Optimal Antitrust Auditing and Cartel Pricing*

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Abstract

In this paper, we analyze a game between firm(s) and an antitrust authority that has imperfect knowledge about production cost and chooses its auditing policy, strategically and without commitment, to maximize social welfare which is a linear weighted function of consumer and producer surplus. We find that for a relatively high weight of consumer surplus in welfare function, the game has a unique semi-separating equilibrium with mixed strategies in which low-cost firm colludes and the antitrust investigates the market with some positive probability. Only for this high weight, the leniency program, which gives prosecution immunity for whistle-blower(s) on cartel, might be effective in destabilizing cartels. Moreover severity of punishment has deterrence effect whereas in presence of substantial under-deterrence, probability and severity of punishment may become complements. Finally we show that under some circumstances, authority would be better off, ex post, if it cares only about consumer surplus.

Keywords: Antitrust Policy, Cartel, Competition Policy.

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1 Introduction

Illegal anti-competitive behavior classically is a concerted criminal action performed to fix price(s) or productions based upon an agreement among firm(s), called a cartel. Detection and deterrence of collusion are long-standing antitrust issues, because collusive arrangements are usually surreptitious. Despite a large literature on the theory of enforcement against these behaviors, the theory of antitrust policy is still in its infancy when it comes to the strategic actions of the antitrust authority (AA hereafter).

In practice, competition authorities are subject to two sorts of constraints: limited resources and imperfect information. Because resources are restricted, authorities cannot keep an eye on all markets and pursue all firm(s) which are suspected of colluding. The second problem is that markets are hardly ever transparent and authorities could not perfectly observe characteristics and behaviors of firm(s). This information asymmetry creates adverse selection and moral hazard problems that lessen the efficiency and impact of public interventions.

On the one hand, when an AA observes anomalous, unusual, or inexplicable pricing - compared to the pricing process when firm(s) had been competing - might become suspicious, pursue legal actions and initiate a process that eventually means collapse of cartel. On the other hand, in choosing a price path, it is natural to expect a cartel to attempt to avoid creating doubts that collusion is in the works. In deciding whether or not to form a cartel and what price(s) to set, a cartel takes into account how their price(s) influence likelihood of triggering detection of collusion by AA.

A commitment on auditing policy would lead to so called dynamic (time) inconsistency where a decision-maker's preferences do not adjust over time in such a way that a player's best decision at one point is inconsistent with what is preferred at another point in time. Dynamic consistency requires, specific optimality principle remains optimal at any instant of time throughout a game along the equilibrium path. Hence the credibility of an equilibrium strategy requires that players do not possess incentives to deviate from the previously adopted optimal behavior.

Commitment is an important issue in the law enforcement literature. The literature on optimal incentive contracts and auditing has typically assumed that AA either commits ex ante to some probability of investigation [e.g. Motta and Polo (2003)] or investigates according to an arbitrary rule of thumb [e.g. Harrington (2005)]. However ex post, there is no incentive to audit since the threat of audit induces full compliance.

In this paper, we endogenize detection of anti-competitive behavior by explicitly modeling the beliefs of AA and its strategic pro-market actions. We analyze a game between firm(s) and the AA, to study the situation of violation of antitrust law by the firm(s), which fix the price(s) above competitive level or participate in a cartel. Previous models typically assume that AA does not act strategically, by supposing that AA commits to a fixed probability of detection. The premise of the current paper is that in a more realistic framework, AA acts strategically and without commitment on its auditing policy. In general, if a player had an incentive to deviate from its strategy, then the other player(s) would not believe this announcement of strategy in the first place. Therefore, they would compute their own strategies by taking into account the expected future deviation of the first player which in general would lead to strategies different from its announced strategy.

There are few papers in the literature dealing with a strategic antitrust which has no commitment on its policy. [e.g. Khalil (1997), Franckx (2002), and Finke and Shin (2007)]. Using a principal-agent model, Khalil (1997) assesses the optimal contract when a principal cannot commit to an audit policy. The contract must provide incentives for the agent to conform as well as for the principal to inspect. He finds that for high production cost, the agent is asked to produce more than the amount under full information and the probability of audit is higher when the principal cannot commit compared to when it can. Finke and Shin (2007) demonstrate that audits take place with the highest frequency, but the accuracy of audits is found the middle ground in equilibrium. They also ascertain that without commitment to the audit policy, the first-best outcome cannot be achieved even when auditing is costless.

The competition policy literature has mostly assumed that auditing takes place because AA has authentic incentive to scrutinize compliance and this credible threats would frighten the cartel to be more watchful about its anti-competitive behavior. Harrington (2004) finds that antitrust laws with a simple and exogenous detection technology, may have a perverse effect as they make cartel stability easier and consequently allow for higher cartel prices. Later, Harrington (2005) explores the dynamic behavior of a cartel when it is afraid about creating doubts that a cartel has been formed and shows that cartel's steady-state price is independent of the level of fixed fines.

Frezal (2006) compares a standard random and stationary audit strategy with a simple deterministic but non stationary strategy and demonstrates that the certainty of an ulterior control may better deter collusion. Houba et al. (2010) find that without monitoring, fines that are either fixed or proportional to illegal gains cannot eliminate the monopoly price, but more-than-proportional fines can. Moreover, policy design with auditing based on price-monitoring implies that the profit-maximizing cartel price always lies below the monopoly price independently of the fine structure.

There is also a vast literature in competition policy on asymmetric information, mostly with respect to the production cost. Baron and Myerson (1982) explicitly derive the optimal policy to regulate a monopolistic firm whose cost is unknown to the regulator. In the optimal policy of Baron and Besanko (1984), if the regulator realizes that the firm had misrepresented its costs, it can order compensation to consumers. A separation result indicates that the initial pricing decision is independent of the auditing decision. However, the auditing decision depends on the price that was initially set.

Besanko and Spulber (1989) show that with costly enforcement, AA commits itself to a schedule of probabilities of bringing suit that depends on the observed market price and collusive firms moderate markups to reduce the risk of being accused. Cyrenne (1999) scrutinizes the deterrence efficacy of an antitrust enforcement policy of inferring possible collusion from significant prices changes. He shows that this investigation strategy, can decrease the expected profits from the collusive agreement. However, unless the punishment is large enough, it will be ineffective in reducing the frequency of collusion. Souam (2001) also demonstrates how antitrust laws can be enforced efficiently, under different regimes of pecuniary punishment. The analysis confirms that since investigation is costly, it is optimal from a welfare point of view to tolerate some degree of collusion.

The reporting by parties of their own behavior to AA is a commonly observed aspect of law enforcement. Laws often persuade violators to self-report their crimes by offering a lower sanction and avoid illegal conduct rather than subject themselves to probabilistic law enforcement. The stylized fact in this literature [e.g. Feess and Heesen (2002)] is that self-reporting increases social welfare. In their seminal paper on self-reporting, Kaplow and Shavell (1994) add self-reporting to the model of the control of destructive externalities through probabilistic law enforcement and show that the social costs of law enforcement can be reduced by lowering the fines imposed on self-reporting individuals.

Innes (1999) considers a model of probabilistic law enforcement in which a violator can commence remediation that shrinks not only the damage caused but also sanction. He shows that self-policing increases efficiency not only because efficient remediation is achieved early and with certainty, but also since the enforcement effort needed to deter violations is often reduced. Later, Innes (2000) studies the merits of self-reporting when violators otherwise face heterogeneous probabilities of apprehension. He discerns that an optimal enforcement regime does not educe self-reporting by all violators and efficiency can often be improved by inducing some violators to self-report.

Leniency programs make enforcement more effective but they may also induce collusion, since they decrease the expected cost of misbehavior. Mottaa and Polo (2003) show that in the optimal policy the former effect dominates, calling for leniency programs when AA has limited resources. Brisset and Thomas (2004) develop a simple model of cartel behavior under a first-price sealed-bid procurement auction and show how an effective leniency program can avert the internal coordination of cartel members. Buccirossi and Spagnolo (2006) study the effects of leniency on sequential, bilateral, illegal transactions, such as corruption, manager-auditor collusion, or drug deals. They find that leniency may provide an effective governance mechanism for occasional sequential illegal transactions that would not be feasible in its absence. Auberta et al. (2006) argue that rewarding individuals rather than reducing fines, can deter collusion in a more effective way .

Herre and Wambach (2007) investigate the impact of antitrust enforcement policies on collusion sustainability. They show that the effect of leniency programs is ambiguous, since the program has a weakly positive effect in industries with low probability of demand shocks and an adverse effect if this probability is high. Harrington (2008) characterizes the corporate leniency policy that minimizes the frequency with which collusion occurs. He provides plausible sufficient conditions whereby AA should relinquish all sanctions for the first firm to come forward and also shows that it can be optimal to award amnesty even when AA is very likely to win the case without insider testimony.

In one of a few empirical papers, Brenner (2009) applies his theoretical model of cartel behavior to the complete set of indictments and information reports issued over a 20-year span. He shows that statistical tests are consistent with the notion that leniency enhances deterrence and detection capabilities and provides incentives to reveal information on criminal activities.

The rest of this paper is organized as follows. In Section 2, we explain the general model. Section 3 analyses the model under the perfect and imperfect information cases and provides comparative statics. Section 4, discusses the stability of cartel in a dynamic setting with leniency program. Finally Section 5 concludes. We collect all proofs and extensions in the Appendixes.

2 Model

Presume an industry with symmetric firm(s) which produces a homogeneous good and can agree and increase price over the marginal cost, $\theta \geq 0$, which is the same across firm(s) and are either θ_h or θ_l, where $\theta_h > \theta_l \geq 0$. AA perceives cost as being θ_l with probability υ and θ_h with probability $1-\upsilon$, where $\upsilon \in (0,1)$ is its prior belief. Because the firm(s) are symmetric, each of them has equal weight in the coalition; therefore, the overall cartel profits will be divided equally among them.

We assume that there is no strategic interaction between cartel members in the sense that we abstract from the possibility of betray by undercutting, self-reporting or any other non-cooperative behavior that would influence the internal stability of the cartel. For the sake of simplicity, we only consider one representative firm, not the whole cartel, and apply similar sanctions to all the members of cartel. The firm(s) face a market demand curve $Q(p)$ which has a finite choke price $\bar{p}$. We assume that the monopoly price of any cost-type is higher than the choke price.

Assumption 1: $p^m(\theta_h) > p^m(\theta_l) > \bar{p} > \theta_h$.

This assumption is not crucial for the model but will just make our life easier. Later we will show the general case in the Appendix. The market price p is the minimum of the prices of all firm(s) and $\bar{p}$. Let p_{-i} be the minimum of the prices of all firm(s) and $\bar{p}$ excluding firm i. Given that $p_{-i} \leq \bar{p}$, firm i's gross profit (i.e. net of fines), $\pi(p_i)$, is $Q(p_i)(p_i - \theta)$ if $p_i < p_{-i}$ and zero otherwise. If they all set the same price, the profit would be shared equally. We also assume that profit is monotonously increasing in price in the feasible interval.

After the firm(s) observe their cost, they may either act non-cooperatively and compete or act cooperatively and form a cartel. In the former case, the firm(s) compete à la Bertrand, which implies that the equilibrium market price is equal to the marginal cost and each firm earns zero profits. In the latter case when the firm(s) colludes, they agree to charge a price that maximizes their expected joint profits. If then, AA decides to investigate the industry that yields legal evidence of the industry's conduct.

Since collusion is strictly illegal per se, AA may impose a penalty $F := \alpha p Q(p)$ on a collusive industry, where α is a positive constant that determines the steepness of the penalty scheme with respect to the turnover of the firm(s). This penalty scheme resembles the main feature of the current European system[1], namely the base penalty is proportional to the turnover involved in the undertaking[2].

Although in practice, there seems to be a consensus among antitrust authorities that fines should not lead to a firm's bankruptcy, in order to keep the analysis interesting, suppose that the fine is relatively large so that the expected profit of the industry when they get caught for sure is negative, $Q(p)\,(p-\theta_k) - \alpha p Q(p) \leq 0$ for $k = l, h$. Otherwise, collusion would be impossible to deter and firm(s) will always collude.[3]

The crucial assumption here is that AA reasonably cannot commit to any arbitrary antitrust policy. The inability to commit may also derive from the fact that it is hard to fully describe an antitrust policy. Each industry is different and this makes it more likely that AA deals with the industry on a case-by-case basis. It might be also even impossible for outsiders to observe whether AA was able to commit when it did not investigate a particular industry.

Since AA neither observes cost nor the industry's conduct, it is without loss of generality to let the probability that AA investigates the industry, conditional on the market price. AA aims to maximize its own profit via fine and a social welfare which is a weighted linear function of consumer and producer surplus. More precisely, AA can choose the relative weight on how it cares about consumer and producer welfare. Let $\mu \in (1/2, 1]$ be the relative weight of consumer welfare in AA's objective function. Then, AA maximizes

$$V(p,\theta) = E\left[\mu \int_{p}^{\bar{p}} Q(t)dt + (1-\mu)\left[Q(p)(p-\theta) - \beta\alpha p Q(p)\right] + \beta\alpha p Q(p) - \beta K\right]. \quad (1)$$

[1] The result is also robust with respect to the different fine regime and in particular the American one which could be resembeled as the fine that is a fraction of eraned profit $\tilde{F} := \tilde{\alpha}\,(p-\theta)\,Q(p)$. We will show this in the Appendix.

[2] It should be mentioned, however, that this functional form does not capture all the properties of the penalty schemes, which are determined in the current "Guidelines for the Setting of the Fines", such as longer duration of the offence or leading role in the infringement would increase the penalty. That is why we call this scheme a "Stylized EU penalty scheme".

[3] A high fine may conflict with other objectives of the AA. For instance, a high fine might induce some firms to exit the market, leaving a higher concentrated industry with a high non-cooperative price. For the sake of simplicity, we do not take into considration this issue here.

The idea of defining social welfare as a linear function of the consumer and producer surplus is to capture the intristic 'left-wing' or 'right-wing' preferences of the authority in implementing social policies. The more left-wing authority would choose the higher μ.

The timing is as follows. First, the relative weight of consumer welfare, μ, is realized and firm(s) privately learn their costs. They may commit to form a cartel. The firm(s) subsequently set price(s). Given these price(s), AA may investigate the firm(s). If it finds evidence of collusive behavior, it can impose a fine.

3 Analysis

3.1 The perfect information case

Consider antitrust policy when AA simply knows the industry's marginal cost and perfectly observes the mode of behavior. AA might intervene in the market after the price has been set. Therefore, it could change neither consumer surplus nor producer surplus. Its payoff will be the fine transfer net of auditing cost. Hence, AA would investigate the industry if and only if its payoff is higher than when it simply stay aside and do not intervene in the market, $H(p) := \mu\alpha p Q(p) - K > 0$. When offense is little, the deterrent value of monetary sanctions is low. Thus, the government does not bother to invest a lot in detection whereas if infringement is huge, the deterrent value of monetary sanctions is high, so it is more profitable to prosecute them.

Assumption 2: *$H(\theta_l) < 0$ and $H(\bar{p}) > 0$.*

In fact if $H(\theta_l) > 0$ the AA will always audit and if $H(\bar{p}) < 0$, it never investigate since it is too costly. The Assumption 2, rules out these two extreme cases to make our model more interesting. For now, we also presume that $H(\theta_h) > 0$. Later in Appendix , we will consider the less attractive case in which $H(\theta_h) \leq 0$. It is straightforward to show that $\partial H(p)/\partial p > 0$, thus by fix point theorem, there is a unique $\hat{p}$ in (θ_l, θ_h) which makes $H(\hat{p}) = 0$. Clearly $\beta(\theta; \mu)$ is 1 if $\mu > K/\alpha\hat{p}Q(\hat{p})$, and 0 otherwise. Therefore as long as investigating is costly, AA is better off if it tolerates some degree of collusion.

Block et al. (1981) formulates and test a model of collusive pricing in the presence of antitrust enforcement. They also show that a cartel's optimal price is likely to be neither the competitive price nor the price that the cartel would set in the absence of antitrust enforcement but rather an intermediate price that depends on the levels of antitrust enforcement efforts and penalties.

This result is in-line with the general message from the literature saying that the perfect cartel deterrence is not socially optimal even when there is no asymmetric information [e.g. Souam (2001)]. Hence, we have the following Lemma.

Lemma 1 *In the perfect information case, the subgame between the industry and AA has a unique separating equilibrium in which the low type firm colludes to* $\hat{p}$*, the high type does not collude and set the competitive price* θ_h*, and AA does not investigate the market at all. In the equilibrium of this subgame,* $\tau(\theta_l;\mu) = 0$*,* $\tau(\theta_h;\mu) = 1$*,* $\beta(\theta;\mu) = 0$*. The government's payoff is* $W = \upsilon V(\hat{p}, \theta_l) + (1-\upsilon)V(\theta_h, \theta_h)$*.*

3.2 The Imperfect Information Case

For given μ let $\tau(\theta, \mu) : \{\theta_l, \theta_h\} \to [0, 1]$ be the probability that firm(s) do not collude and $\beta(p;\mu) : [\theta_l, \bar{p}] \to [0, 1]$ be the probability that AA investigates the industry after observing price p. Firm(s) maximize expected profit(s) by choosing τ and p whereas AA maximizes the social welfare by setting β. Players must update their beliefs according to the Bayes' rule whenever applicable and their strategies must be optimal given their beliefs about the other players' strategies.

Suppose first the antitrust has a relatively low weight on consumer surplus, $\mu \in (1/2, \mu_l]$ where $\mu_l := \frac{K}{\alpha \bar{p} Q(\bar{p})}$[4]. Then it is straightforward to show that given the value of μ and irrespective of its prior belief, it is not rational for AA to investigate the industry at all simply because it is too costly. The firm(s) anticipate this and always collude to the highest possible price, $\bar{p}$, irrespective of cost realization. The Lemma bellow summarizes this result.

Lemma 2 *For* $\mu \in (1/2, \mu_l]$*, the subgame between the industry and AA has a unique pooling equilibrium in which both types collude by setting* $\bar{p}$ *and AA never investigates. Hence,* $\tau(\theta_k;\mu) = 0$ *for* $k = l, h$ *and* $\beta(p;\mu) = 0$ *for any* $p \in [\theta_l, \bar{p}]$*. The expected social welfare is* $W(\mu) = E[V(\bar{p}, \theta)] = \upsilon V(\bar{p}, \theta_l) + (1-\upsilon)V(\bar{p}, \theta_h)$*.*

[4] One could think of it as a right-wing authority.

For an intermediate weight, $\mu \in (\mu_l, \mu_h]$ where $\mu_h = \frac{K/\upsilon}{\alpha\theta_h Q(\theta_h)}$, any price other than θ_h and $\hat{p}$, is a clear signal of collusive agreement and it is also profitable for AA to investigate for sure these price(s), $\beta(p;\mu) = 1$ for any $p \notin \{\hat{p}, \theta_h\}$. Therefore for the given interval of μ, in the equilibrium we will just observe θ_h as the market price and AA will not investigate it. Thus compare to the previous case, the intermediate weight for μ reduces the likelihood of collusion.

Lemma 3 *For $\mu \in (\mu_l, \mu_h]$, the subgame between the industry and AA has a unique equilibrium in which both cost types set the price θ_h and AA does not investigate the market: $\tau(\theta_k;\mu) = 0$ for $k = l, h$, $\beta(\theta_h;\mu) = 0$, and $\beta(p;\mu) = 1$ for any $p \notin \{\hat{p}, \theta_h\}$. The expected social welfare is $W(\mu) = E[V(\theta_h, \theta)] = \upsilon V(\theta_h, \theta_l) + (1-\upsilon)V(\theta_h, \theta_h)$.*

Proof. See Appendix. ■

Finally, the most interesting case is $\mu > \mu_h$ in which we have mixed strategies.

Lemma 4 *For $\mu \in (\mu_h, 1]$, the subgame between the industry and AA has a unique (semi-separating) equilibrium in which the low type does not collude with probability*

$$\tau^*(\theta_l;\mu) = \frac{\upsilon\mu\alpha\theta_h Q(\theta_h) - K}{\upsilon\left[\mu\alpha\theta_h Q(\theta_h) - K\right]}, \tag{2}$$

and the high type acts non-cooperatively, $\tau(\theta_h;\mu) = 1$. Both types set a price θ_h and AA investigate collusion with probability

$$\beta^*(\theta_h;\mu) = \frac{\theta_h - \hat{p}}{\theta_h(\alpha+1) - \theta_l}, \tag{3}$$

and $\beta(p;\mu) = 1$ for any $p \notin \{\hat{p}, \theta_h\}$. Expected social welfare becomes

$$W(\mu) = \upsilon\left[\tau V(\theta_l, \theta_l) + (1-\tau)V(\theta_h, \theta_l)\right] + (1-\upsilon)V(\theta_h, \theta_h). \tag{4}$$

Proof. See Appendix. ■

A relatively low μ does not deter collusion because AA has no incentive to investigate. Increasing μ induces the high type to act non-cooperatively and the low type to collude by mimicking the high type. A relatively high μ, gives an additional decrease in the probability of collusion and low-cost type firm(s) and AA randomize their actions. Observe that, for any value of μ, collusion cannot be perfectly deterred. In each of the three cases, the firm(s) collude to some extent. The lowest degree of collusion can be found for $\mu > \mu_h$, in which only the low type colludes with some positive probability.

In fact the degree of collusion decreases not only in μ, but also in α. As we expected, the higher fine makes the collusive profit less attractive and thus decrease the likelihood of cartel formation. The following Corollary states it more formally.

Corollary 1 *The fine parameter has cartel deterrence effect.*

Proof. See Appendix. ■

A branch of literature on crime and punishment deals with the relationship between probability and severity of punishment, and suggests that detection probability and fines are substitutes, namely if we increase one, we could decrease the other and still keep the same level of deterrence. Garoupa (2001) have argued that the trade-off between probability and severity of punishment may not be always consistent with optimal law enforcement. It shows that it depends on the degree of deterrence and in the presence of substantial under-deterrence, caused by costly detection and punishment, these instruments may become complements.

Corollary 2 *The probability and severity of cartel punishment are complement for $\mu \in (\mu_l, \mu_h]$ whereas they are substitute for $\mu \in (\mu_h, 1]$.*

Proof. See Appendix. ■

This result is basically in-line with Garoupa (2001). Since we also have substantial under-deterrence and full collusion of low-cost firm(s) for $\mu \in (\mu_l, \mu_h]$, whereas for $\mu \in (\mu_h, 1]$, cartel formation has been deterred to a great extent. It is easy to show that the expected sanction is increasing with α. On the one hand for $\mu \in (\mu_h, 1]$, when the optimal expected sanction is sufficiently large, for basically large enough α, firm(s) approach complete deterrence, τ tends to 1 and thus AA can relax the auditing probability, achieves the same deterrence level and saves on enforcement cost. This leads the probability and severity of cartel punishment to be substitute. On the other hand, since μ_h decreases with α, by increasing α it will be more likely that for μ to be more than μ_h which then τ

declines from 1 to some positive τ^*. Hence, for $\mu \in (\mu_l, \mu_h]$, increasing α for $\mu \in (\mu_l, \mu_h]$ has no deterrence effect and we should also increase the probability making further gains in deterrence. In this sense, the fine parameter has a deterrence effect.

3.3 Comparative Statics

Social welfare is non-monotonic in μ. Since for $\mu \in (1/2, \mu_l]$ all firm(s) collude to the highest possible price, consumer surplus is simply zero by construction, and social welfare function is a negative function of μ whereas for $\mu > \mu_l$, the changes of social welfare function depends on the fraction of low type firm(s) in the market. If there are a lot of them, social planner might be better off if it cares more about producer surplus or in other words change objective towards more right-wings ones. In this case, social welfare function is decreasing with respect to μ, as well.

Proposition 1 *Social welfare function is decreasing with respect to μ for $\mu \in (1/2, \mu_l]$; it is increasing for $\mu \in (\mu_l, \mu_h]$ if the prior belief on the probability of low type firm(s), υ, is low enough and decreasing otherwise; and finally for $\mu \in (\mu_h, 1]$, it will be increasing for low magnitudes of υ or small values of $\hat{p}$.*

Proof. See Appendix. ■

It has been always debate on how to define social welfare function. We take the safe side and chose social welfare to be a linear function of consumer and producer surplus. Nevertheless, we show that the planner is better off ex post if it cares either only about consumer or producer surplus and this depends on how the market is composed of low type firm(s) or in other words, how is the prior belief of AA on realization of low cost, υ. Under some circumstances, it may be optimal for AA to only maximizes consumer welfare. The following explains in details these conditions.

Proposition 2 *For low enough prior belief on υ and small values of $\hat{p}$, social welfare function is maximized when it cares only about consumer surplus.*

Proof. See Appendix. ■

In fact, it practice it is mostly assumed that authorities are just maximizing consumer surplus, instead of total social welfare.

We show that if welfare function has higher weight on consumer surplus rather than producer surplus, the welfare function would start at the higher level right after each discontinuous points of μ_l and μ_h. More precisely

Corollary 3 $\lim_{\mu \to \mu_l^-} W(\mu = \mu_l) < \lim_{\mu \to \mu_l^+} W(\mu = \mu_l)$ *and* $\lim_{\mu \to \mu_h^-} W(\mu = \mu_h) < \lim_{\mu \to \mu_h^+} W(\mu = \mu_h)$.

Proof. See Appendix. ■

4 Cartel Stability and the Leniency Program

In light of the illegality of collusion, firms want to not only achieve internal stability, but also avoid creating suspicion that a cartel might exist. A cartel agreement is internally stable if no cartel member is tempted to deviate from it. Given that all other firms adhere to the collusive price, a firm could dramatically boost its profit by slightly undercutting this price. Each firm understands this temptation and therefore the market price is driven down to the marginal cost.

In this Section we relax the representative firm assumption and allow for strategic interaction between the firms in the cartel that gives them the possibility of betray by undercutting, self-reporting or any other non-cooperative behavior that would influence the internal stability of the cartel.

Solutions of the one-shot game still hold in the repeated game, because we have assumed that marginal costs are distributed independently across periods and firms observe only their current marginal costs. Therefore players play the optimal one-shot Nash response. There are N identical risk-neutral firms with the same marginal cost, θ_h or θ_l, where $\theta_h > \theta_l \geq 0$, as before. The game is infinitely repeated and firms discount payoffs with common discount factor $\delta \in (0,1)$. Just as before, the model is solved by considering the equilibria of the subgames for given values of μ. For $\mu \in (1/2, \mu_l]$, AA never investigates and the remaining constraint to consider is the firms' incentive compatibility condition which is

$$\frac{1}{N}\bar{\pi}(\theta_k) + \frac{1}{N}\frac{\delta}{1-\delta}E\left[\bar{\pi}(\theta)\right] > \bar{\pi}(\theta_k), \tag{5}$$

where the left hand side is the expected profit from sustaining the cartel, the right hand side is the expected profit of deviating from the cartel agreement and obtaining the whole market demand trough undercutting the collusive price, $E\left[\bar{\pi}(\theta)\right] = \upsilon\bar{\pi}(\theta_l) + (1-\upsilon)\bar{\pi}(\theta_h)$, and $\bar{\pi}(\theta_k) = Q(\bar{p})(\bar{p} - \theta_k)$.

For $\mu \in (\mu_l, \mu_h]$, it is not optimal to report a cartel. This is intuitive since simply the future payoff of sustaining the collusion is higher than reporting which leads to zero expected future profit.

Assumption 3: $\pi(\hat{p}, \theta_l) > \pi(\theta_h, \theta_l) - \alpha\theta_h Q(\theta_h)/N$.

This assumption is also not crucial for the model and would just make the problem more interesting since otherwise reporting the cartel is meaningless. Then for $\mu \in (\mu_l, \mu_h]$, in particular, cartel members could undercut to $\hat{p}$

$$\frac{1}{N}\pi(\theta_h, \theta_l) + \frac{1}{N}\frac{\delta}{1-\delta}E\left[\pi(\theta_h, \theta)\right] > \pi(\hat{p}, \theta_l), \tag{6}$$

which give us the threshold value for the discount rate.

$$\delta > \tilde{\delta}_2^w := \frac{N\pi(\hat{p}, \theta_l) - \pi(\theta_h, \theta_l)}{N\pi(\hat{p}, \theta_l) - (1-\upsilon)\,\pi(\theta_h, \theta_l)}, \tag{7}$$

where $\tilde{\delta}_2^w$ is the threshold value for the discount rate under the case in which the leniency program has not been introduced.

The cornerstone of cartel enforcement in the United States and elsewhere is a commitment to the lenient prosecution of early confessors. Leniency programs are widely used as instruments of competition policy. They are supposed to serve two purposes: in the short-run to facilitate the detection of cartels and thereby to reduce cost of legal enforcement, and in the long-run to deter firms from antitrust abuse. A burgeoning game theoretical literature is ambiguous regarding the impacts of leniency.

If the expected fine in the leniency regime is $\tilde{F} := \tilde{\alpha}pQ(p)$. Here we have assumed that AA gives full immunity to prosecution for any firm that reports a cartel, $\tilde{\alpha} = 0$. AA would go for leniency if it could gain more profit under this new setting than the standard competition policy, $\mu\tilde{\alpha}pQ(p) > \mu\alpha pQ(p) - K$, or $K > \mu pQ(p)\,(\alpha - \tilde{\alpha}) = \alpha\mu pQ(p)$, which is the case for $p < \hat{p}$. In this sense, leniency program is a tool to go after weak cartels which are not treated otherwise[5]. Therefore, if audit cost or the fine reduction are not high enough, it will not make sense for AA to launch this program. For $\mu \in (\mu_l, \mu_h]$,

[5]Note that the cost of investigation in the case of whistle-blowing is normalized to zero.

leniency only deters the deviator to deviate to the best price, $\hat{p}$, since otherwise other cartel members will report this to the authority to punish the deviator.

The expected profit of undercutting is $\Pi := Q(p)(p-\theta) - \alpha p Q(p)/N$. The following Lemma shows that it is in fact increasing in price. Therefore the deviator firm is better off by choosing a price just a bit less that θ_h.

Lemma 5 *The expected profit of undercutting is increasing in price.*

Proof. See Appendix. ■

Note that, if a firm defects, AA learns that a cartel exists and imposes a fine on the industry, which is equally borne by all firms. Therefore reporting the cartel in this case is not awarded since it would not help the authority to detect a cartel. Hence other cartel members could punish the deviator just in case their report help AA to detect a cartel that otherwise would not have been discovered. This could be the case only for $\hat{p}$ which is in fact is would not be selected in the equilibrium. The firms' incentive compatibility condition is then

$$\frac{1}{N}\left(1+\frac{\delta \upsilon}{1-\delta}\right)\pi(\theta_h,\theta_l) > \pi(\theta_h,\theta_l) - \frac{\alpha\theta_h Q(\theta_h)}{N}, \tag{8}$$

which gives us

$$\delta > \tilde{\delta}_2^u := \frac{(N-1)(\theta_h-\theta_l)-\alpha\theta_h}{(N-1+\upsilon)(\theta_h-\theta_l)-\alpha\theta_h}. \tag{9}$$

$\tilde{\delta}_2^u$ stands for the threshold discounted value for the undercutting case. Antitrust policy helps firms to form a cartel because defection is immediately punished by AA. As soon as a firm deviates from the cartel agreement, the rational AA learns that a cartel exists, launches a successful investigation and imposes a fine on all firms, including the defector. This strategic response of AA makes defection less attractive, and thereby collusion more stable. Various authors (e.g. Motta and Polo, 2003) have observed similar pro-collusive effects of well-intended antitrust legislation.

If $\mu \in (\mu_h, 1]$, both types set $p = \theta_h$. In the standard competition policy where there is no leniency, the deviator is better off to undercut to $\hat{p}$. Therefore the incentive compatibility condition is

$$\frac{1}{N}\left(1+\frac{\delta \upsilon}{1-\delta}\right)\left[\pi(\theta_h,\theta_l) - \beta\alpha\theta_h Q(\theta_h)\right] > \pi(\hat{p},\theta_l), \tag{10}$$

which give rises to

$$\delta > \tilde{\delta}_3^w := \frac{N\pi(\hat{p},\theta_l) - [\theta_h - \theta_l - \beta\alpha\theta_h] \, Q(\theta_h)}{N\pi(\hat{p},\theta_l) - (1-\upsilon) \, [\theta_h - \theta_l - \beta\alpha\theta_h] \, Q(\theta_h)}. \tag{11}$$

$\tilde{\delta}_3^w$ stands for the threshold discounted value for the deviating without leniency option. In the case with leniency, if the deviator undercut to $\hat{p}$, other cartel members would punish the deviator by reporting the case to the authority. Hence,

$$\frac{1}{N}\left(1 + \frac{\delta\upsilon}{1-\delta}\right)[\pi(\theta_h,\theta) - \beta\alpha\theta_h Q(\theta_h)] > \pi(\theta_h,\theta_l) - \frac{\alpha\theta_h Q(\theta_h)}{N}, \tag{12}$$

which gives us

$$\delta > \tilde{\delta}_3^u := \frac{(N-1)\,(\theta_h - \theta_l) - \alpha\,(1-\beta)\,\theta_h}{(N-1+\upsilon)\,(\theta_h - \theta_l) - \alpha\,(1-\beta+\beta\upsilon)\,\theta_h} \tag{13}$$

In this case, leniency program has also destabilizing effect through the possibility of reporting the noncompetitive behavior to the authority

$$\frac{1}{N}\left(1 + \frac{\delta\upsilon}{1-\delta}\right)[\pi(\theta_h,\theta_l) - \beta\alpha\theta_h Q(\theta_h)] > \frac{1}{N}\pi(\theta_h,\theta_l), \tag{14}$$

which gives us

$$\delta > \tilde{\delta}_3^r := \frac{\beta\alpha\theta_h}{\upsilon(\theta_h - \theta_l) + (1-\upsilon)\,\beta\alpha\theta_h}, \tag{15}$$

where $\tilde{\delta}_3^r$ stands for the threshold discounted value for reporting.

Following the success of the U.S. Antitrust Division's Corporate Leniency Program, many national antitrust authorities have adopted similar policies, by granting partial or full fine reduction to firms that voluntarily report their cartel. A few recent papers examine the effects of leniency on cartel stability, [e.g., Spagnolo (2004) or Aubert et al. (2006)].

Theoretically leniency has two opposite effects on cartel stability. On the one hand, it gives the possibility of blowing the whistle on other cartel members and simply breaks it down; and on the other hand it reduces the expected fine and gives cartel members the possibility of punishing the cheater by simply reporting the cartel to the authority. Therefore ex ante it is not clear from the theoretical perspective whether launching the leniency program would reduce or enhance the stability of cartels. In fact it turns out that in our case the stabilizing effect of leniency is dominant.

Proposition 3 *For $\mu \in (\mu_l, \mu_h]$, cartels are more stable under leniency regime whereas $\mu \in (\mu_h, 1]$ only if $N\pi(\hat{p},\theta_l) < \pi(\theta_h,\theta_l)$, the leniency is effective in destabilizing cartels.*

Proof. See Appendix. ■

Intuitively if the profit from undercutting is not attractive enough or there are not that many members in the cartel agreement, the deviator firm is better off to simply report the cartel rather that undercutting. This would be clear if we compare the right hand side of (**??**) and (14) whereas their left hand side is just the same. Nevertheless a leniency program has no effect for $\mu \in [0, \mu_l]$, as in that case AA does not investigate the industry and a leniency program has no 'bite'. Interestingly for $\mu \in (\mu_l, \mu_h]$, a higher maximum fine have perverse effects on the firms' ability to collude whereas it destabilize the cartel for $\mu \in (\mu_h, 1]$.

Proposition 4 *For $\mu \in (\mu_l, \mu_h]$, increasing the fine has stabilizing effect whereas for $\mu \in (\mu_h, 1]$ it has destabilizing effect.*

Proof. See Appendix. ■

For $\mu \in (\mu_l, \mu_h]$, basically the leniency program acts as only a punishing device for the cartel deviator. Thus increasing the fine will make the threat even stronger and cartel more stable whereas for $\mu \in (\mu_h, 1]$, the leniency has also whistle blowing effect which makes is even more attractive with higher fine.

5 Conclusion

There is no reason to suppose that competition authorities have the ability to commit to an antitrust enforcement policy. It seems more realistic to suppose that antitrust authorities strive to deter collusion on a case-by-case basis, respond to suspicious pricing behavior, and impose fines that are optimal ex post. In this paper we analyze a game between firm(s) and AA that has imperfect knowledge on production cost.

Contrary to the previous models, the premise and novelty of the current paper is that AA act strategically and without commitment on its auditing policy. AA maximizes social welfare which is a linear function of consumer and producer surplus. Given that fines are not perceived as mere welfare-neutral transfers, AA would not refrain from setting a fine, and does not shy away from imposing the maximum fine on firms that have been found guilty of price-fixing.

As it has been shown, we confirm that as long as the investigation is costly, even when there is no asymmetric information, the total cartel deterrence is not socially optimal and AA is better off if it could tolerate some degree of collusion. We demonstrate also that for the low and intermediate consumer surplus weight in the welfare function, there is a unique equilibrium with pure strategies in which AA does not investigate the market whereas for a relatively high weight, the game has a unique semi-separating equilibrium with mixed strategies in which the low type colludes and AA investigates with some positive probability.

We also show that, in the presence of substantial under-deterrence, probability and amount of punishment may become complements, whereas amount of punishment has deterrence effect in the sense that it will reduce the likelihood of forming cartel. Though welfare is shown to be non-monotonic in the consumer surplus weight, we show that the planner might be better off ex post if it cares only about consumer surplus. In fact, in practice since it may be difficult to select an intermediate weight, it is mostly assumed that AA is just maximizing consumer surplus.

The leniency program grants partial or full fine reduction to firms that voluntarily report their cartel. Theoretically ex ante it is not clear whether launching the leniency program would reduce or enhance the stability of cartels. We show that only for the relatively high consumer surplus weight, if the profit from undercutting is not attractive enough or there are not that many members in a cartel, a deviator firm is better off to apply for the leniency program rather that undercutting and basically only in this case the leniency is effective in destabilizing cartels. For the intermediate consumer surplus weight, the leniency program act as only a punishing device for the cartel deviator. Thus increasing the fine have perverse effects on the firms' ability to collude and will make the threat even stronger and cartel more stable whereas for the high bias, the leniency has whistle blowing effect which makes is even more attractive with higher fine.

6 Appendix A: Extensions

6.1 Auditing before Market Clearance

In the main model, AA might intervene into the market after the market has been cleared. Therefore it is not possible to change neither consumer surplus nor producer surplus and

AA's payoff will be from fine transfer net of auditing cost. In fact, the authority might also intervene in market before the market clearance in order to able to change the social surplus. In that case AA will impose the competitive price, which is equals to the marginal cost. Note that in this case, AA could not punish the anti-competitive behavior as a fraction of the turn-over or collusive profit since in fact they have not been realized yet. Thus the punishment regime is the fix fine $F > K$, which is independent of the observed market price. Thus AA would go for investigation if it is profitable to do so

$$\mu \int_{\theta}^{\bar{p}} Q(t)dt + \mu F - K > \mu \int_{p}^{\bar{p}} Q(t)dt + (1-\mu)\, Q(p)(p-\theta).$$

The left hand side is the payoff from certain investigation, $\beta = 1$, whereas the right hand side is the payoff of non-investigation, $\beta = 0$. Here the role of μ as consumer surplus weight is more visible than before. Therefore in this case

$$\hat{\mu}_l := \frac{K + Q(\bar{p})(\bar{p}-\theta)}{F + \int_{\theta}^{\bar{p}} Q(t)dt + Q(\bar{p})(\bar{p}-\theta)},$$

and

$$\hat{\mu}_h := \frac{K/\upsilon + Q(p)(p-\theta)}{F + \int_{\theta}^{p} Q(t)dt + Q(p)(p-\theta)}.$$

Similarly to the mail model, we have the same result but just with different intervals for μ.

6.2 Fine Distribution

So far, we have assumed that the fine would go to the packet of the authority but in fact in practice, at least part of it, would be used to compensate the consumers who have suffered from the illegal activity. Here we have taken this into account namely a fraction of fine, φ, is added to consumer surplus and AA enjoys the rest,

$$V(p,\theta) = E\left[\begin{array}{c} \tilde{\mu}\left[\int_{p}^{\bar{p}} Q(t)dt + \varphi\beta\alpha p Q(p)\right] \\ +(1-\tilde{\mu})\left[Q(p)(p-\theta) - \beta\alpha p Q(p)\right] + (1-\varphi)\,\beta\alpha p Q(p) - \beta K \end{array}\right].$$

AA would investigate the market if

$$\tilde{\mu}\varphi\alpha p Q(p) - (1-\tilde{\mu})\,\alpha p Q(p) + (1-\varphi)\,\alpha p Q(p) - K > 0,$$

which gives us

$$\tilde{\mu}_l := \frac{\varphi\alpha\bar{p}Q(\bar{p}) + K}{(1+\varphi)\,\alpha\bar{p}Q(\bar{p})}.$$

Note that since $\partial\tilde{\mu}_l/\partial\varphi > 0$ and $\mu_l = K/\alpha\bar{p}Q(\bar{p}) = \tilde{\mu}_l(\varphi = 0)$ we have $\tilde{\mu}_l > \mu_l$. Basically, AA has less incentive to investigate the market since its payoff from fine now has been shared also with the consumer.

7 Appendix B: Omitted Proofs

Proof of Lemma 3: Suppose that AA observes $p = \theta_h$. AA rationally expects that this price might be a collusive price originates from a low type with probability υ or a non-cooperative price of high type with probability $1 - \upsilon$. Given this belief, investigation will not be worthwhile as the expected payoff of an investigation is $\upsilon\mu\alpha\theta_h Q(\theta_h) - K < 0$. Both types set $p = \theta_h$ and in the equilibrium AA will not investigate at all. **Q.E.D.**

Proof of Lemma 4: As in the previous Lemma with an intermediate μ, the high type firm does not form a cartel and set price θ_h. Suppose the low type forms a cartel with certainty in equilibrium. Then, given the high bias, it will be optimal for AA to investigate $p = \theta_h$ with certainty. But then it would has not been optimal for the low type to collude. Suppose the low type never collude in equilibrium. Then, AA interprets $p = \theta_h$ as a signal that cost are high and does not investigate. But then it would has been optimal for the low type to collude in the first place. As a result, this subgame will not feature an equilibrium with pure strategies.

In order to find mixed strategies, θ_l must be indifference between setting $\hat{p}(\theta_l)$ and θ_h,

$$Q(\hat{p})(\hat{p} - \theta_l) = (1 - \beta)\, Q(\theta_h)(\theta_h - \theta_l) - \beta\alpha\theta_h Q(\theta_h),$$

and AA uses the Bayes' rule to update its prior belief and must be indifferent between investigating upon observing $p = \theta_h$ or not

$$\eta_{l|h}\mu\alpha\theta_h Q(\theta_h) = \frac{\upsilon(1-\tau)}{1-\tau\upsilon}\lambda\alpha\theta_h Q(\theta_h) = K,$$

where

$$\eta_{l|h} = \frac{\upsilon(1-\tau)}{\upsilon(1-\tau) + (1-\upsilon)} = \frac{\upsilon(1-\tau)}{1-\tau\upsilon},$$

express the posterior belief of AA on collusion. Solving these equations gives the equilibrium probabilities β and τ. **Q.E.D.**

Proof of Corollary 1: From (2), we have

$$\tau = \begin{cases} \tau^* & \mu > \mu_h \\ 0 & \mu \leq \mu_h \end{cases} .$$

Since $\partial \mu_h / \partial \alpha = -K/\alpha^2 \upsilon \theta_h Q(\theta_h) < 0$, for $\mu \leq \mu_h$ by increasing α, it will be more likely that $\mu > \mu_h$ and firms end up changing their strategy from being fully collusive to partially collusive whereas for $\mu > \mu_h$ since

$$\frac{\partial \tau^*}{\partial \alpha} = \frac{\mu (1-\upsilon) K \theta_h Q(\theta_h)}{\upsilon \left[K - \alpha \mu \theta_h Q(\theta_h)\right]^2} > 0,$$

the enforcement policy has deterrence effect in the sense that it increase the probability of competing. **Q.E.D.**

Proof of Corollary 2: From (3), we have

$$\beta = \begin{cases} \beta^*(\theta_h; \mu) & \mu > \mu_h \\ 0 & \mu \leq \mu_h \end{cases} .$$

For $\mu \leq \mu_h$, since by increasing α, it will be more likely that $\mu > \mu_h$, and β would increase from zero some positive number β^*. For $\mu > \mu_h$ we have

$$\frac{\partial \beta^*(\theta_h; \mu)}{\partial \alpha} = -\frac{\theta_h (\theta_h - \hat{p})}{\left[\theta_h (\alpha + 1) - \theta_l\right]^2} < 0,$$

which shows substitution effect. **Q.E.D.**

Proof of Proposition 1: Since for $\mu \in (1/2, \mu_l]$ consumer surplus is just zero, we are left with producer surplus for different cost realizations

$$\begin{aligned} W(1/2 < \mu < \mu_l) &= E\left[V(\bar{p}, \theta)\right] = \upsilon V(\bar{p}, \theta_l) + (1-\upsilon) V(\bar{p}, \theta_h) \\ &= (1-\mu)\left[\upsilon Q(\bar{p})(\bar{p} - \theta_l) - \upsilon Q(\bar{p})(\bar{p} - \theta_h) + Q(\bar{p})(\bar{p} - \theta_h)\right] \\ &= (1-\mu) Q(\bar{p}) \left[\upsilon(\theta_h - \theta_l) + \bar{p} - \theta_h\right], \end{aligned} \tag{16}$$

and obviously in this interval $\partial W(\mu) / \partial \mu < 0$.

For $\mu \in (\mu_l, \mu_h]$, both cost types would set θ_h as their price that leads to

$$\begin{aligned} W(\mu_l < \mu \leq \mu_h) &= E\left[V(\theta_h, \theta)\right] = \upsilon V(\theta_h, \theta_l) + (1-\upsilon) V(\theta_h, \theta_h) \\ &= \upsilon \left[\mu \int_{\theta_h}^{\bar{p}} Q(t) dt + (1-\mu) Q(\theta_h)(\theta_h - \theta_l)\right] + (1-\upsilon)\mu \int_{\theta_h}^{\bar{p}} Q(t) dt \\ &= \upsilon (1-\mu) Q(\theta_h)(\theta_h - \theta_l) + \mu \int_{\theta_h}^{\bar{p}} Q(t) dt. \end{aligned} \tag{17}$$

And finally

$$
\begin{aligned}
W\left(\mu_h<\mu<1\right) &= \upsilon\left[\tau V(\hat{p},\theta_l)+\left(1-\tau\right)V(\theta_h,\theta_l)\right]+\left(1-\upsilon\right)V(\theta_h,\theta_h) \qquad (18)\\
&= \upsilon\left\{\begin{array}{c}\tau\left[\mu\int_{\hat{p}}^{\bar{p}}Q(t)dt+\left(1-\mu\right)Q(\hat{p})(\hat{p}-\theta_l)\right]\\ +\left(1-\tau\right)\left\{\begin{array}{c}\left(1-\mu\right)\left[Q(\theta_h)(\theta_h-\theta_l)-\beta\alpha\theta_hQ(\theta_h)\right]\\ +\mu\int_{\theta_h}^{\bar{p}}Q(t)dt+\beta\alpha\theta_hQ(\theta_h)-\beta K\end{array}\right\}\end{array}\right\}\\
&\quad +\left(1-\upsilon\right)\mu\int_{\theta_h}^{\bar{p}}Q(t)dt\\
&= \upsilon\left\{\begin{array}{c}\tau\left[\mu\int_{\hat{p}}^{\bar{p}}Q(t)dt+\left(1-\mu\right)Q(\hat{p})(\hat{p}-\theta_l)\right]\\ +\left(1-\tau\right)\left\{\begin{array}{c}\left(1-\mu\right)\left[Q(\theta_h)(\theta_h-\theta_l)-\frac{(\theta_h-\hat{p})\alpha\theta_hQ(\theta_h)}{\theta_h(\alpha+1)-\theta_l}\right]\\ +\mu\int_{\theta_h}^{\bar{p}}Q(t)dt+\frac{(\theta_h-\hat{p})\alpha\theta_hQ(\theta_h)}{\theta_h(\alpha+1)-\theta_l}-\frac{(\theta_h-\hat{p})K}{\theta_h(\alpha+1)-\theta_l}\end{array}\right\}\end{array}\right\}\\
&\quad +\left(1-\upsilon\right)\mu\int_{\theta_h}^{\bar{p}}Q(t)dt.
\end{aligned}
$$

For $\mu_l<\mu\leq\mu_h$, we have two cases, if the prior belief of AA on facing a low type cost firm is low enough,

$$\upsilon<\tilde{\upsilon}:=\frac{\int_{\theta_h}^{\bar{p}}Q(t)dt}{Q(\theta_h)(\theta_h-\theta_l)},$$

then $\partial W\left(\mu\right)/\partial\mu=\int_{\theta_h}^{\bar{p}}Q(t)dt-\upsilon Q(\theta_h)(\theta_h-\theta_l)>0$, otherwise $\partial W\left(\mu\right)/\partial\mu<0$.

For $\mu>\mu_h$, if $\upsilon<\tilde{\upsilon}$ we have

$$
\begin{aligned}
\frac{\partial W\left(\mu\right)}{\partial\mu} &= \upsilon\left\{\begin{array}{c}\tau\left[\int_{\hat{p}}^{\bar{p}}Q(t)dt-Q(\hat{p})(\hat{p}-\theta_l)\right]\\ +\left(1-\tau\right)\left\{\int_{\theta_h}^{\bar{p}}Q(t)dt-\left[Q(\theta_h)(\theta_h-\theta_l)-\frac{(\theta_h-\hat{p})\alpha\theta_hQ(\theta_h)}{\theta_h(\alpha+1)-\theta_l}\right]\right\}\end{array}\right\}\\
&\quad +\left(1-\upsilon\right)\int_{\theta_h}^{\bar{p}}Q(t)dt\\
&= \upsilon\tau\left\{\int_{\hat{p}}^{\theta_h}Q(t)dt+\left[Q(\theta_h)(\theta_h-\theta_l)-Q(\hat{p})(\hat{p}-\theta_l)-\frac{\left(\theta_h-\hat{p}\right)\alpha\theta_hQ(\theta_h)}{\theta_h\left(\alpha+1\right)-\theta_l}\right]\right\}\\
&\quad +\int_{\theta_h}^{\bar{p}}Q(t)dt-\upsilon\left[Q(\theta_h)(\theta_h-\theta_l)-\frac{\left(\theta_h-\hat{p}\right)\alpha\theta_hQ(\theta_h)}{\theta_h\left(\alpha+1\right)-\theta_l}\right]\\
&= \upsilon\tau\left[\int_{\hat{p}}^{\theta_h}Q(t)dt+Q(\theta_h)(\theta_h-\theta_l)-Q(\hat{p})(\hat{p}-\theta_l)\right]\\
&\quad +\upsilon\left(1-\tau\right)\frac{\left(\theta_h-\hat{p}\right)\alpha\theta_hQ(\theta_h)}{\theta_h\left(\alpha+1\right)-\theta_l}\\
&\quad +\int_{\theta_h}^{\bar{p}}Q(t)dt-\upsilon Q(\theta_h)(\theta_h-\theta_l)\\
&> 0.
\end{aligned}
$$

Now we should check for $\upsilon > \tilde{\upsilon}$, but first note that $\Pi(\hat{p}) := \int_{\hat{p}}^{\bar{p}} Q(t)dt - Q(\bar{p})(\bar{p} - \theta_l)$, is positive for $\hat{p} = \theta_l$ and since $\partial\Pi(\hat{p})/\partial\hat{p} < 0$, $\Pi(\hat{p})$ would be still positive for small enough values of $\hat{p}$. Then $\partial W(\mu)/\partial\mu$ in this interval for $\upsilon = 1$,

$$\partial W(\mu)/\partial\mu(\upsilon = 1) = \int_{\hat{p}}^{\bar{p}} Q(t)dt - Q(\hat{p})(\hat{p} - \theta_l) > \int_{\hat{p}}^{\bar{p}} Q(t)dt - Q(\bar{p})(\bar{p} - \theta_l) > 0,$$

and for $\upsilon = 0$, $\partial W(\mu)/\partial\mu(\upsilon = 0) = \int_{\theta_h}^{\bar{p}} Q(t)dt$, both are positive and since $\partial W(\mu)/\partial\mu$ is linear with respect to υ, we have $\partial W(\mu > \mu_h)/\partial\mu > 0$. **Q.E.D.**

Proof of Proposition 2: If $\upsilon < \tilde{\upsilon}$ since $\partial W(\mu > \mu_h)/\partial\mu > 0$, $\mu = 1$ would maximizes the social welfare for $\mu > \mu_h$. Now we could compare it with the social welfare when $\mu_l < \mu \leq \mu_h$. From (18), we have

$$\begin{aligned} W(\mu = 1) &= \upsilon\tau \int_{\hat{p}}^{\bar{p}} Q(t)dt + (1 - \tau\upsilon) \int_{\theta_h}^{\bar{p}} Q(t)dt \\ &\quad + \upsilon(1 - \tau)\left\{\int_{\theta_h}^{\bar{p}} Q(t)dt + \frac{(\theta_h - \hat{p})\,\alpha\theta_h Q(\theta_h)}{\theta_h(\alpha + 1) - \theta_l} - \frac{(\theta_h - \hat{p})\,K}{\theta_h(\alpha + 1) - \theta_l}\right\}. \end{aligned}$$

Note that when $\upsilon = 1$, τ from (2) is also equals to 1. Subtracting (17) from it gives us

$$\begin{aligned} \Lambda(\upsilon) \quad &: = W(\mu = 1) - W(\mu_l < \mu \leq \mu_h) \\ &= \left[\upsilon\tau \int_{\hat{p}}^{\bar{p}} Q(t)dt + (1 - \upsilon\tau) \int_{\theta_h}^{\bar{p}} Q(t)dt\right] \\ &\quad + \upsilon(1 - \tau)\left\{\int_{\theta_h}^{\bar{p}} Q(t)dt + \frac{(\theta_h - \hat{p})\,\alpha\theta_h Q(\theta_h)}{\theta_h(\alpha + 1) - \theta_l} - \frac{(\theta_h - \hat{p})\,K}{\theta_h(\alpha + 1) - \theta_l}\right\} \\ &\quad - \left[\upsilon(1 - \mu)\,Q(\theta_h)(\theta_h - \theta_l) + \mu \int_{\theta_h}^{\bar{p}} Q(t)dt\right] \\ &= \upsilon\tau \int_{\hat{p}}^{\theta_h} Q(t)dt + (1 - \mu)\left[\int_{\theta_h}^{\bar{p}} Q(t)dt - \upsilon Q(\theta_h)(\theta_h - \theta_l)\right] \\ &\quad + \upsilon(1 - \tau)\left\{\int_{\theta_h}^{\bar{p}} Q(t)dt + \frac{(\theta_h - \hat{p})\left[\alpha\theta_h Q(\theta_h) - K\right]}{\theta_h(\alpha + 1) - \theta_l}\right\}. \end{aligned}$$

It is easy to show that $\Lambda(\upsilon = 0) = (1 - \mu)\int_{\theta_h}^{\bar{p}} Q(t)dt > 0$ and

$$\Lambda(\tilde{\upsilon}) = \tilde{\upsilon}\tau \int_{\hat{p}}^{\theta_h} Q(t)dt + \tilde{\upsilon}(1 - \tau)\left\{\int_{\theta_h}^{\bar{p}} Q(t)dt + \frac{(\theta_h - \hat{p})\left[\alpha\theta_h Q(\theta_h) - K\right]}{\theta_h(\alpha + 1) - \theta_l}\right\} > 0$$

and since $\Lambda(\upsilon)$ is linear in υ, thus $\Lambda(\upsilon) > 0$.

If $\upsilon > \tilde{\upsilon}$ and $\hat{p}$ is small enough, $W(\mu)$ would be still increasing in μ. Given $\Lambda(\tilde{\upsilon}) > 0$ and since

$$\begin{aligned}
\Lambda(\upsilon &= 1) = \int_{\hat{p}}^{\theta_h} Q(t)dt + (1-\mu)\left[\int_{\theta_h}^{\bar{p}} Q(t)dt - Q(\theta_h)(\theta_h - \theta_l)\right] \\
&> \int_{\hat{p}}^{\bar{p}} Q(t)dt - (1-\mu)\, Q(\theta_h)(\theta_h - \theta_l) - \mu \int_{\theta_h}^{\bar{p}} Q(t)dt \\
&> \int_{\hat{p}}^{\bar{p}} Q(t)dt - (1-\mu)\, Q(\theta_h)(\theta_h - \theta_l) - \mu \int_{\hat{p}}^{\bar{p}} Q(t)dt \\
&= (1-\mu)\left[\int_{\hat{p}}^{\bar{p}} Q(t)dt - Q(\theta_h)(\theta_h - \theta_l)\right] \\
&> (1-\mu)\left[\int_{\hat{p}}^{\bar{p}} Q(t)dt - Q(\bar{p})(\bar{p} - \theta_l)\right] \\
&> 0,
\end{aligned}$$

therefore $\Lambda(\upsilon) > 0$ which means $W(\mu = 1) > W(\mu_l < \mu \leq \mu_h)$.

Now we could check for $\mu \in (1/2, \mu_l]$. We showed that the social welfare function is decreasing in this interval with respect to μ, hence we just need to check for $\mu = 0$. Given $W(\mu = 0) = Q(\bar{p})\left[\upsilon(\theta_h - \theta_l) + \bar{p} - \theta_h\right]$ from (16), we have

$$\begin{aligned}
\Omega(\upsilon) \quad &: = W(\mu = 1) - W(\mu = 0) \\
&= \upsilon\tau \int_{\hat{p}}^{\bar{p}} Q(t)dt + (1 - \upsilon\tau) \int_{\theta_h}^{\bar{p}} Q(t)dt \\
&\quad + \upsilon(1-\tau)\left\{\int_{\theta_h}^{\bar{p}} Q(t)dt + \frac{(\theta_h - \hat{p})\,\alpha\theta_h Q(\theta_h)}{\theta_h(\alpha+1) - \theta_l} - \frac{(\theta_h - \hat{p})\,K}{\theta_h(\alpha+1) - \theta_l}\right\} \\
&\quad - Q(\bar{p})\left[\upsilon(\theta_h - \theta_l) + \bar{p} - \theta_h\right] \\
&= \upsilon\tau \int_{\hat{p}}^{\bar{p}} Q(t)dt - \upsilon\tau \int_{\theta_h}^{\bar{p}} Q(t)dt + \int_{\theta_h}^{\bar{p}} Q(t)dt - \int_{\theta_h}^{\bar{p}} Q(\bar{p})dt - \upsilon \int_{\theta_l}^{\theta_h} Q(\bar{p})dt \\
&\quad + \upsilon(1-\tau)\left\{\int_{\theta_h}^{\bar{p}} Q(t)dt + \frac{(\theta_h - \hat{p})\,\alpha\theta_h Q(\theta_h)}{\theta_h(\alpha+1) - \theta_l} - \frac{(\theta_h - \hat{p})\,K}{\theta_h(\alpha+1) - \theta_l}\right\} \\
&= \upsilon\tau \int_{\hat{p}}^{\theta_h} Q(t)dt + \int_{\theta_h}^{\bar{p}} \left[Q(t) - Q(\bar{p})\right] dt - \upsilon \int_{\theta_l}^{\theta_h} Q(\bar{p})dt \\
&\quad + \upsilon(1-\tau)\left\{\int_{\theta_h}^{\bar{p}} Q(t)dt + \frac{(\theta_h - \hat{p})\,\alpha\theta_h Q(\theta_h)}{\theta_h(\alpha+1) - \theta_l} - \frac{(\theta_h - \hat{p})\,K}{\theta_h(\alpha+1) - \theta_l}\right\}.
\end{aligned}$$

For a market with only high cost type firms we have $\Omega(\upsilon = 0) = \int_{\theta_h}^{\bar{p}} \left[Q(t) - Q(\bar{p})\right] dt > 0$ and for the one with only with only low type firms we have

$$\Omega(\upsilon = 1) = \int_{\hat{p}}^{\bar{p}} Q(t)dt - \int_{\theta_l}^{\bar{p}} Q(\bar{p})dt = \int_{\hat{p}}^{\bar{p}} Q(t)dt - Q(\bar{p})(\bar{p} - \theta_l),$$

which is positive for small values of $\hat{p}$. Since $\Omega(\upsilon)$ is linear with respect to υ, therefore $\Omega(\upsilon) > 0$ or in other words $W(\mu = 1) > W(\mu = 0)$. All in all we have shown that $(\mu = 1) = \arg\max W(\mu)$. **Q.E.D.**

Proof of Lemma 5:

$$\begin{aligned}
\partial\Pi/\partial p \quad : \quad & = Q'(p)(p-\theta) + Q(p) - \frac{\alpha}{N}\left[pQ'(p) + Q(p)\right] \\
& > \left(1 - \frac{\alpha}{N}\right)\left[pQ'(p) + Q(p)\right] \\
& > 0.
\end{aligned}$$

Q.E.D.

Proof of Corollary 3:

$$\begin{aligned}
\lim_{\mu\to\mu_l^-} W(\mu = \mu_l) &= (1-\mu_l)\, Q(\bar{p})\left[\upsilon(\theta_h - \theta_l) + \bar{p} - \theta_h\right] \\
&< (1-\mu_l)\, Q(\theta_h)\upsilon(\theta_h - \theta_l) + (1-\mu_l)\, Q(\bar{p})\,(\bar{p} - \theta_h) \\
&< \upsilon\,(1-\mu_l)\, Q(\theta_h)(\theta_h - \theta_l) + \mu_l \int_{\theta_h}^{\bar{p}} Q(t)dt \\
&= \lim_{\mu\to\mu_l^+} W(\mu = \mu_l)
\end{aligned}$$

$$\begin{aligned}
\lim_{\mu\to\mu_h^+} W(\mu = \mu_h) \quad = \quad & \upsilon \left\{ \begin{array}{c} \tau\left[\mu_h \int_{\hat{p}}^{\bar{p}} Q(t)dt + (1-\mu_h)\, Q(\hat{p})(\hat{p} - \theta_l)\right] \\ +(1-\tau)\left\{ \begin{array}{c} (1-\mu_h)\left[Q(\theta_h)(\theta_h - \theta_l) - \frac{(\theta_h - \hat{p})\alpha\theta_h Q(\theta_h)}{\theta_h(\alpha+1)-\theta_l}\right] \\ +\mu_h \int_{\theta_h}^{\bar{p}} Q(t)dt + \frac{(\theta_h - \hat{p})\alpha\theta_h Q(\theta_h)}{\theta_h(\alpha+1)-\theta_l} - \frac{(\theta_h - \hat{p})K}{\theta_h(\alpha+1)-\theta_l} \end{array} \right\} \end{array} \right\} \\
& + (1-\upsilon)\,\mu_h \int_{\theta_h}^{\bar{p}} Q(t)dt
\end{aligned}$$

$$\lim_{\mu\to\mu_h^-} W(\mu = \mu_h) = (1-\mu_h)\, Q(\theta_h)\upsilon(\theta_h - \theta_l) + \mu_h \int_{\theta_h}^{\bar{p}} Q(t)dt$$

$$
\begin{aligned}
& \lim_{\mu \to \mu_h^+} W(\mu = \mu_h) - \lim_{\mu \to \mu_h^-} W(\mu = \mu_h) \\
= \;& \upsilon\tau \left\{ \mu_h \int_{\hat{p}}^{\theta_h} Q(t)dt + (1-\mu_h) \left[Q(\hat{p})(\hat{p}-\theta_l) - Q(\theta_h)(\theta_h - \theta_l) \right] \right\} \\
& + \frac{\upsilon(1-\tau)(\theta_h - \hat{p}) \left[\mu\alpha\theta_h Q(\theta_h) - K \right]}{\theta_h(\alpha+1) - \theta_l} \\
> \;& \upsilon\tau \left\{ \mu_h \int_{\hat{p}}^{\theta_h} Q(t)dt - (1-\mu_h) Q(\theta_h)(\theta_h - \hat{p}) \right\} \\
& + \frac{\upsilon(1-\tau)(\theta_h - \hat{p}) \left[\mu\alpha\theta_h Q(\theta_h) - K \right]}{\theta_h(\alpha+1) - \theta_l} \\
> \;& \upsilon\tau (2\mu_h - 1) Q(\theta_h)(\theta_h - \hat{p}) + \frac{\upsilon(1-\tau)(\theta_h - \hat{p}) \left[\mu\alpha\theta_h Q(\theta_h) - K \right]}{\theta_h(\alpha+1) - \theta_l} \\
> \;& 0
\end{aligned}
$$

Q.E.D.

Proof of Proposition 3: We have

$$
\tilde{\delta}_2^u = \frac{(N-1)(\theta_h - \theta_l) - \alpha\theta_h}{(N-1+\upsilon)(\theta_h - \theta_l) - \alpha\theta_h}.
$$

$$
\tilde{\delta}_2^w = \frac{N\pi(\hat{p},\theta_l) - \pi(\theta_h,\theta_l)}{N\pi(\hat{p},\theta_l) - (1-\upsilon)\pi(\theta_h,\theta_l)} = \frac{(N-1)(\theta_h - \theta_l) - \alpha\theta_h + \Omega}{(N-1+\upsilon)(\theta_h - \theta_l) - \alpha\theta_h + \Omega},
$$

where by assumption $\Omega := N\left[\pi(\hat{p},\theta_l) - \pi(\theta_h,\theta_l)\right] + \alpha\theta_h Q(\theta_h) > 0$ therefore $\tilde{\delta}_2^w > \tilde{\delta}_2^u$. Also

$$
\tilde{\delta}_3^u = \frac{(N-1)(\theta_h - \theta_l) - \alpha(1-\beta)\theta_h}{(N-1+\upsilon)(\theta_h - \theta_l) - \alpha(1-\beta+\beta\upsilon)\theta_h}.
$$

And

$$
\begin{aligned}
\tilde{\delta}_3^w \; : \; &= \frac{N\pi(\hat{p},\theta_l) - \left[\pi(\theta_h,\theta_l) - \beta\alpha\theta_h Q(\theta_h)\right]}{N\pi(\hat{p},\theta_l) - (1-\upsilon)\left[\pi(\theta_h,\theta_l) - \beta\alpha\theta_h Q(\theta_h)\right]} \\
&= \frac{\beta\alpha\theta_h Q(\theta_h) + \left[N\pi(\hat{p},\theta_l) - \pi(\theta_h,\theta_l)\right]}{\upsilon\pi(\theta_h,\theta_l) + (1-\upsilon)\beta\alpha\theta_h Q(\theta_h) + \left[N\pi(\hat{p},\theta_l) - \pi(\theta_h,\theta_l)\right]}.
\end{aligned}
$$

It is east to show that $\tilde{\delta}_3^w > \tilde{\delta}_3^u$. If $N\pi(\hat{p},\theta_l) < \pi(\theta_h,\theta_l)$, $\tilde{\delta}_3^r > \tilde{\delta}_3^w > \tilde{\delta}_3^u$ where

$$
\tilde{\delta}_3^r = \frac{\beta\alpha\theta_h}{\upsilon(\theta_h - \theta_l) + (1-\upsilon)\beta\alpha\theta_h},
$$

otherwise

$$
\tilde{\delta}_3^u = \frac{(N-1)(\theta_h - \theta_l) - \alpha(1-\beta)\theta_h}{(N-1+\upsilon)(\theta_h - \theta_l) - \alpha(1-\beta+\beta\upsilon)\theta_h} = \frac{\beta\alpha\theta_h + \Delta}{\upsilon(\theta_h - \theta_l) + (1-\upsilon)\beta\alpha\theta_h + \Delta}
$$

where $\Delta := \tilde{\delta}_3^u - \tilde{\delta}_3^r = (N-1)(\theta_h - \theta_l) - \alpha\theta_h < 0$ and thus $\tilde{\delta}_3^w > \tilde{\delta}_3^u > \tilde{\delta}_3^r$. **Q.E.D.**

Proof of Proposition 4:

$$\frac{\partial \tilde{\delta}_2^u}{\partial \alpha} = -\frac{\upsilon\theta_h(\theta_h - \theta_l)}{[(N-1+\upsilon)(\theta_h - \theta_l) - \alpha\theta_h]^2} < 0$$

$$\begin{aligned}
\frac{\partial \tilde{\delta}_3^w}{\partial \alpha} &= \frac{\upsilon N\pi(\hat{p},\theta_l)\theta_h Q(\theta_h)}{\{N\pi(\hat{p},\theta_l) - (1-\upsilon)[\pi(\theta_h,\theta_l) - \beta\alpha\theta_h Q(\theta_h)]\}^2}\left(\beta - \alpha\frac{\partial\beta}{\partial\alpha}\right) \\
&= \frac{\upsilon N\pi(\hat{p},\theta_l)\theta_h Q(\theta_h)}{\{N\pi(\hat{p},\theta_l) - (1-\upsilon)[\pi(\theta_h,\theta_l) - \beta\alpha\theta_h Q(\theta_h)]\}^2}\left[\frac{(\theta_h - \hat{p})(\theta_h - \theta_l)}{\theta_h(\alpha+1) - \theta_l}\right] > 0
\end{aligned}$$

$$\frac{\partial \tilde{\delta}_3^r}{\partial \alpha} = \frac{\upsilon\theta_h(\theta_h - \hat{p})(\theta_h - \theta_l)^2}{[\upsilon(\theta_h - \theta_l) + \alpha\beta\theta_h - \alpha\beta\upsilon\theta_h]^2[\theta_h(\alpha+1) - \theta_l]^2} > 0$$

$$\tilde{\delta}_3^u := \frac{(N-1)(\theta_h - \theta_l) - \alpha(1-\beta)\theta_h}{(N-1+\upsilon)(\theta_h - \theta_l) - \alpha(1-\beta+\beta\upsilon)\theta_h} = \frac{\beta\alpha\theta_h + \Delta}{\upsilon(\theta_h - \theta_l) + (1-\upsilon)\beta\alpha\theta_h + \Delta}$$

$$\begin{aligned}
\frac{\partial \tilde{\delta}_3^u}{\partial \alpha} &= \frac{1}{[\upsilon(\theta_h - \theta_l) + (1-\upsilon)\beta\alpha\theta_h + \Delta]^2}\left\{\frac{\upsilon\theta_h(\theta_h - \hat{p})(\theta_h - \theta_l)^2}{[\theta_h(\alpha+1) - \theta_l]^2} - \Delta'\upsilon\beta\alpha\theta_h + \Delta(\upsilon\beta\alpha\theta_h)'\right\} \\
&= \frac{1}{[\upsilon(\theta_h - \theta_l) + (1-\upsilon)\beta\alpha\theta_h + \Delta]^2}\left\{\frac{\upsilon\theta_h(\theta_h - \hat{p})(\theta_h - \theta_l)^2}{[\theta_h(\alpha+1) - \theta_l]^2} + \upsilon\beta(N-1)\theta_h(\theta_h - \theta_l)\right\} \\
&> 0
\end{aligned}$$

Q.E.D.

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