Economics Bulletin

Volume 30, Issue 3

Antitrust enforcement with price-dependent fines and detection probabilities

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Abstract

We analyze the effectiveness of antitrust enforcement in repeated oligopoly models in which both fines and detection probabilities depend on the cartel price. Such fines reflect actual guidelines. Inspections based on monitoring of market prices imply endogenous detection probabilities. Without monitoring, fines that are either fixed or proportional to illegal gains cannot eradicate the monopoly price, but more-than-proportional fines can. Policy design with inspections based on price-monitoring implies that the profit-maximizing cartel price always lies below the monopoly price independently of the fine structure. These results offer partial support for the current practice of monitoring and more-than-proportional fines.

We would like to thank an anonymous referee and the editor for suggestions which were very helpful in improving the present paper.
Citation: Harold Houba and Evgenia Motchenkova and Quan Wen, (2010) ''Antitrust enforcement with price-dependent fines and detection probabilities'', *Economics Bulletin*, Vol. 30 no.3 pp. 2017-2027.
Submitted: May 11 2010. **Published:** July 30, 2010.

1. Introduction

The practice of antitrust enforcement suggests that price-fixing remains a problem despite enforcement efforts. It is therefore important to understand when cartels form and how they behave. Such understanding provides the basis for detecting cartels and developing policies to deter their formation. Though there is a vast theoretical literature on cartel formation, it mostly concentrates on the impact of antitrust enforcement on sustainability of collusion, while an important dimension of cartel pricing behavior has received less attention. Since, price-fixing is illegal, firms want to raise prices but not suspicions that they collude. If high prices may make the antitrust authorities (AA) suspicious that a cartel is operating, one would expect this to have implications for how the cartel sets its price. Moreover, when penalties are also price dependent, firms would manage prices in such a way that benefits of collusive pricing and costs of paying higher penalties are balanced. These effects have an impact on the joint profit-maximizing price set by the cartel, which is expected to be below the simple monopoly price.

This note continues an inquiry started by Harrington (2005) into the exploration of cartel pricing in the presence of detection considerations. We analyze how the decision to form a cartel and the profit-maximizing cartel price respond to various instruments of antitrust policy in a repeated oligopoly model. In this note, the joint profit-maximizing price set is characterized under various specifications of the detection process. Our main contribution is to explore how various designs of antitrust policy impact that price. Some results confirm existing intuition about the influence of antitrust policy, others yield new intuition. Under constant detection probability, we confirm the long-run neutrality result with respect to fixed fines reported in Harrington (2005) meaning that under fixed fines antitrust enforcement is not effective in reducing cartel price below the simple monopoly price. We also extend this result to the case where fines are directly proportional to illegal profits. We investigate the robustness of this result in a repeated oligopoly model with non-constant price-dependent detection probability and show that it is sensitive to the assumptions made in Harrington (2005).

Another intriguing result is related to the analysis of the design of the currently employed US and EU penalty schemes in the framework of the infinitely repeated oligopoly model provided in this paper. Under constant detection probabilities, we consider how effective the widely analyzed proportional fines are and can the design be improved by introducing non-linear fines. We come to a novel conclusion that contrary to fines that are simply proportional to illegal profits, a more-than-proportional functional form can lead to lower prices compared to the situation when antitrust law is absent. This offers partial support for current practice in the US and EU.

A number of papers have investigated optimal cartel pricing under the constraint of possible detection in a static setting. Block et al. (1981) consider a static oligopoly model in which the probability of detection depends on the price-cost margin and the penalty is a multiple of above-normal profits. They show that the optimal cartel price is below the simple monopoly price and that the cartel price is decreasing in the penalty multiple and the level of enforcement expenditures. Several papers consider a dynamic setting. Cyrenne (1999) modifies Green and Porter (1984) by assuming that a price war and the subsequent increase of price after the war result in detection for sure and a fixed fine. Motta and Polo (2003), Rey (2003), Spagnolo (2004), Chen and Rey (2007) consider the effects of leniency programs on the incentives to collude when the probability of detection and penalties are both fixed. Though considering collusive behavior in a dynamic setting with antitrust laws, these papers exclude the important sources of dynamics, the probability of detection and penalties that are sensitive to firms' pricing behavior. A number of recent papers by Harrington (2004, 2005, 2008) extend this literature by incorporating endogenous fines and price dependent detection probabilities.

The current paper is most closely related to Harrington (2005), where the dynamic behavior of a price-fixing cartel is explored when it is concerned about creating suspicions that a cartel has formed. In such environment, cartels also need to manage suspicions. It is modeled as if the cartel keeps in mind an endogenous detection probability. This probability is modeled as a function of the cartel's price, where price is a continuous variable that can take values between Nash price and monopoly price. The focus of the Harrington (2005) is on an endogenous antitrust policy and its impact on the joint profit-maximizing cartel price. In this way both cartel formation and cartel's pricing decisions are endogenized. This paper concludes that the cartel's steady-state price is decreasing in the damage multiple and the probability of detection. In addition, it is independent of the level of fixed fines. There are some important differences between our paper and Harrington (2005). In terms of modeling he considers the dynamic process of price-fixing, i.e., the process of raising the price gradually to the agreed cartel price, during which the detection probability depends on the magnitude of price changes, whereas our paper focuses on the cartel pricing in steady state, in which the detection probability is either constant or an increasing function of the current price. Next, the calculation of damages caused by price-fixing is retroactive in the above mentioned paper, while in our paper only current period price-fixing is prosecuted. Although we use a different modeling approach, we confirm the results obtained in Harrington (2005), clarify his long-run neutrality result with respect to fixed fines, extend it to the case when fines are directly proportional to illegal profits, and show superiority of more-than-proportional fines.

The paper is organized as follows. Sections 2 and 3 describe the model. In section 4 the solution of infinitely repeated oligopoly game is analyzed. Section 5 discusses main results and policy implications. The appendix contains all the proofs.

2. The Model

There are $n \geq 2$ firms that compete in every of infinitely many periods in the presence of antitrust enforcement. In each period, the firms choose their prices.[1] Therefore, we adopt an infinitely-repeated oligopoly game with a common discount factor $\delta \in (0, 1)$ per period. The AA investigates the market outcome at the end of every period with certain probability and, upon being caught, violators will be fined. We focus on trigger strategies to sustain cartel prices, in which deviations in price setting lead to the competitive equilibrium price in every period thereafter.

Price competition in each period is described by a symmetric Bertrand model with the n firms, and either homogenous or heterogeneous products. Let $\pi(p_1, \ldots, p_n)$ be an individual firm's per-period profit for prices $p_1, \ldots, p_n \in \mathbb{R}_+$. Since we mostly deal with symmetric outcomes, we denote $\pi(p, \ldots, p) \equiv \pi(p)$ for simplicity. Denote the static Nash equilibrium price and the maximal collusive price by p^N and p^M, respectively. In every period, the firms decide whether to collude and if so, to what degree. In other words, all firms choose a price p. One key element in analyzing cartel stability is a firm's profit from unilateral deviation against the cartel when all the other firms set their prices at p, denoted as $\pi^{opt}(p) = \sup_{p'} \pi(p', p, \ldots, p)$. As in Harrington (2004, 2005), we assume that $\pi(p)$ is continuous and strictly increasing in $p \in [p^N, p^M]$, $\pi^{opt}(p)$ is continuous, strictly increasing, and $0 < \pi(p) < \pi^{opt}(p) \leq n\pi(p)$ for $p \in \left(p^N, p^M\right]$. To simplify the exposition, we normalize the static model so that $\pi(p^N) = 0$ and from now on interpret $\pi(p)$ as the net profit above the competitive profit $\pi\left(p^N\right)$.

The market outcome is investigated at the end of every period with certain probability and the antitrust policy is implemented. Upon being caught, violators will be fined.

[1] This decision also endogenizes the decision of cartel formation. We adapt the economic definition of a cartel that regards pricing above the competitive (Nash) equilibrium price as cartel activity. The cartel is formed whenever the price set is above the Nash equilibrium price.

1. Given $p \in (p^N, p^M]$, the firms will be found guilty of collusion with probability $\beta(p) \in [0, 1)$. We assume that $\beta(p) \geq 0$ is a non-decreasing differentiable function on $p \in (p^N, p^M]$ such that $\lim_{\varepsilon \to 0^+} \beta(p^N + \varepsilon) = \underline{\beta} \geq 0$, and $\beta(p^N) = 0$.

2. If the firms are found guilty of sustaining cartel price $p \in (p^N, p^M]$, every firm will have to pay the one-time fine $F(p) = k(p)\pi(p)$, where $k(p) \geq 0$ is a non-decreasing differentiable function on $p \in (p^N, p^M]$ such that $\lim_{\varepsilon \to 0^+} k(p^N + \varepsilon) = \underline{k} \geq 0$, and $k(p^N) = 0$.

The function $\beta(\cdot)$ reflects that a higher cartel price might invoke more attention about cartel abuse and make detection more likely, due to e.g. active monitoring policy by the AA. Any cartel will take this negative impact of its price into account when deciding upon the price. The penalty function, which is given by $F(p) = k(p)\pi(p)$ reflects that in practice penalties are related to the illegal profits from price-fixing (see e.g. OECD (2002), EC (2006), or DOJ (2009)). Note that $\beta(p)$ and $k(p)$ depend on the price in the current period only. As in Rey (2003), only current period's misconduct is prosecuted. The benchmark case of no regulation is captured by $\beta(p)k(p) = 0$ for all $p \in [p^N, p^M]$. To avoid triviality of the model we assume $\beta(p)k(p) < 1$ for all $p \in [p^N, p^M]$. We also assume that price-deviating firms are not prosecuted, as in e.g. Motta and Polo (2003).[2]

The equilibrium concept we use is subgame perfect equilibrium and equilibrium conditions are verified by applying the one-stage deviation principle, see e.g., Fudenberg and Tirole (1991). The variable of interest in our study is the joint profit-maximizing cartel price. The first-best outcome without collusion would coincide with the competitive Nash equilibrium price $p = p^N$.

3. Cartels and Antitrust Enforcement

Sentencing guidelines in the US and the EU specify fines as multiples of illegal profits (or damages) that increase proportionally and in some cases more than proportionally in illegal profits. Most papers that consider price-fixing and detection in repeated oligopoly settings assume constant fines that are independent of illegal profits or damages, e.g. Motta and Polo (2003), Spagnolo (2004), Rey (2003). Very few contributions like Block et al. (1981), Harrington (2004, 2005), or Motchenkova (2008) do assume fines that are functions of illegal profits, damages, or the degree of price-fixing in general. Since illegal profits, damages, or, more generally, the gravity of the violation are related to the cartel price, effectively the fine becomes a function of the cartel price. In this note, we study probabilities of detection that depend upon the cartel price and fines that depend upon illegal net profits.

In order to take into account the incentives to collude and the incentives of individual firms to cheat on the cartel we consider the following trigger strategy profile: Firms set a price $p > p^N$ in the first period and continue to set price p as long as there was no price deviation. As in Harrington (2004, 2005) any deviation by some of the firms or detection by the AA will lead to the competitive equilibrium price p^N in every period.

Under this strategy profile, let $V(p;\delta)$ be the present value of a firm's expected profit if the cartel sets price $p \in \left[p^N, p^M\right]$ in every period. $V(p;\delta)$ is equal to the current illegal net profits $\pi(p)$, minus the expected fine $\beta(p)\, k(p)\, \pi(p)$, plus the expected continuation net gain of not being detected $(1 - \beta(p))\, \delta V(p;\delta)$. Hence,

$$V(p;\delta) = \pi(p) - \beta(p)\, k(p)\, \pi(p) + (1 - \beta(p))\, \delta V(p;\delta).$$

[2]Alternative assumptions such as the possibility of prosecution price-deviating firms would only relax the equilibrium condition for collusion to be sustainable. Hence, our results will not qualitatively change if such alternative assumption were imposed.

Solving for $V(p;\delta)$ yields the following joint cartel profit function

$$V(p;\delta) = \frac{1-\beta(p)\,k(p)}{1-\delta\left[1-\beta(p)\right]}\pi(p). \tag{1}$$

Note that $V(p;\delta)$ is continuous on $p \in (p^N, p^M]$, and $V\left(p^N;\delta\right) = 0$ due to $\pi\left(p^N\right) = 0$. For all $p \in (p^N, p^M]$, $V(p;\delta) > 0$ because $\beta(p)\,k(p) < 1$. Or, for the opposite case, the cartel would be unprofitable if the AA could set the expected fine above illegal profits. Since $\beta(p) \geq 0$ and $k(p) \geq 0$ for all $p \in (p^N, p^M]$, we have $V(p;\delta) \leq \pi(p)/(1-\delta)$. The upper bound is the benchmark case $\beta(p) = k(p) = 0$ that reflects the absence of regulation. For technical convenience, we also assume that $V(p;\delta)$ is strictly log-concave on $\left[p^N, p^M\right]$. This ensures that $V(p;\delta)$ always has a unique maximum on $\left[p^N, p^M\right]$ that is a continuous function of $\delta \in (0,1)$ and other parameters.

Given the trigger strategy profile, the profit from a unilateral deviation is equal to the short-term net gain $\pi^{opt}(p)$ in the current period, minus an expected fine of zero (no prosecution), plus the normalized profit from the competitive equilibrium forever. So, the necessary and sufficient condition to support cartel price $p \in \left(p^N, p^M\right]$ is $V(p;\delta) \geq \pi^{opt}(p)$:

$$\frac{1-\beta(p)\,k(p)}{1-\delta\left[1-\beta(p)\right]}\pi(p) \geq \pi^{opt}(p). \tag{2}$$

The joint profit-maximizing cartel price is denoted by $p^C(\delta)$:

$$p^C(\delta) \in \arg\max_{p \in [p^N, p^M]} V(p;\delta) \quad \text{subject to } V(p;\delta) \geq \pi^{opt}(p). \tag{3}$$

Note that any price higher than p^M cannot be profit-maximizing cartel price, since the value function (1) is decreasing in p for $p > p^M$. Similar to Harrington (2005), we are mainly interested in the situation where equilibrium condition (2) is non-binding. In the Appendix (Lemma 7), we show that $\beta(p^M)[n + k(p^M)] < 1$ is a sufficient condition that implies a non-binding equilibrium condition. Then, the joint profit-maximizing cartel price simply solves

$$p^C(\delta) = \arg\max_{p \in [p^N, p^M]} V(p;\delta). \tag{4}$$

Given the optimization problem (4) specified above, the interior joint profit-maximizing cartel price is computed as the price $p \in [p^N, p^M]$ that maximizes $V(p;\delta)$. Formally,

$$\max_{p \in [p^N, p^M]} V(p;\delta) \equiv \max_{p \in [p^N, p^M]} \frac{1-\beta(p)\,k(p)}{1-\delta\left[1-\beta(p)\right]}\pi(p). \tag{5}$$

By taking the first-order condition (FOC) of the logarithm of $V(p;\delta)$, we obtain

$$\frac{\pi'(p)}{\pi(p)} - \frac{\beta'(p)\,k(p) + \beta(p)\,k'(p)}{1-\beta(p)\,k(p)} - \frac{\delta\beta'(p)}{1-\delta\left[1-\beta(p)\right]} = 0. \tag{6}$$

In the following section, we analyze the cartel's profit-maximization problem given in (5) for several regimes of antitrust enforcement. We analyze and compare the effects of three different specifications of fines on the profit-maximizing cartel price and distinguish between detection probabilities that are either constant or depend on cartel prices. The constant detection probability $\beta(p) = \bar{\beta} > 0$ can be interpreted as random inspections without price monitoring at the fixed rate $\bar{\beta}$. While the price dependent detection probability $\beta(p)$ with $\beta'(p) > 0$ reflects inspection rates based on price monitoring. For each of these two cases, we consider three specifications of fines (fixed, proportional, and more-than-proportional). First, we consider fixed fines, i.e. $F(p) = \bar{F}$. This is not the current practice, but it is the benchmark in order to relate our results to previous analyses by e.g. Harrington (2005) or Motta and Polo (2003). Next, we analyze proportional fines when the fine is determined as a multiple of illegal profits, i.e. $F(p) = k\pi(p)$. This system is employed in some OECD countries, such as Germany or New Zealand, see e.g. OECD (2002) or Bundeskartellamt (2006). Finally, we also consider fines that increase more than proportionally in illegal profits, i.e. $F(p) = k(p)\pi(p)$ with $k'(p) > 0$. This system captures the current US system, where the "level fine" imposed by courts exhibits some convex mapping from offence levels (illegal profits) into fine levels, see DOJ (2009). Also, the EU system of fine imposition can be approximated by a piecewise convex function of the gravity of the offense, which assigns a higher multiplier $k(p)$ to more grave violations, see Wils (2007) or EC (2006).

4. The profit-maximizing cartel price

In order to clarify the impact of monitoring in augmenting inspection, we first analyze different fine structures under the benchmark case of a constant inspection rate and then consider monitoring-based inspections.

4.1 The benchmark case with constant inspection rate

In this subsection, we analyze three types of fine specifications in case the detection probability is constant, i.e. $\beta(p) = \bar{\beta} > 0$ and hence $\beta'(p) = 0$ for all $p \in [p^N, p^M]$. The first result establishes the profit-maximizing cartel price for the case of fixed fines.

Proposition 1 *Under an antitrust regime with constant inspection rates* $\left(\beta(p) = \bar{\beta} > 0\right)$ *and fixed fines* $\left(F(p) = \bar{F} > 0\right)$ *such that* $\bar{\beta}[n + \bar{F}/\pi\left(p^M\right)] < 1$, *there exists a* $\delta' < 1$ *such that for all* $\delta \in [\delta', 1)$ *the profit-maximizing cartel price coincides with the simple monopoly price, i.e.* $p^C(\delta) = p^M$ *for all* $\delta \in [\delta', 1)$. *So, this antitrust enforcement is ineffective in reducing cartel prices.*

This proposition implies that under a constant rate of law enforcement and fixed fines the profit-maximizing cartel price coincides with the simple monopoly price, i.e. $p^C(\delta) = p^M$. It implies that under fixed fines and fixed detection probabilities it is without loss of generality to focus on whether or not the simple monopoly price can be sustained, which is exactly what most of the literature does (see e.g. Motta and Polo (2003) or Rey (2003)). A similar result holds for proportional fines:

Proposition 2 *Under an antitrust regime with constant inspection rates* ($\beta(p) = \bar{\beta} > 0$) *and fines that are proportional to illegal profits* ($F(p) = k\pi(p)$ *with* $k > 0$) *such that* $\bar{\beta}[n+k] < 1$, *there exists a* $\delta' < 1$ *such that for all* $\delta \in [\delta', 1)$ *the profit-maximizing cartel price coincides with the simple monopoly price, i.e.* $p^C(\delta) = p^M$ *for all* $\delta \in [\delta', 1)$. *So, this antitrust enforcement is ineffective in reducing cartel prices.*

Proposition 1 is the repeated game analogue of the long-run neutrality result in Harrington (2005) that states that, in case of fixed fines, the steady-state cartel price is the simple monopoly price. So, the cartel's steady-state price is the same as in the absence of antitrust laws. That paper also notices that the steady-state cartel price cannot be reduced below the simple monopoly price if damages are proportional to profit, and Proposition 2 is the repeated game analogue of this result. Both results in Harrington (2005) are derived under $\beta'(p) = 0$, which we interpret as constant inspection rate. Both results imply that, given constant inspection rate without additional monitoring, both fixed and the widely employed proportional penalties cannot reduce the profit-maximizing cartel price below the simple monopoly price. Although not new, this fundamental insight has not yet received much attention in the literature.

The following result shows that qualitatively different insights are obtained in case fines are increasing more than proportionally in illegal profits.

Proposition 3 *Under an antitrust regime with constant inspection rates ($\beta(p) = \bar{\beta} > 0$) and fines that increase more-than-proportionally in illegal profits ($F(p) = k(p)\pi(p)$ with $k'(p) > 0$ for all $p \in (p^N, p^M]$) with $\beta\left(p^M\right)\left[n + k\left(p^M\right)\right] < 1$, there exists a $\delta' < 1$ such that for all $\delta \in [\delta', 1)$ the profit-maximizing cartel price $p^C(\delta) < p^M$ for all $\delta \in [\delta', 1)$. So, this antitrust enforcement is effective in reducing cartel price below the simple monopoly price.*

This proposition implies that more-than-proportional fines deter the simple monopoly price p^M. The steeper the function $k(p)$ around p^M, the larger the impact. This offers partial support for current practice in the US and in some parts of the EC, where fines increase more than proportionally in illegal profits.

An important implication of our results is that a constant inspection probability $\beta'(p) = 0$ in FOC (6) implies independence of the profit-maximizing cartel price and discount factor, δ. Then, the inspection rate based on price-monitoring ($\beta'(p) > 0$) is a necessary condition for the profit-maximizing cartel price to depend upon δ. Constant detection probabilities imply that such dependence reported in Harrington (2005) is impossible in the repeated game version.

4.2 Inspections based on price-monitoring

In this subsection, we first establish that inspection rates based on monitoring are effective in reducing the profit-maximizing cartel price below the simple monopoly price independent of the precise specification of the fine schedule. Then, we elaborate further on fines that are proportional and more-than-proportional in illegal profits.

Under inspection with monitoring, we can derive the result stated in the Proposition 4. It should be stressed that here we are dealing with arbitrary penalty function, $F(p)$. Hence, not all the prices in $[p^N, p^M]$ are sustainable as cartel prices even if p^M can be sustained as a cartel price. This is shown formally in the Lemma 5 in Appendix, which provides formal analysis of the equilibrium condition under arbitrary penalty function.

Proposition 4 *Under an antitrust regime with monitoring-based inspections ($\beta\left(p^N\right) = 0$ and $\beta'(p) > 0$ for all $p \in \left[p^N, p^M\right]$) and arbitrary fines ($F(p) > 0$ with $F'(p) \geq 0$ for $p \in (p^N, p^M]$ and $F\left(p^N\right) = 0$), there exists a $\delta' < 1$ such that for all $\delta \in [\delta', 1)$ the profit-maximizing cartel price $p^C(\delta) < p^M$ for all $\delta \in [\delta', 1)$. Such antitrust enforcement is effective in reducing cartel price below the simple monopoly price.*

This result shows that inspection with price-monitoring is always effective in reducing the profit-maximizing cartel price below the simple monopoly price. This includes fixed fines $F(p) = \bar{F}$ and fines that are proportional to illegal profits, for which we obtained the simple monopoly price in the previous subsection under constant inspection rates. Several remarks are in place. First, Proposition 4 remains silent about by how much the profit-maximizing cartel price lies below the simple monopoly price. Second, the key argument of the proof is that even if the simple monopoly price p^M can be supported as equilibrium price, it can never be a profit-maximizing cartel price, because the cartel value function has negative slope at p^M due to $\beta'(p^M) > 0$ (see the proof of Proposition 4 in the Appendix). This also implies that p^M would not be the price set by the cartel regardless whether it can be supported in equilibrium or not.[3]

[3]We thank an anonymous referee for pointing out the necessity of this clarification. Following this referee's remarks we also added some clarifications on the implications of dealing with arbitrary penalty function, $F(p)$, prior to discussion of Proposition 4.

We continue this section by investigating the joint effect of price-monitoring and (more-than) proportional fines. Under $F(p) = k(p)\pi(p)$, FOC (6) can be rewritten as

$$\frac{\pi'(p)}{\pi(p)} = \frac{\beta'(p)k(p) + \beta(p)k'(p)}{1-\beta(p)k(p)} + \frac{\delta\beta'(p)}{1-\delta[1-\beta(p)]}. \tag{7}$$

Proposition 2 exploits the fact that under proportional fines and constant detection probabilities the right-hand side of (7) is equal to zero, and then the simple monopoly price solves (7). In case the right-hand side of (7) is positive, which can be accomplished by either more-than-proportional fines ($k'(p) > 0$) or monitoring-based inspections ($\beta'(p) > 0$), the simple monopoly price is no longer optimal. The larger the right-hand side of (7) (or the bigger the $k'(p)$, or $\beta'(p)$, or both), the lower the profit-maximizing cartel price will be. These fundamental insights show that the two enforcement mechanisms (namely, manipulating the fine structure or putting more efforts into monitoring) are complementary.

To conclude, when inspection is accompanied by additional monitoring (i.e. $\beta'(p) > 0$) any fine scheme would allow to reduce joint profit-maximizing cartel price below the simple monopoly price. In addition, fines that are more-than-proportional to illegal profits allow for an even larger reduction of the profit-maximizing cartel price compared to a proportional fine, since the right hand side in (7) is larger when $k'(p) > 0$.

Our results also provide additional insights and some clarifications into the robustness analysis of the dynamic model in Harrington (2005) (p.157-159), where we interpret the profit-maximizing cartel price in the repeated game version as the steady-state cartel price in Harrington's dynamic model. Then, Harrington's main results rest on the assumption that the detection probability depends on price changes only, and that the derivative of the detection probability with respect to the current price is *zero* whenever the current price is equal to last period price. The latter assumption would translate into $\beta'(p) = 0$ in the repeated game version. Our analysis extends the one in Harrington (2005) to $\beta'(p) > 0$. Then, Proposition 4 implies that allowing $\beta'(p) > 0$ qualitatively changes the type of results in Harrington (2005): Monitoring-based inspections are effective in reducing cartel price below the simple monopoly price independent of the specification of the fines and even when fines are fixed. Note, however, that this has been informally argued in Harrington (2005). Our analysis offers a general proof for the repeated oligopoly model.

5. Conclusions

We analyze the effectiveness of antitrust regulation in a repeated oligopoly model in which fines and detection probabilities depend on the cartel price. In particular, we compare the effectiveness of two fundamentally different enforcement mechanisms. The first deals with the specification of the fines and the other whether or not to monitor market prices. Our main conclusion is that both mechanisms are complementary to each other.

The main policy implications are as follows. Under constant inspection probabilities, we confirm the long-run neutrality result with respect to fixed fines reported in Harrington (2005) and extend it to the case where fines are directly proportional to illegal profits. Antitrust policy design with non-constant inspection rates that are based on price-monitoring allows to achieve profit-maximizing cartel prices below the simple monopoly price even when fines are fixed. This would change the neutrality result in Harrington (2005).[4] We attribute this difference to the fact that there is no first-order effect of the current price on the probability of detection in the steady state in the Harrington's model (so detection probability is effectively constant), while the repeated oligopoly model captures the effect of the current price on the probability of detection.

[4]Harrington (2005) mentions this possibility while discussing the robustness of his results in the section 4.3 (p.159). However, only informal discussion was provided.

A major result is related to the design of the currently employed US and EU penalty schemes. Under constant inspection rates, we arrive at the novel conclusion that, contrary to fines that are simply proportional to illegal profits, more-than-proportional fines can lead to lower prices. In addition, in settings where inspection rates are based on price-monitoring fines that increase more than proportionally when illegal profits increase allow for the higher price reductions compared to proportional fines. This offers partial support for current practice in the US and EU.

Appendix

In this appendix, we first establish a simple sufficient condition for general fine functions under which a subinterval of high prices in $[p^N, p^M]$ can be sustained by the cartel for sufficiently large discount factors $\delta \in (0,1)$. Then for the class of fine functions $F(p) = k(p)\pi(p)$, we derive the stronger result that all prices in $[p^N, p^M]$ can be sustained by the cartel for sufficiently large $\delta \in (0,1)$. The importance of this result is twofold: First, it implies a non-binding equilibrium condition that allows unconstrained profit maximization as specified in (5). Second, if the FOC yields profit-maximizing cartel prices in the neighborhood of p^M, such price can be sustained by the cartel. The first result is rather general and it includes as a special case fines and detection probabilities that are both constant. Finally, we include the proofs of our main results.

As fine functions, we consider differentiable $F(p) > 0$ with $F'(p) \geq 0$ for $p \in (p^N, p^M]$ and $F(p^N) = 0$. For these functions we derive the following result.

Lemma 5 *Let $F(p) > 0$ with $F'(p) \geq 0$ for $p \in (p^N, p^M]$ and $F(p^N) = 0$. If $\beta(p^M)[n + F(p^M)/\pi(p^M)] < 1$, then there exists a $\delta' < 1$ and an $\varepsilon > 0$ such that all $p \in [p^M - \varepsilon, p^M]$ are sustainable cartel prices for all $\delta \in [\delta', 1)$.*

Proof. Since $\beta(\cdot)$, $F(\cdot)$ and $\pi(\cdot)$ are continuous, there exists an $\varepsilon > 0$ such that for all $p \in [p^M - \varepsilon, p^M]$ it holds that $\beta(p)[n + F(p)/\pi(p)] < 1$. Then,

$$\beta(p)[n + F(p)/\pi(p)] < 1 \quad \Longrightarrow \quad \frac{\pi(p) - \beta(p)F(p)}{1 - [1 - \beta(p)]} > n\pi(p) \geq \pi^{opt}(p).$$

Define $W(p;\delta) = \frac{\pi(p)-\beta(p)F(p)}{1-\delta[1-\beta(p)]}$, then $W(p;1)=\frac{\pi(p)-\beta(p)F(p)}{1-[1-\beta(p)]}$. By continuity of $W(p;\delta)$ in δ and given $\delta \in (0,1)$, there exists a $\delta'(p) < 1$ such that for all $\delta \in [\delta'(p), 1)$ it holds that $W(p;\delta)=\frac{\pi(p)-\beta(p)F(p)}{1-\delta[1-\beta(p)]} > n\pi(p) \geq \pi^{opt}(p)$. Obviously, $\delta' \equiv \sup_{p\in[p^M-\varepsilon,p^M]} \delta'(p) < 1$. Hence, the equilibrium condition that deters price deviations holds for all $p \in [p^M - \varepsilon, p^M]$ and all $\delta \in [\delta', 1)$. ■

Without suitable additional restrictions, it is impossible to sustain all $p \in [p^N, p^M]$. To see this, consider $\beta(p) = \bar{\beta} > 0$ and $F(p) = \bar{F} > 0$. Then for sufficiently small $p \in [p^N, p^M]$ $\beta(p)F(p) = \bar{\beta}\bar{F} > \pi(p)$ implies that such small p yield a negative present expected value and can never be sustained as cartel prices. This proves the following result, which is a special case of Lemma 5.

Corollary 6 *Let $\beta(p) = \bar{\beta} > 0$ and $F(p) = \bar{F} > 0$ for all $p \in (p^N, p^M]$ and $\beta(p^N) = F(p^N) = 0$. If $\bar{\beta}[n + \bar{F}/\pi(p^M)] < 1$, then there exists a $\delta' < 1$ and an $\varepsilon > 0$ such that all $p \in [p^M - \varepsilon, p^M]$ are sustainable cartel prices for all $\delta \in [\delta', 1)$.*

Our main interest concerns the analysis of the class of fine functions $F(p) = k(p)\pi(p)$. For this class we obtain the stronger result:

Lemma 7 *Let $F(p) = k(p)\pi(p)$ for $p \in [p^N, p^M]$. If $\beta(p^M)[n + k(p^M)] < 1$, then there exists a $\delta' < 1$ such that all $p \in [p^N, p^M]$ are sustainable cartel prices for all $\delta \in [\delta', 1)$.*

Proof. Since both $\beta(\cdot)$ and $k(\cdot)$ are non-decreasing, $\beta(p)[n+k(p)] \leq \beta(p^M)[n+k(p^M)] < 1$ for all $p \in [p^N, p^M]$. Then as before $\beta(p)[n+k(p)] < 1$ implies $V(p;1) > n\pi(p) \geq \pi^{opt}(p)$ for all $p \in [p^N, p^M]$. By continuity of $V(p;\delta)$ in δ, there exists a $\delta'(p) < 1$ such that for all $\delta \in [\delta'(p), 1)$ it holds that $V(p;\delta) > n\pi(p) \geq \pi^{opt}(p)$. Obviously, $\delta' \equiv \sup_{p\in[p^N,p^M]} \delta'(p) < 1$. Hence, equilibrium condition (2) holds for all $p \in [p^N, p^M]$ and all $\delta \in [\delta', 1)$. ■

We are now ready to prove our main results.

Proof of Proposition 1:
Proof. By Corollary 6, there exists an $\varepsilon > 0$ and a $\delta' < 1$ such that all $p \in [p^M - \varepsilon, p^M]$ can be sustained as a cartel price for all $\delta \in [\delta', 1)$. So, the equilibrium condition is not binding for $p \in [p^M - \varepsilon, p^M]$ whenever $\delta \in [\delta', 1)$. Under $\beta(p) = \bar{\beta}$ and $F(p) = \bar{F}$, the cartel's profit maximization problem has the following form:

$$\max_{p\in[p^M-\varepsilon,p^M]} \frac{\pi(p) - \bar{\beta}\bar{F}}{1-\delta\left[1-\bar{\beta}\right]}.$$

The FOC is equivalent to $\pi'(p) = 0$. Hence, p^M is the unique solution in $[p^M - \varepsilon, p^M]$. ■

Proof of Proposition 2:
Proof. By Lemma 7, there exists a $\delta' < 1$ such that all $p \in [p^N, p^M]$ can be sustained as a cartel price for all $\delta \in [\delta', 1)$. So, the equilibrium condition is not binding for $p \in [p^N, p^M]$ whenever $\delta \in [\delta', 1)$. Under $\beta(p) = \bar{\beta}$ and $F(p) = k\pi(p)$, the second and the third term in FOC (6) are both equal to zero, due to $\beta'(p) = k'(p) = 0$. Hence, FOC (6) is equivalent to $\pi'(p) = 0$. Hence, p^M is the unique solution of $V'(p;\delta) = 0$ for all $\delta \in [\delta', 1)$. ■

Proof of Proposition 3:
Proof. By Lemma 7, there exists a $\delta' < 1$ such that all $p \in [p^N, p^M]$ can be sustained as a cartel price for all $\delta \in [\delta', 1)$. So, the equilibrium condition is not binding for $p \in [p^N, p^M]$ whenever $\delta \in [\delta', 1)$. Under $\beta(p) = \bar{\beta} > 0$ and $F(p) = k(p)\pi(p)$ with $k'(p) > 0$, the third term in FOC (6) is equal to zero due to $\beta'(p) = 0$, and the second term is strictly positive due to $\bar{\beta} > 0$ and $k'(p) > 0$. Hence, FOC (6) is equivalent to

$$\frac{\pi'(p)}{\pi(p)} = \frac{\beta k'(p)}{1-\beta k(p)} > 0. \tag{8}$$

Recall $\pi'\left(p^M\right) = 0$ and $\pi'(p) > 0$ for all $p < p^M$. Hence, by the positive right-hand side in (), the joint profit-maximizing cartel price $p^C(\delta)$ is less than p^M. ■

Proof of Proposition 4:
Proof. By Lemma 5, there exists an $\varepsilon > 0$ and a $\delta' < 1$ such that all $p \in [p^M - \varepsilon, p^M]$ can be sustained as a cartel price for all $\delta \in [\delta', 1)$. So, the equilibrium condition is not binding for $p \in [p^M - \varepsilon, p^M]$ whenever $\delta \in [\delta', 1)$. Under $\beta'(p) > 0$ and $F(p) > 0$ with $F'(p) \geq 0$, the profit maximization problem becomes

$$\max_{p\in[p^N,p^M]} \frac{\pi(p) - \beta(p)F(p)}{1-\delta\left[1-\beta(p)\right]}.$$

By taking the FOC of the logarithm of the profit function, we obtain

$$\frac{\pi'(p)}{\pi(p) - \beta(p)F(p)} = \frac{\beta'(p)F(p) + \beta(p)F'(p)}{\pi(p) - \beta(p)F(p)} + \frac{\delta\beta'(p)}{1-\delta\left[1-\beta(p)\right]} > 0.$$

The right hand side of this FOC is strictly positive. Recall also $\pi'\left(p^M\right) = 0$ and $\pi'(p) > 0$ for all $p < p^M$. Hence, the joint profit-maximizing cartel price $p^C(\delta)$ is less than p^M. To put it differently, $\beta'(p) > 0$ for all $p \in [p^N, p^M]$ implies $p^C(\delta) < p^M$ independent of $F(p)$. ■

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