_i + \rho\; d(e^{-zj}\,)]=0$$

where $d(e^{-zj}\,) < 0$. Solving for dz_i:

$$dz_i = -\frac{\rho\; d\left(e^{-z_j}\right)}{1-\rho e^{-z_j}} > 0$$

have a unique intersection point, that is on the 45 line. Therefore, there exists a unique interior solution:[13]

$$z_i^c = 1 - a_i^c = -\ln\left[\frac{F - \sqrt{F^2 - 4F}}{2F\rho}\right] \tag{5}$$

Lemma 1: Under collusion, $a_i^c + z_i^c = 1$, and there exist F_0 and F_1, where $F_0 < F_1$, such that: for $F < F_0$, all effort is allocated to productive efficiency ($a_i^c = 1$), and for $F > F_1$, all effort is allocated to concealment ($z_i^c = 1$). For $F \in (F_0, F_1)$, effort is allocated partially to each activity as determined by (5), thus $a_i^c, z_i^c \in (0,1)$

For $F < F_0$, productive efficiency is the relatively more important activity, thus firms allocate all effort to it. However, as fines go up, the relative importance of concealment increases, such that for $F \in (F_0; F_1)$, firms find it profitable to allocate effort among both productive efficiency and concealment: the higher the fine and/or the probability of inspection, the more biased the firms' effort allocation towards concealment. Finally, for $F > F_1$, concealment is the relatively more important activity, and thus firms allocate all effort to it.

The critical fine value F_0 is downward sloping in ρ: the higher is this probability, the higher is the relative importance of concealment with respect to productive efficiency, and therefore the lower is the critical fine value at which firms find it profitable to devote effort to concealment.[14]

If firm i decides to deviate, it slightly reduces price to get all demand ($q_i = 2$), and redetermines effort allocation considering that its rival follows the price agreement ($q_j = 0$).[15] Setting $q_i = 2$ in equations (2) and (4), Lemma 2 follows immediately:

13. To assure a solution in the set of rational numbers, I assume $F > \underline{F} = 4$. This assumption is purely numerical and does not restrict the results of the paper.

14. Actually, both of the critical fine values, F_0 and F_1, are downward sloping in ρ:

$$F_0 \begin{cases} \frac{1}{\rho(1-\rho)} & if\ \rho \leq \frac{1}{2} \\ 4 & if\ \rho > \frac{1}{2} \end{cases} \qquad F_1 = \frac{1}{\rho e^{-1}\left(1 - \rho e^{-1}\right)}$$

15. As discussed in the benchmark case, firm i can deviate with a slight reduction in price, an increase in effort devoted to productive efficiency, or both. In this way it gets all demand. However, while a price reduction does not alter i's productive efficiency, an increase of effort on productive efficiency does it. Thus, to maximize profits from deviation, the firm always reduces price. Whether it also increases effort devoted to productive efficiency depends on the antitrust parameters ρ and F

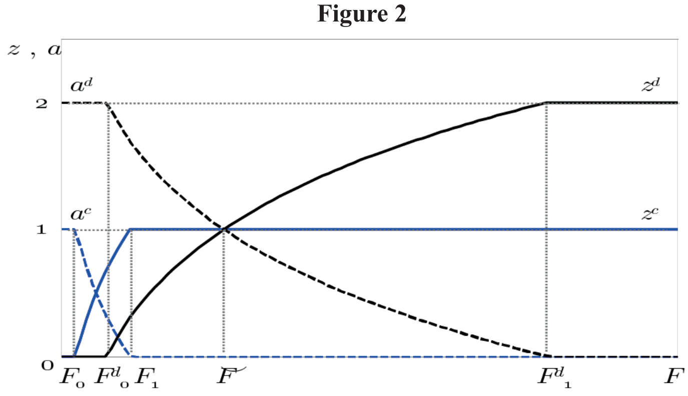
Lemma 2: (Assume firm i deviates) Under deviation $a_i^d + z_i^d = 2$, and there exist F_0^d and F_1^d, where $F_0 < F_0^d < F_1 < F_1^d$ such that: for $F_0 < F_0^d$, firm i allocates all effort to productive efficiency ($a_i^d = 2$), and for $F > F_1^d$, to concealment ($z_i^d = 2$). For $F \in (F_0^d; F_1^d)$, it allocates effort partially to each activity as determined by $R_i(z_j^c \mid q_i = 2)$, thus $a_i^d; z_i^d \in (0, 2)$.

Critical fine values F_0^d and F_1^d are downward sloping in ρ.[16]

Notice that firms allocate effort under deviation similarly than under collusion: all effort is allocated to productive efficiency when fines are low, but as fines go up it is reallocated from productive efficiency to concealment.

However, the critical fine value at which the firm finds it profitable to devote effort to concealment is higher under deviation, $F_0 < F_0^d$. In this the key issue is that under deviation there are produced more units of the good, and so that the opportunity cost of devoting effort to concealment is higher for a deviant. Indeed, for $F \in (F_0; F_0^d)$ while the firm that follows the price agreement finds it profitable to devote effort to concealment, the deviant does not; this still prefers to devote effort to productive efficiency. For the same logic, for $F \in (F_1; F_1^d)$ the deviant finds it profitable to devote some effort to productive efficiency, while the firm that follows the price agreement does not. Notice that for these fine values further reductions in the cartel probability of detection depend exclusively on the deviant. (Figure 2).

Figure 2



Firm's effort allocation under collusion (a^c, z^c) and under deviation (a^d, z^d) in terms of F, for $\rho < 1/2$. Effort devoted to productive efficiency in dashed lines and effort devoted to concealment in solid lines.

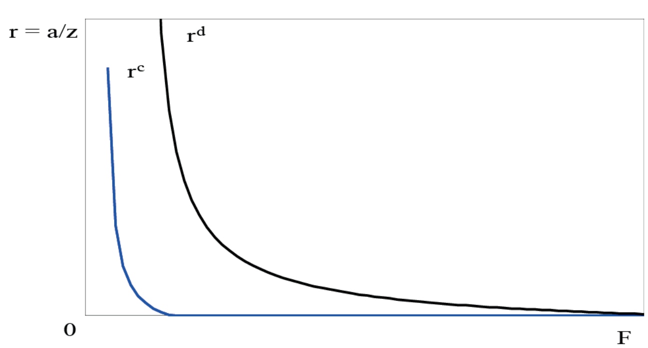
16. $F_0^d = \frac{4}{\rho(2-\rho)}$ and $F_1^d = \frac{4}{\rho e^{-2}(2-\rho e^{-2})}$.

Two final comments are in order. First, for $\hat{F} = \frac{2}{e^{-1}\rho(1-e^{-1}\rho)} \in \left(F_1, F_1^d\right)$, efforts devoted to concealment under collusion and under deviation are equal, $z_i^d = z_j^c = 1$. Hence, the corresponding probabilities of cartel detection are equal as well, $h^d = h^c$. For $F < \hat{F}$ there is more effort devoted to concealment under collusion, and for $F > \hat{F}$ this is so under deviation. Thus:

Corollary 1: There exists $\hat{F} \in (F_1; F_1^d)$ such that: $z_i^d > z_j^c$ if and only if $F > \hat{F}$. Hence, for $F > \hat{F}$, the cartel probability of detection following a deviation is lower as compared to when no deviation has taken place. Otherwise, the opposite holds.

The second comment refers to firm's productive efficiency under collusion and under deviation. Firm's relative productive efficiency following a deviation is higher as compared to when no deviation has taken place. To see this, define the ratio of effort devoted to productive efficiency over effort devoted to concealment: $r^c = a_i^c / z_i^c$, under collusion, and $r^d = a_i^d / z_i^d$, under deviation. These ratios lie in $\mathbb{R}_0^+$ and are decreasing and convex in F. Then, the higher the fine, the more biased the firm's effort allocation towards concealment. But, they are not equal: $r^d \geq r^c$, as under deviation more units of the good are produced and, thus, each unit of effort devoted to productive efficiency is more valued then that under collusion. Thus, the deviant's relative productive efficiency is higher than (or equal to) that of the firm that follows the price agreement. (Figure 3).

Figure 3



Firm's ratio of effort devoted to productive efficiency over effort devoted to concealment, in terms of F. r^c and r^d denote ratios under collusion and deviation, respectively.

V.1 Cartel's Sustainability

Effort on concealment does not affect the previous result that states that collusion is sustainable if and only if it is sustainable at the reservation price, $p^c = v$.[17] However, it affects the result that an increase in F or ρ always improves deterrence. To see this, recall ICC:

$$G \leq \frac{\delta}{1-\delta}\Pi^c$$

For the benchmark case (without effort on concealment), an increase in F or ρ reduces firm's profits through higher expected detection costs. This profit loss is independent of whether the firm follows the price agreement or deviates, as the cartel probability of detection is exogenous to the firm's effort allocation. Therefore, whereas a more severe antitrust policy reduces the RHS of ICC, it does not affect the LHS. As a direct consequence, the more severe the antitrust policy, the fewer the number of cartels.

Allowing for effort on concealment, an increase in F or ρ affects firm's profits in two ways: directly through higher expected detection costs, and indirectly through a distortion in the effort allocation. The magnitude of these two effects depends on whether the firm follows the price agreement or deviates (Lemmas 1 and 2). Thus in this context, both the profits from collusion and the gains from deviation depend on F and ρ. Whether a more severe antitrust policy improves deterrence depends on how it distorts the gains from deviation (in sign and magnitude) in comparison to how it distorts the expected profits from collusion.

In what follows, I analyze in detail the endogenous nature of the gains from deviation with respect to fines. On the basis of this analysis, the global implications of a fine increase on deterrence follow immediately.

Endogenous gains from deviation: assume firm i deviates. A fine increase distorts i's gains from deviation as follows:

$$\frac{\partial G}{\partial F} = \underbrace{\left(h^c - h^d\right)}_{Direct\ Effect} + \underbrace{\left(2\,\frac{\partial a_i^d}{\partial F} - F\,\frac{\partial h^d}{\partial F}\right) - \left(\frac{\partial a_j^c}{\partial F} - F\,\frac{\partial h^c}{\partial F}\right)}_{Indirect\ Effect} \quad (6)$$

17. Since the price under collusion does not depend on firms' effort allocation, whether firms devote effort on concealment (and how much effort they devote to it) does not distort the previous result that a price increase relaxes *ICC*.

Equivalently:

$$\frac{\partial G}{\partial F} = \underbrace{\left(h^c - h^d\right)}_{Direct\ Effect} + \underbrace{F\ \frac{\partial z_j^c}{\partial F}\left(\frac{\partial h^c}{\partial z_j^c} - \frac{\partial h^d}{\partial z_j^c}\right)}_{Indirect\ Effect} \tag{7}$$

The *direct effect* shows the effect of a fine increase on G from different probabilities of cartel detection under collusion and deviation. For $F < F_0$, this effect is zero: when fines are low, all effort is devoted to productive efficiency under both collusion and deviation; thus $h^c = h^d = h^B = 2\rho - \rho^2$. For $F \in (F_0 ; \hat{F})$, this effect is negative because there is more effort devoted to concealment under collusion and, consequently, the cartel probability of detection is lower then, $h^c < h^d$. However this argument is reversed for $F > \hat{F}$, and the direct effect is positive, $h^c > h^d$.

The *indirect* effect shows the effect of a fine increase on G from different reallocations of effort under collusion and under deviation. This is clearly stated in (6): following a fine increase, firms may find it convenient to reallocate effort from productive efficiency to concealment; this effort reallocation depends on whether the firm follows the price agreement or deviates (Lemmas 1 and 2).

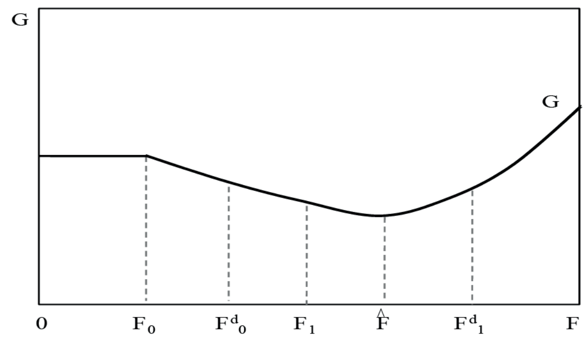
Taking into account forthcoming discussions in this paper, I find it more appropriate to analyze the *indirect effect* as stated in equation (7). The key element behind this formulation is that each firm determines its own, but not the rival's, effort allocation. This implies that, following a fine increase, each firm reallocates effort from productive efficiency to concealment so as to equate the (own) profit losses from a lower productive efficiency to the (own) profit gains from a lower probability of detection, given a rival that follows the price agreement. This effort reallocation has zero algebraical counterpart in profits (thus it is not seen in (7)). Yet, firms' profits alter, as the rival's reallocation of effort creates externalities. This is what (7) states.[18]

[18] Technically, since: (i) $\frac{\partial a_i}{\partial F} = -\frac{\partial z_i}{\partial F}$, and (ii) $\frac{\partial h}{\partial F} = \frac{\partial h}{\partial z_i}\ \frac{\partial z_i}{\partial F} + \frac{\partial h}{\partial z_j}\ \frac{\partial z_j}{\partial F}$, the indirect effect associated to deviation in (6) is:

$$2\ \frac{\partial a_i^d}{\partial F} - F\ \frac{\partial h^d}{\partial F} = -\frac{\partial z_i^d}{\partial F}\underbrace{\left(2 + F\ \frac{\partial h^d}{\partial z_i^d}\right)}_{0} - F\ \frac{\partial h^d}{\partial z_j^c}\ \frac{\partial z_j^c}{\partial F} = -F\ \frac{\partial h^d}{\partial z_j^c}\ \frac{\partial z_j^c}{\partial F}$$

(continued on next page)

Figure 4



With effort on concealment, for $F > F_0$, the gains from deviation are U-shaped in F, with a minimum at $\hat{F}$.

Note that under both collusion and deviation, the 'rival firm' follows the price agreement, thus the indirect effect highly depends on $\partial z_j^c / \partial F$.

For $F < F_0$, the firm that follows the price agreement finds fines too low to worry about. Thus, the indirect effect is zero. For $F > F_1$ the indirect effect is zero too, but for a different reason: for $F > F_1$, fines are so high that the firm has already allocated all its effort to concealment. What if $F \in (F_0, F_1)$? For intermediate fine values, a fine increase induces the firm to reallocate effort from productive efficiency to concealment, $(\partial z_j^c / \partial F) > 0$. As a whole, the indirect effect is negative, as $\partial h / \partial z_i$ is downward sloping in the total effort devoted to concealment, which is higher under collusion $(\partial h^d / \partial z_i^d) > (\partial h^c / \partial z_i^c)$.

Lemma 3: With effort on concealment:
(i) for $F < F_0$, the gains from deviation are independent of F, and are equal to those for the benchmark case, and
(ii) for $F > F_0$, the gains from deviation are U-shaped in F, with a minimum at $\hat{F}$.

18. (continued from last page) In the RHS, the first term is zero, as in brackets there is the equilibrium condition (3). The second term is the change in profits that the deviant obtains from a change in the rival's effort allocation. One can obtain the *indirect effect* associated to collusion analogously. In this way, the *indirect effect* can be written as:

$$F \frac{\partial z_j^c}{\partial F} \left(\frac{\partial h^c}{\partial z_j^c} - \frac{\partial h^d}{\partial z_j^c} \right)$$

which is what equation (7) states.

One final comment related to the negative slope of G with respect to F: for $F \in (F_0\,;\,F_0^d)$, a fine increase induces both firms to reallocate effort under collusion, whereas it does so to only one firm under deviation (the one that follows the price agreement). Therefore, the negative effect of a fine increase on profits is less mitigated under deviation. In other words, a fine increase reduces more profits from deviation. This effect gets stronger as ρ increases, i.e., the higher the ρ, the higher the expected detection costs perceived by the deviant.

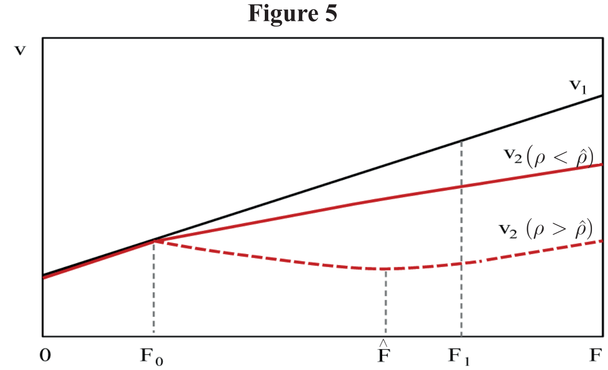
Corollary 2: For $F \in (F_0\,;\,F_0^d)$, the higher the ρ, the higher the reduction in G that follows from a fine increase.

Solving for υ in ICC, and given Lemma 3 and Corollary 2:

Proposition 3: (With effort on concealment) There exist $\upsilon_2 \in [\underline{\upsilon};\,\overline{\upsilon}]$, $\hat{\rho} \in [0;\,1]$ and $\tilde{F} \in (F_0\,;\hat{F})$, such that collusion is sustainable in all industries with $\upsilon > \upsilon_2$, and:
(i) for $\rho < \hat{\rho}$, υ_2 is upward sloping in F, thus a fine increase improves deterrence.
(ii) for $\rho > \hat{\rho}$, υ_2 inherits the U-shaped form of G with respect to F: for $F \notin (F_0, \tilde{F})$, υ_2 is upward sloping in F, and a fine increase improves deterrence. Otherwise, υ_2 is downward sloping in F, and a fine increase facilitates collusion.

While for low fine values ($F < F_0$) a fine increase reduces the present value of net future profits from collusion, for high fine values ($F > F_0$) the same policy also distorts the gains from deviation. As a result, there is a deterrence improvement following a fine increase for $F > F_0$, but not necessarily for higher values of the fine.

Figure 5



With effort on concealment, collusion is sustainable in all industries with $\upsilon > \upsilon_2$.

Points (i) and (ii) in Proposition 3 state how in this latter case the policy effect on deterrence depends on the values of F and ρ. Briefly, there are two possible scenarios: one for $F \in (F_0, \hat{F})$ and another for $F > \hat{F}$. For $F \in (F_0, \hat{F})$ a fine increase reduces the present value of net future profits from collusion and also the gains from deviation. The magnitude of the latter effect depends on ρ, and so also does so the final impact of the policy on deterrence. Particularly, for $\rho > \hat{\rho}$ the reduction in the gains from deviation is higher than that observed for the present value of net future profits from collusion; and hence collusion is facilitated. The opposite holds for $\rho < \hat{\rho}$, and a deterrence improvement follows a fine increase. Alternatively, suppose that $F > \hat{F}$: a fine increase reduces the present value of net future profits from collusion and increases the gains from deviation. Both effects work together to improve deterrence.

Let me stress the perverse effects that Proposition 3 states for intermediate values of the fine: when the probability of inspection is high ($\rho > \hat{\rho}$), the threshold price v_2 inherits the U-shaped form of G with respect to F. In this case, the deviant is severely affected by a fine increase; so severely that collusion is facilitated.

Finally, it is important to mention that the threshold price v_2 lies below that for the benchmark case, $v_2 \leq v_1$. By a revealed preference argument, if it were not the case, firms would not have chosen to devote effort to concealment in the first place.

Corollary 3: For $F = F_0$, $v_2 = v_1$, and for $F > F_0$, $v_2 < v_1$.

VI. Social Welfare

In this economy demand is perfectly inelastic, thus welfare depends exclusively on whether production is efficient. In other words, collusion creates an efficiency loss if and only if the good is inefficiently produced as compared to when competition takes place. Under competition only one firm serves demand, devoting as much effort to productive efficiency as output produced (the rival does not produce, neither devotes effort to production). Thus, production is efficient if production is efficiently allocated among firms (i.e., if only one firm serves demand)[19] and if each firm is technologically

19. Considering total profits, the net contribution of total effort devoted to productive efficiency is higher when only one firm serves demand. (continued on next page)

efficient (i.e., if each firm devotes to productive efficiency as much effort as output privately produced). Under collusion the former condition never holds, as both firms produce. Whether the latter one holds depends on the antitrust policy: when fines are low firms are technologically efficient, but as fines go up their productive efficiency goes down.

In this setup, a fine increase can have two welfare effects. On the one side, it can increase welfare through fewer cartels. But, on the other side, it can reduce welfare through more inefficient surviving ones.

Let W^* and W^c denote the social welfare in an industry under competition and under collusion, respectively. Industries are uniformly distributed in $[\underline{v}\,;\,\overline{v}]$, thus total welfare in this economy is:

$$W = \int_{\underline{v}}^{v_2} W^* \ \frac{v}{(\overline{v}-\underline{v})}\ dv + \int_{v_2}^{\overline{v}} W^c \ \frac{v}{(\overline{v}-\underline{v})}\ dv$$

Within industries, social welfare is defined as the addition of the consumer surplus (CS) and the producer surplus ($\Pi = \Pi_1 + \Pi_2$). Under collusion: $W^c = \Pi^c + R$, as the consumer surplus is equal to the expected revenues from fines ($CS^c = R$). Under competition: $W^* = CS^*$, as firms' profits are zero.[20] Therefore:

$$W = \int_{\underline{v}}^{v_2} CS^* \ \frac{v}{(\overline{v}-\underline{v})}\ dv + \int_{v_2}^{\overline{v}} (\Pi^c + R)\ \frac{v}{(\overline{v}-\underline{v})}\ dv$$

19.(continued from last page) To see this, assume $F < F_0$. For low values of the fine, total effort devoted to productive efficiency is 2 under both competition and collusion, and there is no effort on concealment under collusion. However, while under competition only one firm serves demand, under collusion demand is split in halves. In this context, when firms compete the contribution of effort to social welfare is 4 ($a_i = q_i = 2$ and $a_j = q_j = 0$, $i \neq j \Rightarrow a_i q_i + a_j q_j = 2\times2 = 4$). Under collusion, instead, the contribution of effort to social welfare is 2 ($a_i^c = q_i^c = 1$, $i = 1; 2 \Rightarrow 2(a_i^c\, q_i^c) = 2$). Regarding effort costs, under competition these are 2 ($a_i^2/2 + a_j^2/2 = 4/2 + 0/2 = 2$), and under collusion 1 ($2(a_i^c)^2/2 = 2\times1/2 = 1$)
Consequently, the net contribution of total effort devoted to productive efficiency under competition (2 = 4 – 2) is higher than that under deviation (1 = 2 – 1).
For higher values of the fine, there is less effort devoted to productive efficiency under collusion, and thus the inefficiencies associated to production are higher then.

20. In the analysis I consider competitive profits from the one-shot Nash equilibrium in pure strategies, which yields zero profits to each firm. Considering the equilibria in mixed-strategies would imply positive profits for one firm and, thus, industry profits higher than zero. For social welfare purposes, the distribution of profits between firms in an industry is irrelevant. For details on the one-shot Nash equilibria, please see the Appendix.

Taking partial derivative of W with respect to F:[21]

$$\frac{\partial W}{\partial F} = \frac{1}{(\overline{v} - \underline{v})} \left[(CS^* (v_2) - \Pi^c (v_2) - R\ ) \frac{\partial v_2}{\partial F} \ - 2\ (\overline{v} - v_2) \frac{\partial z_i^c}{\partial F} \right] \qquad (8)$$

Inside brackets, the first term denotes the welfare gains/losses derived from a change in the number of competitive industries. The sign of this term depends on whether the fine increase improves deterrence or not (i.e., $\partial v_2/\partial F>0$). Indeed, the term $CS^* (v_2)–\Pi^c (v_2)–R$ is strictly positive, and shows the inefficiencies created from an inefficient allocation of production under collusion (i.e., inefficiencies from having two firms producing, instead of one). Thus, if there are fewer cartels following a fine increase there is a welfare gain. If, instead, there are more cartels following a fine increase there is a welfare loss.

The second term in brackets $\left(2\ (\overline{v} - v_2)\ \frac{\partial z_i^c}{\partial F}\right)$ represents the welfare losses derived from less efficient cartels. Since higher fines can induce firms to reallocate effort from productive efficiency to concealment this term is non-negative.

Note that for $F \notin (F_0, F_1)$, the second term in (8) is zero, as a fine increase does not distort the effort allocation under collusion (Lemma 1). Thus, a fine increase improves total welfare if and only if it improves deterrence (i.e., iff the first term in (8) is positive). This result is standard in models of collusion. However, for $F \in (F_0 , F_1)$, the second term in (8) is negative, as higher fines induce cartel firms to increase effort on concealment (Lemma 1). In this case, the final effect of a fine increase on total welfare depends on the antitrust parameters F and ρ. This result is a novelty in models of collusion.

From this discussion and Proposition 3, Proposition 4 follows immediately:

Proposition 4: There exists $\check{\rho} \in [0; \hat{\rho}]$, such that,
(i) for $\rho < \check{\rho}$, W is upward sloping in F, thus a fine increase improves total welfare.
(ii) for $\rho > \check{\rho}$, W inherits the U-shaped form of v_2 with respect to F: for $F \notin (F_0, F_1)$, W is upward sloping in F, and a fine increase improves total welfare. Otherwise, W is downward sloping in F, and a fine increase reduces total welfare.

Proposition 4 reinforces the perverse effects of intermediate fine levels: when fines are not high enough, a fine increase may be eventually

21. When taking the derivative, keep in mind that $\frac{\partial(\Pi^c+R)}{\partial F} = -2\ \frac{\partial z_i^c}{\partial F}$, and $\frac{\partial CS^*}{\partial F} = 0$.

detrimental for social welfare despite of its effectiveness to deter cartels. The latter case arises when the welfare gains from fewer cartels are not high enough to compensate society for the welfare losses associated to more inefficient surviving cartels. This result strongly favors setting very large fines such that no cartel survives.

Note that this result is in line with standard literature on collusion, which favors the use of very high fines to achieve deterrence[22]. However, this paper suggests something else: fines and inspections are not exchangeable instruments anymore. Indeed, increasing one of these instruments may have negative consequences on the other instrument's impact on deterrence, firm's productive efficiency and, ultimately, social welfare. Thus, the general recommendation is that the antitrust policy should be carefully designed, pushing crime detection too much with a single instrument may be detrimental for deterrence and social welfare.

VII. Leniency Programs

Consider a leniency program that offers a fine amnesty to the first cartel firm to come forward with hard evidence of the cartel. Leniency applications are public, hence any leniency application is observed by rivals and the cartel breaks. This implies that there are no leniency applications under collusion.[23] However, this may not be so under deviation: for a deviant the introduction of a leniency program implies two strategies to choose from: (a) to deviate and to apply for leniency, and (b) to deviate without leniency application. On this decision, the firm compares its grains from deviation with a leniency application with those without it.

In the benchmark case, when there is no effort on concealment, the deviant makes the decision easily: it applies for leniency if and only if the fine payed after reporting is lower than the expected fine to be paid without it. If we denote with $\theta \in [0;\, 1]$ the amnesty parameter (such that the reporter only pays θF if its leniency report ends in a sentence for collusion), the above decision rule implies that there is a leniency application if and only if θ is lower than the cartel probability of detection: $\theta < \hat{\theta}^B = \rho\,(2-\rho)$.

However, when we introduce the possibility to devote effort on concealment a deviant has an additional element to think about: how a leniency

22. Where it is argued that high fines achieve deterrence at a lower cost than many inspections.

23. Indeed, a leniency application is a betrayal to the price agreement and so leads to cartel breakdown immediately, regardless of whether the application finally ends in a sentence for collusion.

application effects its incentives to conceal evidence. As a matter of fact, a deviant that applies for leniency has no incentives to devote effort on concealment, as it will pay θF regardless of its effort allocation. Thus, assuming firm i deviates, alternative (a) implies maximum productive efficiency and deviation with leniency application, which yields profits:[24]

$$\Pi_i^l = 2\ (v-\beta) + \ 2 - \theta F$$

And alternative (b) implies an effort allocation as stated in Lemma 2 without leniency application. In this case, profits from deviation are:

$$\Pi_i^d = 2\ (v-\beta) + 2\ \ a_i^d - 2 - Fh^{\,d}$$

There is a leniency application if $\Pi_i^l > \Pi_i^d$. Equivalently:[25]

$$\theta \ < \ \hat{\theta} \ = \ h^d \ + \ \frac{2\left(2-a_i^d\right)}{F} \in \left[0\ ,\ \hat{\theta}^B\right]$$

Intuitively, if the deviant devotes effort to concealment, it is because such an effort allocation allows it to achieve the highest expected profits. Hence, to induce the deviant to collect cartel evidence and apply for leniency, the AA should offer a fine amnesty that more than compensates the firm's profit losses associated to a different effort allocation.

Proposition 5 summarizes:

Proposition 5: There exist $\hat{\theta}^B$, $\hat{\theta} \in (0; 1)$, where $\hat{\theta} < \hat{\theta}^B$, such that a leniency program improves deterrence if and only if it sets an amnesty parameter:
(i) Without effort on concealment: $\theta < \hat{\theta}^B$.
(ii) With effort on concealment: $\theta < \hat{\theta}$.

Two comments to conclude. First, deterrence is maximized at $\theta = 0$, regardless of whether we allow for effort on concealment. Thus, the analysis strongly favors full amnesties. Second, with effort on concealment, a

24. Applying for leniency, the problem of a deviant is:

$$\max_{a_i^l} : \ \Pi_i = 2\left[v - (\beta - a_i)\right] - \frac{a_i^2}{2} - \theta F$$

where $\frac{\partial \Pi_i}{\partial a} = a_i - 2$. Thus: $\left(a_i^l, z_i^l\right) = (2, 0)$, and $\Pi\,_i^{\,l} = 2\,(v-\beta) + 2 - \theta F$.

25. With a little bit of algebra, one can easily prove that $\hat{\theta}$ is downward sloping in F and $\hat{\theta} \in (\rho(e^{-2} + e^{-2} - \rho e^{-3}),\ \rho(2-\rho))$.

successful leniency program implies a welfare gain beyond deterrence, as reporting implies full productive efficiency for the firm that deviates. This 'efficiency' gain from leniency programs is a novelty in models of leniency in games of collusion.

VIII. Conclusion

In this paper I develop a model in which cartel firms devote effort to productive efficiency and to concealment: the former reduces marginal costs from production and the latter reduces the probability of detection. Effort is costly and limited, thus firms have to decide on how to allocate it among productive efficiency and concealment.

When fines are low, productive efficiency is relatively more important than concealment, thus firms allocate all effort to productive efficiency. But, as fines go up (or if inspections become more likely), the relative importance of concealment goes up, and firms find it profitable to reallocate effort from productive efficiency to concealment. In this context, a fine increase can have two opposite effects on welfare, while it can improve welfare through fewer cartels, it can also reduce it through more inefficient surviving ones.

Two results stand out. First, firm's possibility to reduce the likelihood of cartel detection makes collusion sustainable in industries where it wouldn't be otherwise. This result is intuitive: since concealment is costly if firms devote effort to it, it must be because this facilitates collusion.

The second result states perverse effects from the antitrust policy: a fine increase can reduce social welfare by inducing surviving cartels to be highly inefficient, or by facilitating collusion, or both. For the second effect, the trigger element is that the effort allocation under deviation is biased towards productive efficiency as compared to that under collusion (as in the former case there are produced more units of the good). For low/intermediate fine values, this implies that the cartel probability of detection is higher under deviation. In this context, a fine increase may relatively affect the deviant so negatively that eventually it induces cartel sustainability rather than deviation.

On the basis of these results the analysis favors setting very high fines such that no cartel survives. However, in practice this is not always credible or possible to implement. In this context, the main message from the paper is that the antitrust policy has to be carefully designed, such that combining both instruments, fines and inspections, conveniently: since deterrence is non-monotonic in the level of any of these instruments individually considered, pushing crime detection too much with a single instrument can lead to undesirable outcomes.

This result leads to a number of interesting observations, some of which may be lines for future work. For instance, what if fines are endogenous to some measure of the crime damage (e.g., to the price mark-up achieved under collusion)? This new element in the model may lead to imperfect collusion, which would distort the relative importance of productive efficiency with respect to concealment. In this context, it becomes crucial the analysis of the implications of endogenous fines on the non-monotonicity observed between deterrence and fines, firms' productive efficiency, and welfare. Other interesting line for future work is related to the modelling assumption on inspections. In this model, inspections are firm specific, but what if inspections are industry specific? Industry-specific inspections implies that each firm can not reduce the probability of detection by itself. In this context, how does the critical fine value at which firms find it convenient to substitute effort from production to concealment change? We should expect this critical value to be greater, as neither firm will devote effort to concealment without being sure that its rival has strong incentives to do so as well. These types of questions lead one to think about the importance of establishing the optimal detection policy under different frameworks; a clear challenge for future work on the subject.

Finally, in Section 7 I show that leniency programs can improve welfare beyond a deterrence improvement. Since leniency programs demand full collaboration from the reporting firm, a leniency application implies no effort on concealment. Thus, by inducing reporting, leniency programs improve deterrence and assure full productive efficiency from the deviant. This result is restricted to the case where deviation takes place, but, nevertheless, is novel in the literature.

IX. Appendix

Proposition 1: Equilibrium in pure strategies

Let's first prove that there is no NE with $a_i = a_j$.

Assume $p_i < p_j$. Since i has the lowest price, it serves all demand. But, this implies that one of the firms is not optimizing. Indeed, firm i serving demand and both firms optimizing implies: $a_i = q_i = 2$ and $a_j = q_j = 0$, which contradicts the initial statement.

Assume $p_i = p_j = p$, then firms split demand in halves, $q_i = q_j = 1$. Optimization implies $a_i = a_j = 1$, and profits $\Pi_i = p - (\beta - 1) - 1/2$, i=1,2. Assume firm i slightly reduces its price: it gets all demand, $q_i = 2$, and makes effort $a_i = 2$. In this context, i's profits are $\Pi_i = [\, p_i - \epsilon - (\beta - 2)]2 - 2$, $\epsilon > 0$, greater than before for low ϵ . As there is a profitable deviation to the candidate outcome, this can not be a NE.

Hence, if there exists an equilibrium, it must be at $a_i \neq a_j$.

Let's prove that there is no NE with $a_i \neq a_j$ and $p_i \neq p_j$.

Assume $p_i < p_j$, then firm i serves all demand, $q_i = 2$ and $q_j = 0$. The optimality condition implies $a_i = 2$ and $a_j = 0$. Notice that firm i can increase profits with a slight increase in its price. In fact, i's most profitable deviation is to charge $p_i = p_j$. But, then, firm j would find it profitable to reduce its price below p_i. This process repeats itself anytime $p_i \neq p_j$. The outcome $p_i \neq p_j$ with $a_i \neq a_j$ is not stable and, therefore, can not be a NE.

Let's prove that there is no NE with $a_i \neq a_j$ and $p_i = p_j \neq p^* = \beta - 1$.

Assume $p_i = p_j > p^* = \beta - 1$ and $a_i < a_j$, then firm i serves all demand, $q_i = 2$ and $q_j = 0$. The optimality condition implies $a_i = 2$ and $a_j = 0$. Since i's profits are positive for $p_i > p^* = \beta - 1$, nothing prevents j to reduce its price and get all demand. But this is a contradiction with the initial statement of equal prices.

Assume $p_i = p_j < p^* = \beta - 1$ and $a_i > a_j$. Firm i obtains negative profits for $p_i < p^* = \beta - 1$, so it won't charge a price below p^*. But this contradicts the initial statement.

Finally, let's prove that $a_i \neq a_j$ with $p_i = p_j = p^* = \beta - 1$ is a NE.

Assume $a_i > a_j$, then firm i serves all demand and obtains profits $\Pi_i = (p^* - \beta + 2)2 - 2 = 0$. Since j does not produce, neither makes effort, it obtains zero profits too. As both firms are maximizing profits: $a_i = q_i = 2$ and $a_j = q_j = 0$. If i reduces its price, it obtains negative profits. If, instead, i increases its price, j charges p^* and serves all demand. In this case, we are back to the initial statement with one firm serving demand and both firms making zero profits. As there is no profitable deviation from the candidate outcome, this is a NE.

Mixed-strategy Equilibria

Each firm's payoff is given by:

$$\Pi_i = (p_i - c_i)q_i - a_2^i/2$$

Let $\underline{p}_i$ and $\overline{p}_i$ denote the infimum and supremum, respectively, of the support of firm i's strategy.

Assume $a_i > a_j$, then $c_i < c_j = c$.

First, note that $\underline{p}_i = \underline{p}_j \geq c$. This follows from the facts that $p_i \geq c_i$, and that profits are strictly increasing in the firm's price whenever it is the lowest.

Then observe that firm i obtains zero profits if $\underline{p}_i > \underline{p}_j$. The same is true if $\underline{p}_i = \underline{p}_j < \overline{p}_i = \overline{p}_j = \overline{p}$ and either no one plays $\overline{p}$ with positive probability or if some firm does (there is at most one), it is firm j. It follows that at least one firm earns zero profits in any mixed-strategy equilibrium. As $c_i < c$, this is not firm i, which can always guarantee positive profits by pricing below c; so $\overline{p}_i < \overline{p}_j$. Further more, $\overline{p}_i = c$, since otherwise firm j could obtain positive profits by undercutting.

Consequently, if $a_i > a_j$, such that $c_i < c_j = c$, there exist mixed-strategy equilibria in which firm i charges $p_i = c$ with probability 1 and firm j mixes price over the range $[c,\ p')$ for any p' $\in (c,\ v]$, according to some strategy $F_j(p) = Pr\ (p_j \leq p)$ that satisfies $F_j(p) \geq\ (p - c)/(p - \beta + a_i)$, so as to deter firm i from raising its price. Given firm j's strategy, firm i's profits from deviating and charging a price $p > c = \beta$ is $[1 - F_j(p)]\ (p - \beta + a_i)\ 2 - a_2^i/2 \leq (c - \beta + a_i)\ 2 - a_2^i/2$

Given above strategies, firms' optimal effort levels are $a_i = 2$ and $a_j = 0$, being profits $\Pi_i = 2$ and $\Pi_j = 0$.

Note that while outputs and costs of the set of mixed-strategy equilibria are identical to those of the pure-strategy equilibrium, profits are not. Note further that while the pure-strategy equilibrium involves firm j playing a weakly dominated strategy, in any mixed-strategy equilibrium firm j plays an undominated strategy almost surely.

Now, assume $a_i = a_j = a$, then $c_i = c_j = \beta - a$, and min $\{p_i , p_j\} = \beta - a$, since otherwise either firm could obtain positive profits by undercutting. It follows that there does not exist a mixed-strategy equilibrium in this case.

Proposition 2: In main text.

Lemma 1: Recalling equations (2) and (3), firm *i*'s optimal behavior, $i = 1{,}2$ is given by:

$$a_i + z_i = q_i$$

$$q_i = F\rho e^{-z_i} \left(1 - \rho e^{-z_j}\right)$$

Under collusion, firms split the market in halves, $q_i^c = q_j^c = 1$. Thus the former equation is: $a_i^c + z_i^c = 1$. This is the first statement in Lemma 1.

For the second statement in Lemma 1 note that the latter equation can be reduced to:

$$F\rho\, e^{-z_i^c} = 1 + F\rho^2 e^{-z_i^c} e^{-z_j^c}$$

for firm i, and:

$$F\rho\, e^{-z_j^c} = 1 + F\rho^2 e^{-z_i^c} e^{-z_j^c}$$

for firm j.

The RHSs of equations (9) and (10) are equal, so that the LHSs are equal too, which implies: $z_i^c = z_j^c$. Particularly:

$$z_i^c = z_j^c = -\ln\left[\frac{F - \sqrt{F^2 - 4F}}{2F\rho}\right]$$

With a little bit of algebra, the reader can proof that $z_i^c \in (0,\ 1)$ for $F \in (F_0,\ F_1)$, where:

$$F_0 = \begin{cases} \frac{1}{\rho(1-\rho)} & if\ \rho \leq \frac{1}{2} \\ 4 & if\ \rho > \frac{1}{2} \end{cases} \qquad F_1 = \frac{1}{\rho e^{-1}\left(1 - \rho e^{-1}\right)}$$

Remember that $z_i^c \geq 0$ implies that $F \geq 4$; this restriction over the value of F affects the minimum value that F_0 can take.

Lemma 2: Assume i deviates: i has two units of effort to allocate among production and concealment (condition 2).

Setting $q_i^d = 2$ and $z_j = z_j^c$ in equation (3): $F\rho e^{-z_i} = 2 + F\rho^2 e^{-z_i} e^{-z_j^c}$ Solving for z_i, there is a unique solution at:

$$z_i^d = -\ln\left(\frac{2}{F\rho\left(1 - \rho e^{-z_j^c}\right)}\right)$$

With a little bit of algebra, the reader can proof that $z_i^d \in (0,2)$, for $F \in (F_0^d, F_1^d)$, where: $F_0^d = 4/[\rho(2-\rho)]$ and $F_1^d = 4/[\rho e^{-2}(2-\rho e^{-2})]$

Lemma 3: Holds from considering Lemmas 1 and 2 and Corollary 1 in equation (7). See main text.

Proposition 3: By definition, v_2 follows from setting $p^c = v$ in ICC and solving for v.

$$v > v_2 = \begin{cases} \beta + \frac{\delta F\rho(2-\rho)+\frac{1}{2}(3-4\delta)}{2\delta-1} & if{:}F < F_0 \\ \beta + \frac{5-4\delta+\delta\left(F-\sqrt{F^2-4F}\right)-2\ln(A^c)-\rho(1-\delta)\left(F+\sqrt{F^2-4F}\right)}{2(2\delta-1)} & if{:}F_0 < F < F_0^d \\ \beta + \frac{1+\delta\left(F-\sqrt{F^2-4F}\right)-2\ln(A^c)+4\ln\left(A^d\right)(1-\delta)}{2(2\delta-1)} & if{:}F_0^d < F < F_1 \\ \beta + \frac{\frac{1}{2}+F\rho e^{-1}\left(1+\delta-\rho e^{-1}\right)+2(1-\delta)\ln\left(\hat{A}^d\right)}{2\delta-1} & if{:}\ F_1 < F < F_1^d \\ \beta + \frac{\left(-\frac{3}{2}\right)+F\rho e^{-1}\left(1-e^{-1}\right)(1+\delta)-F\rho^2 e^{-2}\left(1+e^{-1}\delta\right)}{2\delta-1} & if{:}F > F_1^d \end{cases}$$

where $A^d = \frac{4}{\rho\left(F+\sqrt{F^2-4F}\right)}$ and $\hat{A}^d = \frac{2}{F\rho(1-\rho e^{-1})}$.

The partial derivative of v_2 with respect to F is positive; except when $F \in (F_0, \widetilde{F})$; $\widetilde{F} < \hat{F}$, and $\rho > \hat{\rho}$, case in which v_2 inherits the U-shaped form of G with respect to F (See Lemma 3).

Proposition 4: Holds from considering the results described in Lemma1 and Proposition 3 in equation (8). See main text.

Proposition 5: In main text.

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