Imperfect Competition Law Enforcement*

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Abstract

Competition policy is a subject of often heated debate. Competition authorities, seeking to battle anticompetitive acts in complex cases to the best of their abilities, regularly find themselves advised by rival economic theories and disputed empirical analyses. As a consequence, there is a real possibility that they may occasionally err, missing true violations of competition law or finding firms liable that have actually done nothing but good competition. In this paper, possible consequences of such imperfect competition law enforcement on firm strategies are considered. In a simple cartel setting, it is found that the incidence of anti-competitive behavior increases in both types of enforcement errors: Type II errors decrease expected fines, while Type I errors encourage industries to collude precautionary when they face the risk of false allegations. Hence, fallible antitrust enforcement may stifle genuine competition. Moreover, when enforcement error are non-negligible, competition authorities run the risk of being over-zealous, in the sense that welfare is best served by an authority that is selective in its targeting of alleged anticompetitive acts.

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1 Introduction

Competition policy is controversial and often advised by rival economic theories. Many contributors to the central debate whether antitrust intervention is a cure for imperfect competition and inefficiency or rather a cause take the latter view as point of departure. Exponents of what is commonly referred to as 'the Chicago School', such as Robert Bork and Richard Posner, point to a variety of reasons for why one should be wary of competition policy.[1] They stress that it is often difficult to determine in merger control, for example, whether the alleged significant lessening of competition is really there, and if so, whether there is indeed a net consumer detriment when the potential efficiency gains in mergers are taken into account. Likewise, in antitrust investigations they would point out that it is no easy matter to disentangle alleged anticompetitive behavior, such as predatory pricing, and good competition. In particular also, these scholars express concern for the appropriateness of the enforcement process. In his now classical monograph *Antitrust Law*, first published in 1976, Posner warned in no uncertain terms that in his experience antitrust cases are complicated and costly, yet often handled by

> "[t]rial lawyers [that] tend to be combative rather than reflective, and ... division's trial lawyers [that], because they are relatively poorly paid, tend to be young or mediocre, or to be zealots, [... who, ...] [a]s a result of neglect of economic principles, ... have fashioned a body of substantive doctrine and a system of sanctions and procedures that are poorly suited to carrying out the fundamental objectives of antitrust policy—the promotion of competition and efficiency." (*op.cit.*, pp.231-6)[2]

In Baumol and Ordover (1985) the concern for government failure is taken a step further by raising the issue of antitrust institutions being strategically misused as an instrument of monopolization. The authorities may be seduced to bring spurious antitrust cases, intended to subvert competition—a "specter," they say, that is likely to be "... more than offsetting the contributions to economic efficiency promised by antitrust activities," and that we "would do well to take steps to exorcise."[3] And in fact, there now is a substantive literature on perverse strategic firm behavior in the presence of an antitrust authority.

The wording that these authors choose is rather strong, yet a reserve towards competition intervention is found with scholars that are sympathetic to checking competitive processes, as well. Franklin Fisher, an antitrust veteran in both defendant and plaintiff camps, for example, teaches on the difficulty to establish true anticompetitive behavior that:

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[1] *Cf.* Bork (1993) and Posner (1976, 2002).

[2] In the recent and extensively re-edited 2002 edition of this monograph, Posner expresses—albeit in somewhat milder terms—a similar concern for particularly the enforcement process as the main open problem area in competition policy today. *Cf.*, *op.cit.*, Chapter 10.

[3] *Op.cit.*, p.247.

> "Economists and others ought to approach the public policy problems involved in these areas with a certain humility. Real industries tend to be very complicated. One ought not to tinker with a well-performing industry on the basis of simplistic judgments. The diagnosis of the monopoly disease is sufficiently difficult that one ought not to proceed to surgery without thorough examination of the patient and a thorough understanding of the medical principles involved." (Fisher, 1991, p.32)

And also some of those who explicitly advocate active government oversight of competitive processes acknowledge that there potentially are serious problems in the enforcement of complicated merger control and sophisticated antitrust analysis.[4]

Controversy has, as a result, surrounded the US antitrust practice from the very formulation of the Sherman Act. Bork (1966) narrates how several senators asked that men of "superior skill and intelligence," that thus obtained dominance in their markets, were to be kept from being made "culprits by the bill." Early conflicting Supreme Court decisions in the *Standard Oil* case in 1911 and *U.S. vs. United States Steel* in 1920, where in the latter case the court passed overt and clear collusion by majority vote, paralyzed the Sherman Act until after World War II. Likewise, in one of the first major European Commission decisions, *Continental Can* in 1973, the European Court of Justice found on appeal in favor of the defendant. And very recently, both the US and the EU Microsoft cases pivoted around the question whether Microsoft bundled Internet Explorer with Windows and Media Player to produce a competitive product necessary to survive in the viciously competitive operating systems market, or whether instead it did so out of predatory motives with the intent to levy its monopoly power.

With so much indication that the enforcement of competition policy may not be trouble free, the question presents itself as to what could be the consequences of antitrust cases brought that in hindsight turned out to have had little merit, or worse, that led to false convictions. Again, conjectures diverge and are occasionally strong. Harold Demsetz, for example, once quite sceptically wrote that:

> "Unfortunately, our antitrust laws are being used to protect competitors and penalize efficiency. Competitive pricing policies, effective advertizing campaigns, and the efficient management of resources are *as likely* to run afoul of antitrust as are attempts to collude." (Demsetz, 1974, p.183, italics added)

Others, however, are confident that enforcement errors are negligible, in particular that firms found in breach of competition law did indeed behave anticompetitively. Comfort then is taken in the various appeals procedures that exist to filter any judgement errors earlier on in the enforcement chain.

[4] Martin (1993), *e.g.*, discusses enforcement difficulties extensively in Chapter 18 of his introductory book in competition economics.

It is however difficult, and arguably impossible by the nature of the subject, to obtain systematic evidence of mistaken antitrust convictions. Some indication, however, may be had from the history of competition policy enforcement. In the US, this has been a rich source for empirical research and learning for decades. Apart from various summary statistics, such as time trends, in this literature the probability of conviction has been studied. Gallo, Dau-Schmidt, Craycraft and Parker (2000), for example, has a section on the win-loss record of the US Department of Justice (DOJ) antitrust enforcement.[5] From 1955 to 1997, the DOJ won 86 percent of all individual cases, which the authors celebrate. Interestingly enough, however, the average is substantially increased by successful criminal cases: 92 percent won, versus 77 percent civil cases, which is attributed to greater investigatory efforts channeled to criminal cases, as well as the fact that these are hard-core per se violations of which "the illegality of the practice is clear," and that dealt almost exclusively with small firms, without the means to obtain good legal advice.[6]

Similarly comprehensive studies on the sixty years younger European Commission enforcement history of competition law are, to our knowledge, not available.[7] In several isolated EU Member States, national enforcement has been studied. Adverse findings in cases taken up by the Monopolies and Merger Commission in the United Kingdom, for example, are reported on in Davies, Drifield and Clarke (1999). Inspired by that paper, a preliminary study on the "success rate" of the German Bundeskartelamt is set out in Lauk (2002). These studies suggest that in roughly one third of the U.K. cases, to one quarter of German competition policy investigations the cases against alleged violators were eventually found to have insufficient merit. And again, the more complicated cases, such as vertical restraints other than exclusive dealing, are found to be least likely to result in an adverse finding.

A notable singular study on errors in competition policy is Duso, Neven and Roeller (2003), which is concerned with EU merger control. On mergers, there is some anecdotal evidence of enforcement errors from the string of reversals by the Court of First Instance of mergers blocked by Mario Monti's merger task force in the end of 2002. The Duso *et al.* paper uses stock market data to evaluate whether the EU merger control decisions to allow or block mergers between 1990 and 2002 were correct in hindsight, on the argument that anticompetitive mergers would benefit parties outside the merger as well, whereas procompetitive ones would not. They find symmetric error margins close to 25%. A theoretical underpinning of the detrimental effects of such unsophisticated merger control is given in Motta and Vasconcelos (2003).

[5] *Op.cit.*, pp.112-9.

[6] *Op.cit.*, p.119.

[7] That is, apart from several partial data analyses, such as an appendix that tables fines for infringements in EU competition cases in Ritter, *et al.* (2000), and the occasional bar diagram in DG Competition's annual reports, *cf.* European Commission (2003).

There is a distinct literature on the incentive effects of competition policy enforcement—in particular on antitrust which is much more difficult to police—that extends on the seminal Becker (1968). Early references on public enforcement are Block, Nold and Sidak (1981) and Besanko and Spulber (1989). Salop and White (1986), Salant (1987) and Baker (1988) are among the first to consider private enforcement through the claiming of antitrust damages reparation. Refinements of our understanding of enforcement effects include Cyrenne (1999), which takes up commitment issues, and Souam (2001), in which alternative fine structures are studied. Harrington (2003) considers the dynamic pricing behavior of cartels when competition authorities or others use prices as an important signal to detect the presence of collusion, and Briggs, Huryn and McBride (1996) analyses the effects of private damages follow-on suit for legal strategies in public cases. None of these contributions focusses on the possibility that enforcement is fallible, however.

The principal problem in formulating competition policy that makes its enforcement open to mistakes is a lack of information by the authorities on relevant data such as firm costs, consumer demand, prices, sales, potential efficiency gains and possible collusive agreements. When information is indeed asymmetric, observed production levels and prices, for example, are imperfect signals. They can be a sign of collusive behavior with low costs, as well as competition with high costs, for example. When merger control or antitrust investigations into such industries is costly, it is generally good for welfare to tolerate modest levels of market power and collusion, particularly in efficient and low-cost industries. Instead, the authority should then commit itself to investigate firms in the high cost industry with positive probability. This would both prevent the high cost firms from raising prices above marginal costs and moderate the collusive behavior in the low-cost industry.[8]

Although this principal-agent approach to competition policy enforcement introduces the probability of investigation and suit, it assumes that once firms have been targeted for inspection, the competition authority is able to determine with certainty what the situation is and whether or not the notified merger can be allowed or competition laws have been violated. That is, the authority can err by investigating firms that are subsequently found not to lessen competition or to have acted competitively, or by deciding not to inspect firms that are, in fact, forming a competition impeding merger or that are colluding, but screening always lifts the asymmetric information problem fully.

In this paper, we explore the consequences of investigatory procedures that do not necessarily reveal the truth about parties' behaviors. This is done in an antitrust setting comparable to that in Besanko and Spulber (1989). In a simple model of potential cartel behavior with asymmetrically known cost types, two different kinds of deviations from the null hypothesis that only firms that indeed acted anticompet-

[8] *Cf.* Besanko and Spulber (1989), which relates to a literature on a principal-agent approach to tax compliance, in which comparable optimal enforcement results are obtained—*cf.* Andreoni, Erard and Feinstein (1998).

itively are successfully prosecuted arise: Type I errors—finding an industry that is competitive liable of anticompetitive behavior—and Type II errors—acquitting companies that have in fact acted anticompetitively.[9] It is found that the incidence of anti-competitive behavior increases in the competition authority's enforcement error, for two reasons. Firstly, and most obviously, the probability of getting caught when behaving anticompetitively goes down, leading to lower expected fines for firms that are sanctioned. Secondly, the risk of being sanctioned despite having been competitive goes up, inducing industries to collude as a 'precautionary' measure. These two unambiguous effects reveal that fallible antitrust policy may well stifle genuine competition. More specifically, when enforcement error are large, competition authorities run an increased risk of being over-zealous, in the sense that welfare is best served by an authority that is selective in its targeting of alleged anticompetitive acts. Some numerical examples illustrate these findings.

The remainder of this paper is organized as follows. The next section present a basic model of competition law enforcement. Section 3 then studies this benchmark situation, in which the competition authority has the ability to determine with certainty the type of industry upon investigation. In Section 4, the authority is explicitly given an assessment error margin. Subsequently, in Section 5 the full consequences of imperfect competition law enforcement are propositioned. Section 6 illustrates these findings by means of several numerical examples. Section 7 concludes with a discussion of some possible policy implications of the present findings and some suggestions for further refinements of the results.

2 A Benchmark Model of Antitrust Enforcement

Consider an economy with industries that each consist of an equal number of identical risk-neutral firms producing a homogeneous product for which consumer demand is given by a decreasing inverse demand function $P(q)$, where q is industry output. Each industry is characterized by the constant marginal cost level θ of the firms operating in it, which can take on three different values, $\theta_3 > \theta_2 > \theta_1 \geq 0$. The actual cost-type is known to the firms in the industry, but not to the authority, which assigns probability γ_i to the event that the industry is of cost-type i—naturally, $\gamma_1 + \gamma_2 + \gamma_3 = 1$.

Given their cost structure, firms in an industry have the option to behave competitively, or to collude and reduce output. If they behave competitively, firms produce at marginal costs in Bertrand-Nash equilibrium, so that industry output q_i, $i = 1, 2, 3$ is on the perfectly competitive level, implicitly defined by $P(q_i) = \theta_i$. Industry eco-

[9] There are some results on the consequences of errors in tax auditing, relating them to the complexity of tax laws and the training of auditors and courts—*cf.* Kaplow and Shavell (1994). Interestingly enough, it is found that randomness typically edges tax payers to compliance and allows audit expenses to be directed better, increasing total tax revenue—*cf.* Andreoni, Erard and Feinstein (1998).

nomic profits, defined as

$$\pi(q, \theta_i) \equiv P(q)\, q - \theta_i q,$$

are then equal to zero. Note that by construction $q_1 > q_2 > q_3$.[10]

If an industry colludes, it conspires to produce less than the competitive output. In order to hide its anticompetitive arrangements from clients, consumers and ultimately the authorities, the cartel picks the competitive output of another industry type. That is, a collusive industry of type i earns industry profits $\pi(q_j, \theta_i) > 0$ with $j > i$.[11] Note that this setup implies that there is no possibility for type 3 industries to collude. Furthermore, notice that we abstract from the much more sophisticated ways in which competition authorities may detect cartels in practice, such as monitoring parallel price movements, noting substantial long-term profits or failure to compete for some buyers, or following leads by disgruntled employees or customers.[12] In all these cases, however, the price strategy followed by cartels seems an important source of suspicion for either notification by interested parties, or government's own initiative. Ultimately, that is, cartel detection is driven by the extent to which sustained pricing above average costs can be kept a secret.[13] Do note, however, that since costs are unknown to the authorities, it is not an obvious matter to use economic profits as a statistic for cartel detection.

In the absence of antitrust intervention, industry payoffs are represented in Table 1, where the '×-s' in the upper-right cells follow from the assumption that an industry will never produce more than the competitive output corresponding to its cost type.

	θ_1	θ_2	θ_3
q_1	0	$\times$	$\times$
q_2	$\pi(q_2, \theta_1)$	0	$\times$
q_3	$\pi(q_3, \theta_1)$	$\pi(q_3, \theta_2)$	0

Table 1: Industry pay-off matrix without competition law enforcement.

Clearly, without the threat of antitrust intervention, a type 1 industry will produce q_2 or q_3—whichever gives it the highest profit—and a type 2 industry will produce

[10] It is not important for our results that the economic profits of competing in the industry are indeed equal to zero. What matters only is that firm profits (for any costs type) are smaller under competition than under cartellization. Our qualitative findings go through when the competitive benchmark is 'softer', as in Cournot competition with a limited number of firms. One way to think about Bertrand competition here, therefore, is as a convenient normalization.

[11] In the following, issues of internal cartel stability are neglected. A collusive industry is assumed to be able to sustain profits with no problems under reference to the traditional cartel stability arguments—*cf.* Carlton and Perloff (2000), Chapter 5.

[12] *Cf.* McAnney (1991). We thank Paul Geroski for pointing out this issue.

[13] *Cf.* Harrington (2003).

q_3. Type 3 industries always behave competitively at zero profits. Also note that the ranking of marginal costs implies that $\pi(q_3, \theta_1) > \pi(q_3, \theta_2)$. Furthermore, the following restriction of the variety of effects in our model is convenient. To prevent it from being attractive for type 1 industries to attempt to collude at the q_3 level, we assume that a larger profit can be obtained from producing q_2. That is, we make the following assumption.

Assumption 1 $\pi(q_2, \theta_1) > \pi(q_3, \theta_1)$.

Note that, since the parameters of competition law enforcement influence the firms' payoffs in the following, neither the ordering in Assumption 1, nor the fact that it is known to the competition authority gives the authority additional insight into the behavior of the firms. That is, depending on the (possibly fallible) enforcement regime, type 1 firms may still decide to produce q_3, as will be made explicit below. Similar effects to those reported on below follow if, instead of Assumption 1, we assume the opposite; that type 1 firms prefer producing q_3 over producing q_2.

Typically, the collusive behavior of type 1 and type 2 industries runs the risk of being policed by the competition authority. As demand is common knowledge, the authority can observe the industry price and output perfectly. Without costly investigation, however, it has no information about cost types. Consequently, when the authority observes an output of q_2, it cannot distinguish between a competitive industry of type 2 and a collusive industry of type 1. Likewise, when q_3 is produced, the authority cannot *a priori* tell a competitive type 3 industry from either a type 1 or a type 2 industry colluding.

In order to fight collusive behavior, we assume that the competition authority can credibly commit itself to an investigation policy $(\beta_2, \beta_3) \in [0,1] \times [0,1]$, where β_i is the probability with which the authority investigates an industry when it sees an output level of q_i, for $i = 2, 3$. Obviously, there is no reason for the authority to investigate an industry producing q_1, since this output level can only profitably be the competitive output of a type 1 industry. In the following, it is assumed to be common knowledge that the authority operates in the way it does. Note, however, that any uncertainty on the side of firms as to the probability with which they will be visited by the competition authority—occasionally suggested as a possible dimension of competition law enforcement—would lead to firms perceiving a distribution over various values of β, which reduces to a point estimate in the firms' decision making. Even if the objective probability of suit and the firms' subjective evaluation of it are initially different, they are likely to converge over time when the behavior of the authority is observed.

Suppose for the moment that if the competition authority decides to investigate an industry, it learns the industry's type with certainty. Should it discover collusion, the industry is found liable of anticompetitive behavior and given sanction. For simplicity—and in keeping with the static nature of the model—remedies are limited to a simple fine of size A. It is assumed that A is larger than the profit any industry can maximally obtain by colluding—as otherwise deterrence would be difficult to assure. Note that, since imposing fines is assumed to involve next to no cost for the competition authority whereas investigation is not, fine levels should in fact be set as high as possible. However, in practice for a variety of reasons fines are bounded: the Sherman Act presently specifies a maximum fine level of $\$10,000,000$ for corporations, and the Commission Notice on remedies sets an upper-bound to cartel fines of 10% of total associated revenues.[14] Many member states apply a combination of a revenue related maximum and a fixed maximum, where the latter typically binds for larger firms. Although European fines are often much more substantial than those in the US as a result, arguments to punish 'reasonably' apply everywhere. In particular, competition policy should not have as its consequence the elimination of firms from the market through excessive punishment and bankruptcy. Moreover, firms typically have limited liability. In all, even though assuming that remedies bite at all may be strong, assuming that fines are unrelated to profits seems not. Moreover, should, in the present setting, sanctions be related to output, this would introduce three different fixed fine levels that would only marginally change the analysis, and have no bearing on the basic results.[15]

Given A, the authority's policy (β_2, β_3) results in expected payoffs for the industries displayed in Table 2.

	θ_1	θ_2	θ_3
q_1	0	$\times$	$\times$
q_2	$\pi(q_2, \theta_1) - \beta_2 A$	0	$\times$
q_3	$\pi(q_3, \theta_1) - \beta_3 A$	$\pi(q_3, \theta_2) - \beta_3 A$	0

Table 2: Industry pay-off matrix with perfect competition law enforcement.

Each time the competition authority decides to investigate an industry, it pays investigation costs K. It is assumed to be the authority's objective to maximize total welfare, defined as the expected sum of consumer and producer surplus minus expected total investigation costs. That is, total welfare for a certain output (q_i, q_j, q_3), where q_i is the output in the type 1 industry and q_j is the output in the type 2

[14] The Sherman Act further specifies personal fines not exceeding $\$350,000$ and three years imprisonment—*par. 2 Sherman Act, 15 U.S.C. par. 2.* European competition law enforcement can not yet apply personal punishment—which is, however, currently under consideration for the Union as well as many of its member states.

[15] For more on the issue *cf.* Besanko and Spulber (1989), p.410 and Section VII (A), pp.420-1. Incidentally, a further argument for bounded fines in practice derives from the very topic of this paper: enforcement errors. Since wrongful fining is socially undesirable, a more complete theory would introduce such welfare costs of large fines, to conclude on socially optimal fine levels.

industry, $i \in \{1,2,3\}$ and $j \in \{2,3\}$, is given by

$$\begin{aligned} W(q_i, q_j, q_3) &= \gamma_1 (V(q_i) - \theta_1 q_i - \beta_i K) + \gamma_2 \left(V(q_j) - \theta_2 q_j - \beta_j K\right) \\ &\quad + \gamma_3 (V(q_3) - \theta_3 q_3 - \beta_3 K), \end{aligned} \tag{1}$$

in which

$$V(q_i) - \theta_k q_i \equiv \int_0^{q_i} P(y)\, dy - \theta_k q_i$$

is the sum of consumer and producer surplus. Note that $V(q) - \theta_k q$ is increasing in q for $q < q_k$. Observe that the fines imposed on an industry do not appear in the welfare function. This is not primarily due to their 'lump-sum' nature: as will become clear below, these sanctions do affect the behavior of firms—they are, in fact, designed to do so. Fines enter, however, as a welfare-neutral redistribution of income from the firms to the consumers, *given* the level of output.

Fully acknowledging the challenges it faces, the competition authority compares the welfare levels associated with all the different enforcement regimes from which it can choose, taking into account the incentive constraints for the industries set out in the sections below. Having done so, it seeks to install the competitive regime that returns highest total welfare by setting its policing and sanction parameters in such a way that the firms self-select the socially optimal market structure.

Before moving on to the analysis of optimal enforcement, a final remark is in order here. The issues of commitment to police, fining and the authority's understanding of welfare are intimately related. This is particularly relevant as many competition authorities, for example the Directory General Competition of the European Commission, seem to gear their enforcement efforts towards consumer welfare, rather than total welfare—or at least towards a welfare measure that excludes the surplus of the parties that have allegedly infringed upon competition law. In the simple static game setup we use here to illustrate our qualitative effects, once firms have conspired to reduce output and raise prices no additional welfare gains can be obtained by the actions of the competition authorities—which are costly, so that it would always be best to decide not to prosecute. Put differently, the sole welfare enhancing effect of antitrust enforcement in the present model is the deterrence effect it has *ex ante*. Since the cartel moves first in setting output, the antitrust policy does not constitute a credible threat, so competition law enforcement has no teeth. One way to resolve this commitment issue is to take fines up as a return in the welfare function—which is the case when only consumer welfare is considered the objective. In effect, authorities would then maximize the difference between fine revenues and enforcement costs. Although in itself this is a fallacy—after all, ideal enforcement would deter infringements completely and hence not give any such 'returns'—it solves a fundamental commitment problem.[16] We choose here to ignore commitment issues, steer clear of the ongoing discussion on the appropriate welfare standard, and use total welfare instead.

[16] See for a model with fines as an argument in the welfare function Spulber (1989), pp.570-6.

3 Antitrust with Perfect Monitoring

With the structure of the model laid out, consider the incentive constraints for the different types of industries when the competition authority can perfectly observe the type upon investigation. Making the usual assumption that when an industry is indifferent between two output levels it chooses the one most preferred by the competition authority—that is, the highest production level—the incentive constraints of the industry are as follows. A type 1 industry produces the competitive output q_1 only if it expects a loss from colluding, that is if

$$\pi(q_2, \theta_1) - \beta_2 A \leq 0 \text{ and } \pi(q_3, \theta_1) - \beta_3 A \leq 0, \tag{2}$$

as it makes zero profits in perfect competition. It will produce q_2 if such is better than colluding at q_3 and competing at q_1, that is if

$$\pi(q_2, \theta_1) - \beta_2 A \geq \pi(q_3, \theta_1) - \beta_3 A \text{ and } \pi(q_2, \theta_1) - \beta_2 A > 0. \tag{3}$$

Finally, a type 1 industry will opt for q_3 if

$$\pi(q_3, \theta_1) - \beta_3 A > \pi(q_2, \theta_1) - \beta_2 A \text{ and } \pi(q_3, \theta_1) - \beta_3 A > 0. \tag{4}$$

For type 2 industries, there are only two choices. Either it produces q_2 if

$$\pi(q_3, \theta_2) - \beta_3 A \leq 0, \tag{5}$$

or q_3 otherwise. By construction, type 3 industries will always produce q_3.

Since type 1 industries can choose three output levels, type 2 industries two, and type 3 industries only one, there is a total of six different type-output combinations that could potentially materialize. Given the setup of the model, only three of these can possibly maximize welfare, however—the proofs of all results in the following are given in an appendix. That is, the authority will decide on its enforcement policy, seeking to implement one of only three market structures.

Proposition 1 *When competition law enforcement is perfect, the authority seeks to implement one of the following three market structures:*

1. perfect competition, *with outputs* (q_1, q_2, q_3)*, that is, every industry type chooses the competitive output;*
2. partial collusion, *with outputs* (q_2, q_2, q_3)*, that is, only type* 1 *industries collude; or*
3. full collusion, *with outputs* (q_2, q_3, q_3)*, that is, type* 1 *and type* 2 *industries collude.*

The proposition says that the partially collusive output (q_1, q_3, q_3) can never be optimal to implement. The reason for this is that deterring type 1 industries from producing q_3 also keeps type 2 industries from producing output level q_3. Likewise, outputs (q_3, q_2, q_3) and (q_3, q_3, q_3) can never be welfare maximizing, because both type 1 industries—by Assumption 1—and the competition authority prefer output levels q_2 to q_3.

Among the three policies open to the competition authority, it is to select the one with the highest welfare. Which one that is depends on the parameter constellation, in particular on the profits associated with each type-quantity combination and the probabilities with which nature allocates the three different cost types. Proposition 2 characterizes when each of the outputs is optimal, for variable values of the ratio between the investigation costs K and the fine A, $\frac{K}{A}$.

Proposition 2 *When competition law enforcement is perfect, there exist well-defined positive numbers* Ψ_a*,* Ψ_b *and* Ψ_c*, with either* i) $\Psi_a \leq \Psi_b \leq \Psi_c$ *or* ii) $\Psi_c \leq \Psi_b \leq \Psi_a$*, such that:*

1. *If ordering* i) *holds:*
   perfect competition*, with outputs* (q_1, q_2, q_3) *, is optimal for* $\frac{K}{A} \in [0, \Psi_a]$ *;*
   partial collusion*, with outputs* (q_2, q_2, q_3) *, is optimal for* $\frac{K}{A} \in [\Psi_a, \Psi_c]$ *; and*
   full collusion*, with outputs* (q_2, q_3, q_3) *, is optimal for* $\frac{K}{A} \geq \Psi_c$*.*

2. *If ordering* ii) *holds:*
   perfect competition *is optimal for* $\frac{K}{A} \leq \Psi_b$*; and*
   full collusion *is optimal for* $\frac{K}{A} \geq \Psi_b$*.*

The proposition reiterates, in a slightly different framework, the original result by Besanko and Spulber (1989) that, when competition law enforcement is relatively costly, it is socially optimal to allow certain levels of anticompetitive behavior. In particular, the results support the conjecture that low investigation costs make it optimal to implement the perfectly competitive equilibrium, whereas high investigation costs may make the collusive output, in which no enforcement is required, optimal. The constitution of the critical values, developed in the appendix, is insightful. Consider, for example, Ψ_a, the critical value of $\frac{K}{A}$ for which the competition authority is just indifferent between perfect competition and partial collusion:

$$\Psi_a = \frac{\gamma_1 \left([V(q_1) - \theta_1 q_1] - [V(q_2) - \theta_1 q_2] \right)}{\gamma_2 \pi(q_2, \theta_1) + \gamma_3 [\pi(q_3, \theta_1) - \pi(q_3, \theta_2)]}.$$

The numerator represents the expected increase in total surplus from deterring a type 1 industry from colluding. The denominator of Ψ_a reflects the costs of deterring type

1 industries. Only when the return from doing so is sufficiently large, that is, does it pay to incur the enforcement costs to install perfect competition.

Typically, when the probabilities of the different cost-types occurring are reasonably symmetric, the ordering of Proposition 2.1 applies. Note, however, that when γ_1 increases, so that γ_2 and/or γ_3 decrease, Ψ_a increases. The more likely it is that the authority faces a low cost type, therefore, the larger the region in which it is optimal to enforce perfect competition at a given cost. Similarly, Ψ_c, is found to be the ratio of the increase in surplus resulting from keeping firm 2 from colluding and the costs thereof,

$$\Psi_c = \frac{\gamma_2\left(\left[V\left(q_2\right)-\theta_2 q_2\right]-\left[V\left(q_3\right)-\theta_2 q_3\right]\right)}{\gamma_3 \pi\left(q_3, \theta_2\right)},$$

which decreases when γ_2 decreases—possibly increasing γ_3. Hence, the less likely it is to confront a type 2 firm, and the more likely a firm is of type 3, with the more reserve the authority should intervene.

Finally, note that when the only other possible ordering of the regime boundaries, that of Proposition 2.2, holds, the partially collusive output cannot be welfare maximizing and the optimal regime changes from perfect competition to full collusion at Ψ_b.

4 Assessment Errors

Even though we consider arguably the most simple of anticompetitive acts to discover and convict—cartels that fix prices, which are *per se* violations—suppose that the authority, after it has investigated the industry—possible more than once, when appeals are lodged in initial stages of the case—occasionally draws the wrong conclusion on whether or not the industry breached competition law and is to be sanctioned. Let $\widehat{\theta}$ be the competition authority's inference on the type of industry it faces after investigation. We are interested in the probability that, upon observing q_k, the competition authority concludes $\widehat{\theta}=\theta_j$ when the true cost is θ_i, that is, the subjective probability

$$\Pr\left(\widehat{\theta}=\theta_j \mid \theta_i, q_k\right) \text{ for } i, j, k=1,2,3.$$

Note that the probability of bringing antitrust cases that indeed have no merit would typically be a decreasing function of the investigation effort per case, K, of the authority. Since these costs are assumed to be constant here for each case the authority decides to investigate, however, the probabilities $\Pr\left(\widehat{\theta}=\theta_j \mid \theta_i, q_k\right)$ are exogenously given in this model.

4.1 Antitrust Inferences

Naturally, for each i and k, the authority has a complete conjecture over the types. That is,

$$\sum_{j=1}^{3} \Pr\left(\widehat{\theta} = \theta_j | \theta_i, q_k\right) = 1.$$

The possibilities to err are further restricted by the construction of the possible industry structures. Since only type 1 industries can produce q_1 without making a loss the competition authority will always rightfully infer that the true value of the cost parameter has to be θ_1 when observing production quantity q_1, that is, $\Pr\left(\widehat{\theta} = \theta_2 | \theta_1, q_1\right) = \Pr\left(\widehat{\theta} = \theta_3 | \theta_1, q_1\right) = 0$ and $\Pr\left(\widehat{\theta} = \theta_1 | \theta_1, q_1\right) = 1$. Likewise, since a type 3 industry will always produce q_3, the competition authority will never conclude it faces a type 3 industry when q_2 is observed, *i.e.*, $\Pr\left(\widehat{\theta} = \theta_3 | \theta_1, q_2\right) = \Pr\left(\widehat{\theta} = \theta_3 | \theta_2, q_2\right) = 0$. We further make the following assumptions to reduce complexity.

Assumption 2 *(i) The probability of error is symmetric, that is*

$$\Pr\left(\widehat{\theta} = \theta_i | \theta_j, q_k\right) = \Pr\left(\widehat{\theta} = \theta_j | \theta_i, q_k\right) \text{ for } i, j = 1, 2, 3 \text{ and } k = 2, 3.$$

(ii) The probability of error is constant, and indicated as α, *that is*

$$\begin{aligned} \Pr\left(\widehat{\theta} = \theta_3 | \theta_1, q_3\right) &= \Pr\left(\widehat{\theta} = \theta_3 | \theta_2, q_3\right) = \\ \Pr\left(\widehat{\theta} = \theta_2 | \theta_1, q_3\right) &= \Pr\left(\widehat{\theta} = \theta_2 | \theta_1, q_2\right) = \alpha. \end{aligned}$$

The symmetry assumption is mildly restrictive. Typically, there is no particular reason to assume that the competition authority would be able to distinguish between otherwise symmetric cases. Part (ii) of Assumption 2 is less innocent, yet defendable—note that (i) is implied by (ii), but we distinguish between them for clarity of exposition. Part (ii) implies that the competition authority is more likely to make judgment errors, the more different possible market structures can underlie the observed quantities. Alternatively put, the more cost types are excluded by the industry's revealed behavior, the smaller is the error made by the competition authority. Assuming the probability of error to be constant seems more appropriate than its simple counterpart, that is, keeping the total probability of error constant, irrespective of the complexity of the industry under investigation. A more satisfactory setup would allow for different probabilities for each possible type of error, with general conditions on their relationships. This complicates the notation greatly, without adding substantially to the strength of the points here made.

Figure 1 illustrates the various decisions by nature, the authority and the firms in an extensive form game. For ease of exposition, the figure has been reduced to display only those choices that can possibly be made—that is, those type-quantity matches that will not occur because it is never profitable to produce more than the competitive output that goes with one's type are not drawn in.

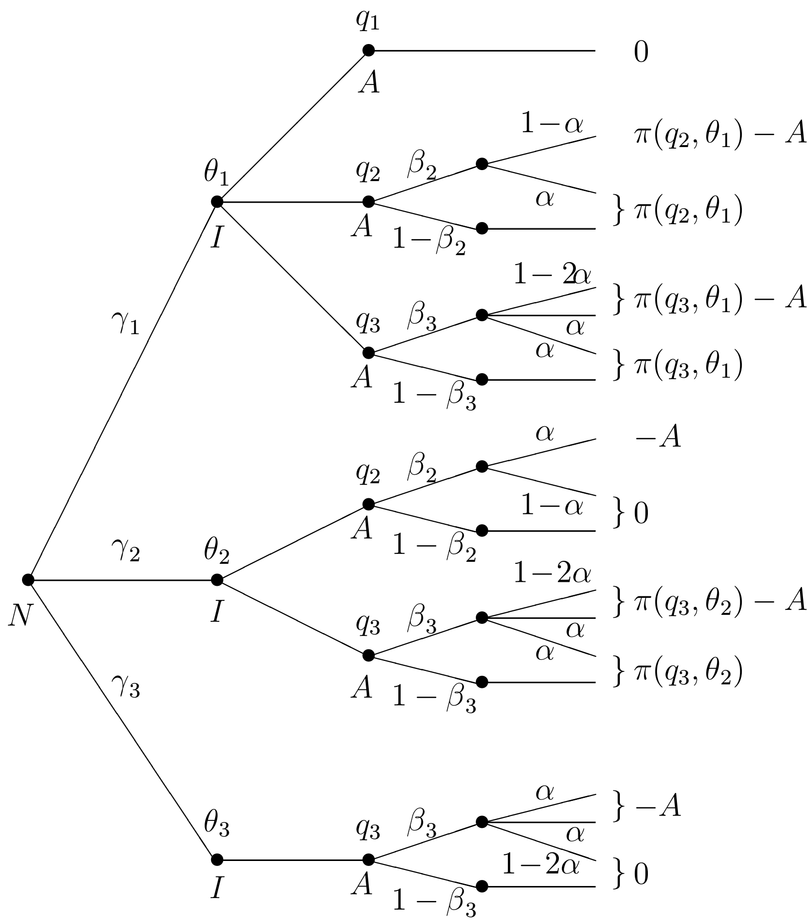

Figure 1: The sequence of moves by nature, industry and authority.

First, nature (N) decides on the cost structure of the industry. Then, the industry (I) decides whether or not to collude, after which suit is brought or not, with a probability committed to by the competition authority (A), and depending on the observed quantity—note that identical q_i's are each in one information set. When quantity q_2 is observed, and in case of an investigation, with probability α the firm is falsely assessed. When q_3 is observed, the competition authority can err twice, taking the industry for a type 2 or a type 3, where it is type 1, for a type 1 or a type 3, where it is a type 2, or for a type 1 or 2, when it is a type 3. This results in the three-way splits associated with investigation upon observing q_3.

The full matrix of antitrust inferences that results is given in Table 3.

	q_1			q_2			q_3		
$\widehat{\theta}$	θ_1	θ_2	θ_3	θ_1	θ_2	θ_3	θ_1	θ_2	θ_3
$\widehat{\theta}_1$	1	$\times$	$\times$	$1-\alpha$	α	$\times$	$1-2\alpha$	α	α
$\widehat{\theta}_2$	0	$\times$	$\times$	α	$1-\alpha$	$\times$	α	$1-2\alpha$	α
$\widehat{\theta}_3$	0	$\times$	$\times$	0	0	$\times$	α	α	$1-2\alpha$

Table 3: Matrix of antitrust inference probabilities.

An $\times$ refers to an inference that cannot be made given the observed behavior of the industry. The other entries state the probability with which the estimate as specified for the entire row is arrived at when the observed-behavior-true-type-combination is that of the respective column. Note that each column sums up to unity, and so does each part of each row associated with a specific output level.

4.2 Type I and Type II Errors

The definition of assessment errors and Assumption 2 together imply the probabilities with which Type I and Type II errors are made. Recall that, relative to the null hypothesis that it is only firms that indeed colluded that are prosecuted and found liable of anticompetitive behavior, a Type I error is defined as "finding a firm that behaved perfectly competitive liable of anticompetitive acts," and a Type II error is "acquitting an industry that has in fact acted anticompetitively." When q_2 is observed, either a type 1 industry is colluding, or a type 2 industry is behaving competitively. Consequently, the symmetry assumption on the probabilities implies symmetry in the error types. That is,

$$\Pr(\text{Type I } |q_2) = \Pr(\text{Type II } |q_2) = \alpha.$$

When q_3 is observed, however, the situation is more complicated. Now, there are three possible states of the world between which the authority cannot discriminate. It either faces a type 1 or a type 2 industry colluding, or a type 3 industry in competition. As a result, the symmetry in error types is broken. The probability of a Type I error is 2α, since when the true type is 3, the authorities believe it is type 1 or 2 with probability α each instead. That is,

$$\Pr(\text{Type I } |q_3) = \Pr\left(\widehat{\theta} \neq \theta_3|\theta_3, q_3\right) = \Pr\left(\widehat{\theta} = \theta_1|\theta_3, q_3\right) + \Pr\left(\widehat{\theta} = \theta_2|\theta_3, q_3\right) = 2\alpha.$$

Should the true type be 1 or 2, however, and q_3 is observed, the possibility arises that the authority makes the wrong assessment, yet takes the right action in fining the industry nevertheless. That is, an industry can be prosecuted and sanctioned for anti-competitive acts that it indeed committed, yet on the basis of a false assessment of its type by the authorities. As a result, the Type II error when q_3 is observed is halved, or

$$\Pr\left(\text{Type II }|q_3\right) = \Pr\left(\widehat{\theta} = \theta_3|\theta_1, q_3\right) = \Pr\left(\widehat{\theta} = \theta_3|\theta_2, q_3\right) = \alpha,$$

where the latter is true since when $\widehat{\theta} = \theta_2$ there is (correctly) a fine levied as well.

Hence, since the authorities can 'get away' with some of their assessment errors, in that the action they take based on their false assessment, that is, imposing a fine, is appropriate, an asymmetry emerges between Type I and Type II errors in the event that q_3 is observed. This is a consequence of the various simplifying assumptions made above—that there are only three types of firms, that fines are independent of sales and that α is constant, in particular that the authorities are more likely to err when more possible underlying structures can explain the observations made. Note, however, that the Type II error we specify is an error made *after* investigation, and not prior to it. It does not include those cases that were never brought to the attention of the authorities in the first place. Rather, it concerns actual cartels, of which the competition authority was correct to be suspicious, but that escaped prosecution, since the authority falsely assessed the industry as competitive upon investigating it.

Nevertheless, a more complete analysis would specify a continuous probability distribution over the assessment errors that can itself be made the object of policy. An obvious way to do this it to introduce that when a firm is found liable, a second investigation round is entered, with associated costs and room for errors. Such an appeals system allows for the type of socially desirable sanction level by weighing the consequences of Type I and Type II errors. Appeals procedures would, in other words, shift the probabilities for errors between the two error types—obviously away from Type I towards Type II errors, as it will be firms that are wrongfully sanctioned that seek correction. A further discussion of some of the constitutional consequences of this is postponed to Section 7. In any case, although more sophisticated error probabilities would be an interesting topic for further research, the present fixed and symmetric case brings out important qualitative effects. For now, it should be interpreted as capturing the full investigatory and judicial process through which competition cases go, including the various appeals procedures that exist. Our only claim is that at the end of that full judicial process, some error margin remains. That it here is symmetric and constant is not essential for the results that follow, nor is the asymmetry in Type I errors when q_3 is produced.

5 Imperfect Antitrust Enforcement

When the competition authority, given fine level A, is committed to the enforcement policy (β_2, β_3) and it is common knowledge that the possibility exists that a liable industry under investigation escapes correction, and an innocent industry is wrongfully sanctioned, the following expected industry payoff table results.

	θ_1	θ_2	θ_3
q_1	0	$\times$	$\times$
q_2	$\pi(q_2, \theta_1) - \beta_2 (1-\alpha) A$	$-\beta_2 \alpha A$	$\times$
q_3	$\pi(q_3, \theta_1) - \beta_3 (1-\alpha) A$	$\pi(q_3, \theta_2) - \beta_3 (1-\alpha) A$	$-2\beta_3 \alpha A$

Table 4: Industry pay-off matrix with imperfect competition law enforcement.

It is important to note that the assessment errors by the competition authority have no influence on the welfare function (1), since misallocated fines amount to a random redistribution of income. Here again the remarks made in Section 2 apply. In particular, the errors are immaterial for society at large, *given* the level of output only. There is an important welfare detriment following from the error margin via the effect assessment errors have on firm behavior, since the incentive constraints of the firms are crucially affected.

When the competition authority observes the industry type imperfectly and investigation is fallible, industry payoff Table 4 applies. The associated incentive constraints (compare to (2)-(5)) are as follows. The type 1 industry chooses to produce:

$$\begin{aligned} q_1 \text{ if } \pi(q_2, \theta_1) - \beta_2 (1-\alpha) A &\leq 0 \text{ and } \pi(q_3, \theta_1) - \beta_3 (1-\alpha) A \leq 0; && (6) \\ q_2 \text{ if } \pi(q_2, \theta_1) - \beta_2 (1-\alpha) A &\geq \max\{0, \pi(q_3, \theta_1) - \beta_3 (1-\alpha) A\} \text{ and}; && (7) \\ q_3 \text{ if } \pi(q_3, \theta_1) - \beta_3 (1-\alpha) A &\geq \max\{0, \pi(q_2, \theta_1) - \beta_2 (1-\alpha) A\}. && (8) \end{aligned}$$

Type 2 industries produce q_3 if

$$\pi(q_3, \theta_2) - \beta_3 (1-\alpha) A > -\beta_2 \alpha A, \tag{9}$$

and otherwise behave competitively at q_2. Invariably, type 3 industries choose to produce q_3. Notice, however, that they do face possible penalties, now, when convicted innocently.

A first result compares the incentives of industries to collude with perfect and imperfect enforcement of competition law. When enforcement is imperfect, the incentive to collude goes up, for any given enforcement strategy, for two reasons. First, the probability of getting caught when behaving anticompetitively goes down, as can be seen by comparing the lower off-diagonal elements of Table 4 to those in Table 2 in Section 2. This decreases the expected costs of anticompetitive behavior. Second, and more interesting, industries that would otherwise behave perfectly competitive are induced to collude as a 'precautionary' measure, because they run the risk of getting wrongfully sanctioned when in fact behaving competitively. The 'fine-reduction' effect stems from the presence of Type II errors, whereas the 'precautionary' effect is driven by the occasional Type I error.

More specifically, for a given competition policy (β_2, β_3), type 1 industries collude under imperfect competition law enforcement, where they would not do so under perfect monitoring, if the cartel profit $\pi(q_2, \theta_1)$ satisfies

$$\beta_2 (1-\alpha) A < \pi(q_2, \theta_1) < \beta_2 A,$$

in which only the expected-fines effect of enforcement errors plays a role. Type 2 industries, however, collude under imperfect monitoring and not under perfect monitoring if

$$\beta_3 (1-\alpha) A - \beta_2 \alpha A < \pi(q_3, \theta_2) < \beta_3 A,$$

so that both effects of erroneous antitrust apply. The expected-fines effect, measured by $-\beta_3 \alpha A$, provides an increased incentive to collude simply by lowering the probability of being caught. The precautionary-collusion effect, given by $-\beta_2 \alpha A$, increases the incentive to collude through the positive probability of being sanctioned unjustly.

The set of market structures that can be implemented and is possibly optimal—that is, the imperfect enforcement analogue of Proposition 1—is given below.

Proposition 3 *When competition law enforcement is imperfect, the authority seeks to implement one of the following four market structures:*

1. perfect competition, *with outputs* (q_1, q_2, q_3), *that is, every industry type chooses the competitive output;*

2. type 1 partial collusion, *with outputs* (q_2, q_2, q_3), *that is, only type* 1 *industries collude;*

3. type 2 partial collusion, *with outputs* (q_1, q_3, q_3), *that is, only type* 2 *industries collude, which is feasible if*

$$\alpha \geq \alpha^* \equiv \frac{\pi(q_3, \theta_1) - \pi(q_3, \theta_2)}{A}; \text{ or}$$

4. full collusion, *with outputs* (q_2, q_3, q_3), *that is, both type* 1 *and type* 2 *industries collude.*

This largest set of potentially optimal regimes is the same as that identified in Proposition 1, with one exception: since collusion is more difficult to fight for the reasons given above—not all offenders are caught, not even when monitored, and innocent firms run a risk of being wrongfully sued, giving them an incentive to collude—a first effect of imperfect monitoring is that a new optimal situation can occur, in which type 1 industries behave competitively, yet type 2 industries collude and conspire on the type 3 production level, provided the government error α is large enough.

In order to determine the conditions under which each of these different outputs is the welfare maximizing choice of government, consider a second critical value of α, $\alpha^{**} > \alpha^{*}$, defined as

$$\alpha^{**} \equiv \frac{\pi(q_3, \theta_1) - \pi(q_3, \theta_2)}{\pi(q_2, \theta_1) + \pi(q_3, \theta_2) - \pi(q_3, \theta_1)}.$$

The fine-reduction effect pertains to the situation with $\alpha \leq \alpha^{**}$. In this case, a result analogous to Proposition 2 applies straightforwardly, with Ψ_i, $i = a, b, c$, replaced by $\Psi_i^{\alpha} = (1 - \alpha)\Psi_i$. Clearly, such modest imperfection in antitrust increases the parameter region in which collusion is socially optimal. This is due to the fact that not all investigated and liable firms are sanctioned, and the induction of competition therefore requires a higher risk of being investigated, hence more investigation costs, that are not offset by higher detection. The more subtle precautionary-collusion effect occurs for values of α higher than α^{**}. It leads to an even lower likelihood of the competitive output being the right objective for competition policy. Proposition 4 summarizes these results and establishes the relationship with Proposition 2.

Proposition 4 *When competition law enforcement is imperfect and type* 2 *partial collusion, with outputs* (q_1, q_3, q_3)*, is not optimal, there exist well-defined positive numbers* Ψ_a^{α}*,* Ψ_b^{α} *and* Ψ_c^{α} *with either* i) $\Psi_a^{\alpha} \leq \Psi_b^{\alpha} \leq \Psi_c^{\alpha}$ *or* ii) $\Psi_c^{\alpha} \leq \Psi_b^{\alpha} \leq \Psi_a^{\alpha}$*, such that:*

1. *If ordering* i) *holds:*

   perfect competition*, with outputs* (q_1, q_2, q_3)*, is optimal for* $\frac{K}{A} \in [0, \Psi_a^{\alpha}]$*;*

   type 1 partial collusion*, with outputs* (q_2, q_2, q_3)*, is optimal for* $\frac{K}{A} \in [\Psi_a^{\alpha}, \Psi_c^{\alpha}]$*; and*

   full collusion*, with outputs* (q_2, q_3, q_3)*, is optimal for* $\frac{K}{A} \geq \Psi_c^{\alpha}$*.*

2. *If ordering* ii) *holds:*

   perfect competition *is optimal for* $\frac{K}{A} \leq \Psi_b^{\alpha}$*; and*

   full collusion *is optimal for* $\frac{K}{A} \geq \Psi_b^{\alpha}$*.*

3. *For* $\alpha \leq \alpha^{**}$*,* $\Psi_i^{\alpha} = (1 - \alpha)\Psi_i$*,* $i = a, b, c$*; and*

   for $\alpha > \alpha^{**}$*,* $\Psi_i^{\alpha} < (1 - \alpha)\Psi_i$ *for* $i = a$ *or* b*,*

   where Ψ_a*,* Ψ_b *and* Ψ_c *are defined in (the proof of) Proposition* 2*.*

Note that the precautionary-collusion effect that further decreases Ψ_i^{α} below $(1 - \alpha)\Psi_i$ only applies for the cases a and b. That is, the transition from type 1 partial collusion to full collusion as the socially optimally enforced regime is not affected by it. The reason for this is that in the type 1 partial collusive situation, the competition authority never investigates when it observes q_2. Therefore, neither type 1 firms colluding at q_2, nor type 2 firms competing at q_2 run the risk of being falsely convicted. Consequently, they have no incentive to collude as a precautionary measure. The precautionary-collusion effect only applies to the transition from perfect competition to partial collusion. A a result, note further that the precautionary-collusion effect observed is not driven by the asymmetry in error types when q_3 is observed. The industry truly suffering from the higher probability of being wrongfully sanctioned is the type 3 industry. They have no option than to produce q_3, however. Precautionary-collusion pertains only to the extent that it encourages type 1 firms to collude rather than behave competitively.

A second result that derives from imperfect competition law enforcement is the novel possibility that the type 2 partially collusive equilibrium maximizes welfare. Crucial in this respect is the fraction of type 1 industries. If this fraction is high enough, it will pay for the competition authority to deter industries of this type from colluding, yet let type 2 industries go.

Proposition 5 *Let $\alpha > \alpha^*$. Then, when antitrust is imperfect, there exists a well-defined number Γ_1 such that for $\gamma_1 > \Gamma_1$ there is an interval of values of $\frac{K}{A}$ in which* type 2 partial collusion, *with outputs (q_1, q_3, q_3), is optimal.*

For the way in which Γ_1 derives, as well as for the borders of the interval in which the effect applies, see the appendix again. Obviously, if the type 2 partially collusive output is not optimal, that is, if $\gamma_1 \leq \Gamma_1$ and/or $\frac{K}{A}$ falls outside the specified interval, the ordering as defined in Proposition 4 applies.

6 Three Illustrative Examples

Some simple numerical examples illustrate the meaning of the different regimes found. Suppose inverse demand is linear and given as $P(q) = 100 - q$. Types are known by: $\theta_1 = 0$, $\theta_2 = 40$ and $\theta_3 = 80$. Consequently, $q_1 = 100$, $q_2 = 60$ and $q_3 = 20$. Profits corresponding to the collusive strategies are as follows.

$$\pi(q_2, \theta_1) = 2400,\ \pi(q_3, \theta_1) = 1600 \text{ and } \pi(q_3, \theta_2) = 800.$$

Surplus is given by $V(q_i) = \int_0^{q_i} P(y)\,dy = 100q_i - \frac{1}{2}(q_i)^2$, so that

$$V(q_1) = 5000,\ V(q_2) = 4200 \text{ and } V(q_3) = 1800.$$

The threshold values that segregate the optimal antitrust regimes when $\alpha = 0$ then are the following:

$$\Psi_a = \frac{\gamma_1}{3\gamma_2 + \gamma_3}, \Psi_b = \frac{\gamma_1 + \gamma_2}{3\gamma_2 + 2\gamma_3} \text{ and } \Psi_c = \frac{\gamma_2}{\gamma_3}.$$

First, let the different cost structures have an equal probability of coming about: $\gamma_1 = \gamma_2 = \gamma_3 = \frac{1}{3}$. Note that $\alpha^{**} = \frac{1}{4}$. Therefore, separate $\alpha \leq \frac{1}{4}$ and $\alpha > \frac{1}{4}$ and the following borders apply:

$$\begin{aligned}
\Psi_a^\alpha &\equiv \begin{cases} \frac{1}{4}(1-\alpha) & \text{for } \alpha \leq \frac{1}{4} \\ \frac{1}{3}(1-\alpha)^2 & \text{for } \alpha > \frac{1}{4} \end{cases} \\
\Psi_b^\alpha &\equiv \begin{cases} \frac{2}{5}(1-\alpha) & \text{for } \alpha \leq \frac{1}{4} \\ \frac{1}{3\alpha}(1-\alpha)^2 & \text{for } \alpha > \frac{1}{4} \end{cases}, \text{ and} \\
\Psi_c^\alpha &\equiv 1-\alpha.
\end{aligned}$$

Figure 2, in which α is set out against $\frac{K}{A}$, illustrates.

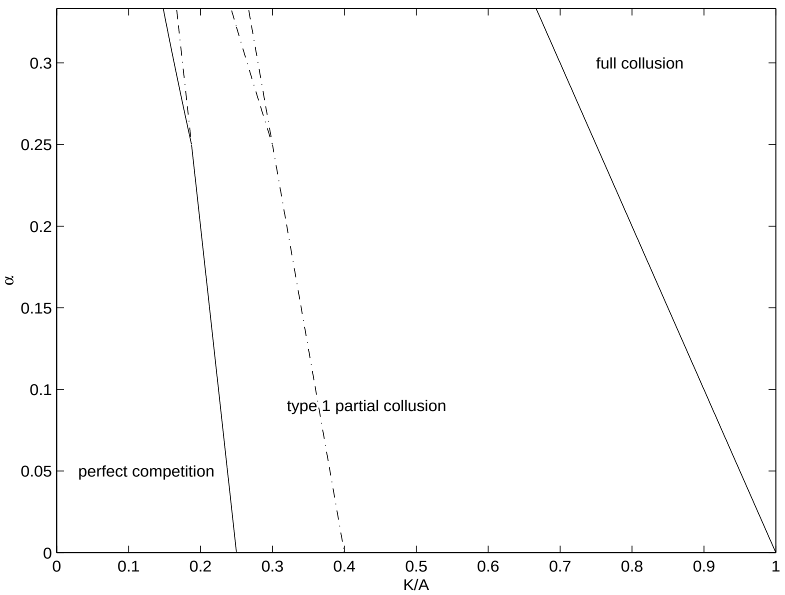

Figure 2: Different optimal antitrust regimes for $\gamma_1 = \gamma_2 = \gamma_3 = \frac{1}{3}$.

When there are no errors made—i.e., on the horizontal axis—the perfectly competitive output $(100, 60, 20)$ is welfare maximizing for the competition authority when $\frac{K}{A} \leq \frac{1}{4}$, the partial collusion outputs $(60, 60, 20)$ for $\frac{1}{4} \leq \frac{K}{A} \leq 1$, and the fully collusive output for $K \geq A$. For positive values of α smaller than $\frac{1}{4}$, the straight lines separate the perfect competition, type 1 partial collusion and the full collusion cases. When α increases from zero, the perfect competition and partial collusion regions are enlarged linearly, at the expense of the area in which perfect competition is optimal. This is the expected-fines effect of imperfect antitrust. When $\alpha > \frac{1}{4}$, the straight line Ψ_a^α curves off to the left, thus reducing the region in which perfect competition is optimal, and type 1 partial collusion is best enforced, more than proportionally from the region delineated by the straight continuation of the Ψ_a^α line—indicated as a dotted line. For these values, the precautionary-collusion consequence of imperfect antitrust take effect.

Next, an example where type 2 partial collusion is both implementable and optimal. Take $A = 5000$, implying $\alpha^* = \frac{4}{25}$. Then, for $\alpha > \alpha^*$ an interval of $\frac{K}{A}$ values for which (q_1, q_3, q_3) is optimal exists when $\gamma_1 \geq \frac{2}{3}$ and $\gamma_2 \leq \gamma_1 - \frac{1}{2}$. Consider the case $\gamma_1 = \frac{3}{4}$ and $\gamma_2 = \gamma_3 = \frac{1}{8}$. There then appears a transition boundary from perfect competition to full collusion for values of α below $\alpha^* = \frac{4}{25}$. For high enough values $\alpha > \frac{4}{25}$, type 2 partial collusion can be implemented and a region in which type 2 partial collusion is preferred is found, as illustrated in Figure 3.

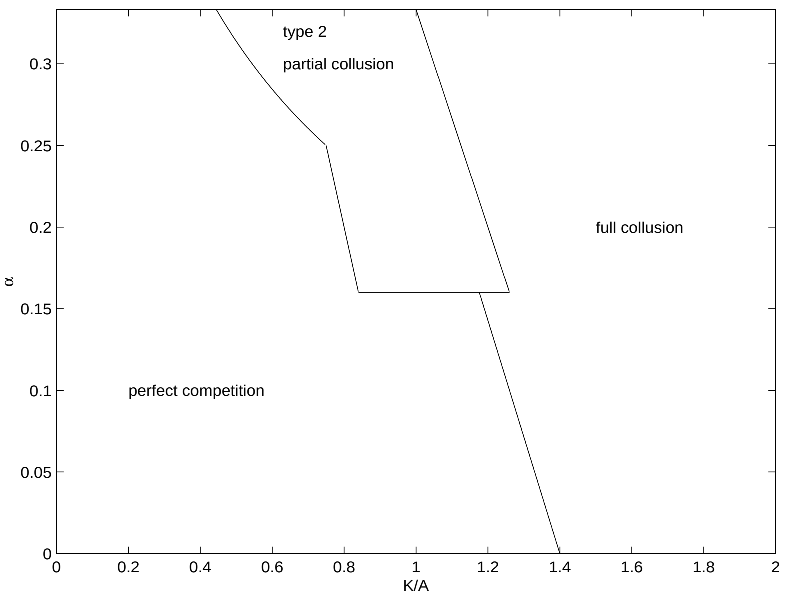

Figure 3: Different optimal antitrust regimes for $\gamma_1 = \frac{3}{4}, \gamma_2 = \gamma_3 = \frac{1}{8}$ and $A = 5000$.

Finally, an example where all four regimes can be optimal. This happens, for example, for $\gamma_1 = \frac{3}{4}$, $\gamma_2 = \frac{3}{16}$ and $\gamma_3 = \frac{1}{16}$. The different regimes are shown in Figure 4. Note that type 2 partial collusion can again only be implemented for $\alpha > \frac{4}{25}$.

In all three these examples, the qualitative effect of errors in enforcement are apparent. When, in Figure 2, perfect competition is the authority's objective, with a solid enforcement costs of twenty percent of fines ($\frac{K}{A} = 0.2$), this is a fine policy, as long as the enforcement error remains low. When α comes close to twenty percent, however, the optimal regime no longer is that of perfect competition, but of partial collusion of type 1. Likewise, in Figure 3 when investigation costs are, for example, twenty percent over the level of fines, so that $\frac{K}{A} = 1.2$, depending on the error level the optimal enforcement regime may well pass from perfect competition as the standard,

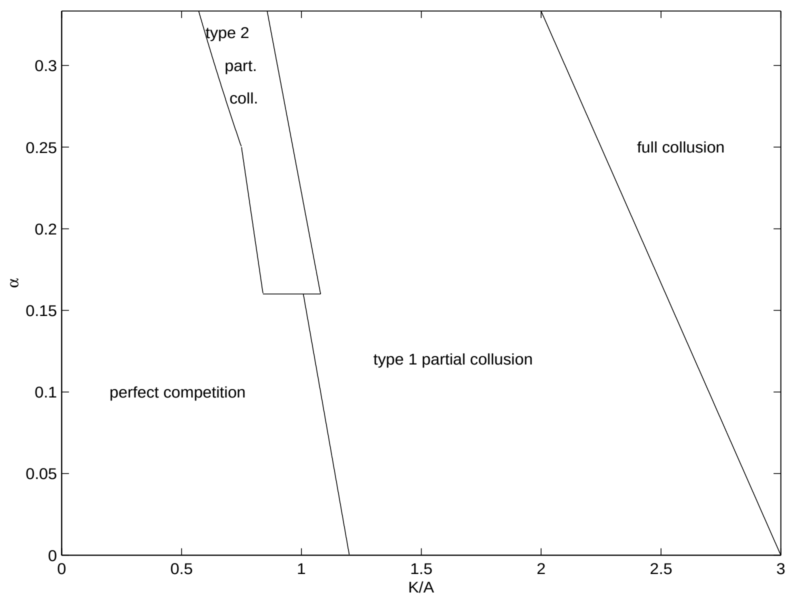

Figure 4: Different optimal antitrust regimes for $\gamma_1 = \frac{3}{4}, \gamma_2 = \frac{3}{16}, \gamma_3 = \frac{1}{16}$ and $A = 5000$.

to type 2 partial collusion for errors above $\frac{4}{25}$, and even full collusion (or type 1 partial collusion in Figure 4) when α is a little over 0.2.

7 Policy Implications and Concluding Remarks

When competition authorities are fallible—and aren't we all?—it is shown that the incidence of anticompetitive behavior may increase in the enforcement error, essentially for two reasons. The first is that the expected sanction for law breaching decreases, due to possibility of firms escaping without a penalty, even when monitored. The second reason is that firms that would otherwise behave perfectly competitive are induced to collude as a precautionary measure when they face the risk of being unjustly sanctioned when obeying the law. The overall conclusion, therefore, is that competition policy may be counter-productive in that its enforcement stimulates, by the authority's imperfect way of policing, the very behavior it was designed to prevent. Put differently, imperfect competition law enforcement may stifle genuine competition. As a result, from a total welfare point of view, more types of collusion are better tolerated than fought, than when competition law enforcement is flawless. In practice, therefore, when enforcement errors are non-negligible competition authorities run the risk of being over-zealous. It may even be the case that competition law enforcement is open to errors to such an extent, that it would be socially desirable not to have an authority at all.[17]

In general, this means that competition policy, where it is costly, is to be enforced with great care. To make this simple demand to base competition policy in sound economic analysis more precise, consider Table 5 below.

α \ $\frac{K}{A}$	Low	High
Low	Perfect Competition	Partial Collusion (type 1)
High	Partial Collusion (type 2)	Full Collusion

Table 5: Policy regimes under imperfect competition law enforcement.

When investigation is both reasonably inexpensive and efficient, a tough competition authority should seek to install perfect competition as the socially optimal market structure—as in the upper-left cell. This may be the case at hand in well established industries, such as traditional bulk production, that are well understood by industry specialists and where the costs of production are fairly easily monitored. These industries are known to have a tendency to collude, which should be fought intensely. When, however, both the investigation costs relative to the fine level is high and the margin of assessment errors is substantial, society is better off with an competition authority that holds back and accepts some social costs of collusion—the lower-right cell. The reason for this is that the authority's own detrimental effect on competition, combined with the higher level of enforcement costs its policing activities require, make it a burden on society. Sectors in the economy to which this situation may apply could well be high-tech fast evolving ones, such as biochemistry, and cutting-edge hard- and software. Here, R&D developments are rapid, true industry experts with sufficient oversight to understand production relationships and costs are unavailable, and progress may be so rapid that intervention is likely to be off the mark with very high probability. In those circumstances, partial, or even full collusion may be the socially efficient outcome—at least for the time being, until the industry matures and is better understood. Naturally, the intermediate options of partial collusion, in which some anticompetitive behavior is taken for granted, are closer to the reality of competition law enforcement. Depending on whether the enforcement costs or the assessment errors are the higher variable, the most cost-efficient industry type, type 1, should be allowed to collude—upper-right cell—or the intermediate marginal cost type industry should be considered with leniency—lower-left cell in Table 5.

These qualitative insights can be of interest particularly to an competition authority that is constrained by a budget. In the present analysis, any optimal enforcement level is viable, for the authority does not face any constraint but the self-selection of the industry types according to the regime the authority determines as optimal.

[17] *Cf.* Mattoo (2001) for a further exploration of this extreme position.

Often, however, competition authorities have limited means to perform their enforcement tasks with. When the authority has to make choices which industries to police and in what order, for example, our analysis seems to suggest that it is best to come down hard on traditional and stable industries, for which enforcement is relatively inexpensive and sharp, and to be more lenient towards high-pace venture industries. Only when the latter mature, and seem to be able to sustain their collusive economic profits is a well-considered and on the mark intervention called for.[18]

When the authority has various different kinds of industries under its control, a binding budget would make it also consider the trade-off between handling a few complicated industries well and with great care, so as to reduce assessment errors, only, or rather take on a large number of cases, in which in each a more substantial error margin is accepted in exchange. After all, typically there will be a trade-off between K and α. Introducing variable investigation costs would allow for the probability of error to depend on the level of investigation, K. Higher investigation costs in the present model discourage enforcement of competition law in partial collusion cases—and in full when very high. If α decreases in K, perfect competition law enforcement could be a limit case for K sufficiently high. This allows for a true cost-benefit analysis of costly, yet less fallible, litigation procedures. Such an endogenous error margin would facilitate the essentially empirical question what combination of error and costs is had in what type of industry, and what optimal competition law enforcement goes with it as a consequence.

Our analysis may also have implications for the organization of competition law enforcement more generally. In Europe, in the realm of the continuing unification process, member states have either adapted if they had some, or adopted where none previously existed, competition policy regimes that tailor to EU example. German competition law, which predates that of the EU and has, in fact, been a source of inspiration for the latter, connects with the European competition practice quite naturally. Likewise, Dutch national competition law enforcement is fully in line with the EU since Holland switched from an 'abuse legislation' with little to no intervention to a European-style prohibition law in January 1998—which initially caused quite a stir in what used to be referred to as the 'Netherlands cartel paradise'. Examples of countries that have recently joined the European Union, however, such as Romania and Estonia, with no former competition discipline, have in very quick pace designed complete regulations, with often quite enormous enforcement offices. It seems not overly skeptical to suspect that these rapid conversions in order to comply with EU law and be evaluated positively for accession to the union did not deliver flawless enforcement regimes over-night. And although, coming from a situation with a lax attitude towards anticompetitive behavior, it clearly is important to show the new regime will be enforced with rigor, novice competition law enforcement institutions are warned not to overshoot the mark, triggering the effects addressed in this paper.

On the supra-national level, our findings are of relevance for a comparison of

[18] For a model of budget constrained authorities, see Martin (2000).

EU and US competition law enforcement. In the EU, competition cases are primarily dealt with under administrative law, with the Directorate General Competition preparing decisions on behalf of the European Commission. Firms suspected of having acted in breach of Article 81(1) of EU competition law can defend themselves in writing and oral hearings against an issued Statement of Objections, with the possibility of asking for an exemption on one of the grounds made explicit in Article 81(3). However, whereas Article 81(1) captures all in principle restrictions of competition for the Commission, the burden of proof to obtain an Article 81(3) exemption in this two-tier approach is with the parties alleged to have infringed the competition laws. If one or more of the parties lodges an appeal against an adverse finding of DG Competition with the Court of First Instance, there a somewhat more integrated judicial evaluation of Article 81. Yet, these procedures remain restricted to a superficial evaluation of the way in which the Commission used its administrative powers. They do not themselves lead to new investigations into the subject matter of a case. As a result, European competition law enforcement is likely to be biased towards Type I errors, thus possibly triggering the precautionary breaches of competition law here identified.

In contrast, US antitrust enforcement is based on the DOJ bringing defendants before a court, which applies the limited set of US competition laws together with the long history of case law. Also, US merger control is substantially more involved. Consequently, rather than being required to appeal to a given number of exemption possibilities, firms can argue more generally that their notified merger plans generate consumer benefits or that any allegation of monopolization against them are unjust. These civil law proceedings ensure a fair weighing of all possible relevant arguments early on. As a result, US enforcement is inclined to be more investigatory, with ample opportunity for appeal and debate, than the EU practice, the more regulatory nature of which provides less room for rule of reason argumentation. This, in turn, rooted the US practice in a long tradition of expert witness contributions to litigation, with academic input often of the highest level.[19] Although this certainly makes the US enforcement system more expensive compared to its European counterpart, it has the potential benefit of increasing the probability of reaching a proper decision with the gains pointed out here. There is reason to believe, therefore, that US competition law enforcement is better directed and less likely to err than EU competition policy, which relates our analysis to a current debate on the possible convergence between the two. In order to determine what constitutes a good competition policy regime, the increased costs of more sophisticated competition law enforcement should be weighted against the benefits of sound conclusions of law. One of these benefits is the prevention of strategic anticompetitive acts that result from the presence of

[19] On the other hand of course, US critics of competition policy, such as Robert Bork, have argued against the degree of interpretative freedom left to courts in the US system, holding that it leads to unsound and inconsistent decisions, requiring lawyers to decide on what are essentially economic issues. *Cf.* Bork (1993), Chapter 3.

enforcement errors.

Appendix: proofs

Proof of Proposition 1. It is first shown how the three market structures in the proposition can be implemented most efficiently and the corresponding welfare levels determined. Then it is shown that the other three market structures can either not be implemented, or never be optimal.

1. The perfectly competitive output (q_1, q_2, q_3) can be implemented by the following policy,
$$\beta_2 = \frac{\pi(q_2, \theta_1)}{A} \text{ and } \beta_3 = \frac{\pi(q_3, \theta_1)}{A}.$$
This deters type 1 industries from colluding. Note that this value of β_3 also deters type 2 industries from colluding since $\pi(q_3, \theta_1) > \pi(q_3, \theta_2)$. Substituting the policy into welfare function (1) gives
$$\begin{aligned} W(q_1, q_2, q_3) &= \gamma_1 [V(q_1) - \theta_1 q_1] + \gamma_2 \left[V(q_2) - \theta_2 q_2 - \frac{K}{A}\pi(q_2, \theta_1)\right] \\ &\quad + \gamma_3 \left[V(q_3) - \theta_3 q_3 - \frac{K}{A}\pi(q_3, \theta_1)\right]. \end{aligned}$$

2. The type 1 partial collusion output (q_2, q_2, q_3) can be implemented by setting
$$\beta_2 = 0 \text{ and } \beta_3 = \frac{\pi(q_3, \theta_2)}{A}.$$
Type 2 industries are deterred from producing q_3 and type 1 industries are allowed to produce their most preferred output level. Corresponding welfare is
$$\begin{aligned} W(q_2, q_2, q_3) &= \gamma_1 [V(q_2) - \theta_1 q_2] + \gamma_2 [V(q_2) - \theta_2 q_2] \\ &\quad + \gamma_3 \left[V(q_3) - \theta_3 q_3 - \frac{K}{A}\pi(q_3, \theta_2)\right]. \end{aligned}$$

3. The full collusion output (q_2, q_3, q_3) is most efficiently implemented by never investigating, that is, $\beta_2 = \beta_3 = 0$. Welfare follows as
$$W(q_2, q_3, q_3) = \gamma_1 [V(q_2) - \theta_1 q_2] + \gamma_2 [V(q_3) - \theta_2 q_3] + \gamma_3 [V(q_3) - \theta_3 q_3].$$

Next, it is established that the remaining three production vectors will never be chosen by the competition authority. First consider the type 2 partial collusive output (q_1, q_3, q_3). It is easily seen that this output can never be implemented, since deterring type 1 industries from producing q_3—by setting $\beta_3 \geq \frac{\pi(q_3, \theta_1)}{A}$—will also deter type 2 industries to produce

q_3, as $\pi(q_3,\theta_1) > \pi(q_3,\theta_2)$. The two remaining outputs have type 1 industries produce q_3. Although these production levels can be implemented, they can never be welfare maximizing, as follows. Consider (q_3,q_2,q_3) first. It is easily checked that the most efficient implementation of this output is

$$\beta_2 = \frac{\pi(q_2,\theta_1) - \pi(q_3,\theta_1) + \pi(q_3,\theta_2)}{A} \text{ and } \beta_3 = \frac{\pi(q_3,\theta_2)}{A}.$$

The corresponding welfare level is given as

$$\begin{aligned} W(q_3,q_2,q_3) &= \gamma_1\left(V(q_3) - \theta_1 q_3 - \frac{K}{A}\pi(q_3,\theta_2)\right) \\ &\quad +\gamma_2\left(V(q_2) - \theta_2 q_2 - \frac{K}{A}\left(\pi(q_2,\theta_1) - \pi(q_3,\theta_1) + \pi(q_3,\theta_2)\right)\right) \\ &\quad +\gamma_3\left(V(q_3) - \theta_3 q_3 - \frac{K}{A}\pi(q_3,\theta_2)\right). \end{aligned}$$

It is immediate that $W(q_3,q_2,q_3) < W(q_2,q_2,q_3)$, eliminating the output (q_3,q_2,q_3) as optimal. Finally, consider the 'over-collusive' output (q_3,q_3,q_3). This can never be optimal, since the cost free policy $\beta_2 = \beta_3 = 0$ will lead to the output (q_2,q_3,q_3), which generates a higher welfare level than (q_3,q_3,q_3), even if the latter outcome could be implemented at zero cost—which it cannot. ■

Proof of Proposition 2. Let Ψ_a be defined as $\frac{K}{A} \leq \Psi_a \Leftrightarrow W(q_1,q_2,q_3) \geq W(q_2,q_2,q_3)$. Analogously, let Ψ_b be defined by $\frac{K}{A} \leq \Psi_b \Leftrightarrow W(q_1,q_2,q_3) \geq W(q_2,q_3,q_3)$ and let Ψ_c be defined by $\frac{K}{A} \leq \Psi_c \Leftrightarrow W(q_2,q_2,q_3) \geq W(q_2,q_3,q_3)$. From Proposition (1) it follows that:

$$\begin{aligned} \Psi_a &= \frac{\gamma_1\left([V(q_1) - \theta_1 q_1] - [V(q_2) - \theta_1 q_2]\right)}{\gamma_2 \pi(q_2,\theta_1) + \gamma_3\left[\pi(q_3,\theta_1) - \pi(q_3,\theta_2)\right]}, \\ \Psi_b &= \frac{\gamma_1\left([V(q_1) - \theta_1 q_1] - [V(q_2) - \theta_1 q_2]\right) + \gamma_2\left([V(q_2) - \theta_2 q_2] - [V(q_3) - \theta_2 q_3]\right)}{\gamma_2 \pi(q_2,\theta_1) + \gamma_3 \pi(q_3,\theta_1)}, \\ \Psi_c &= \frac{\gamma_2\left([V(q_2) - \theta_2 q_2] - [V(q_3) - \theta_2 q_3]\right)}{\gamma_3 \pi(q_3,\theta_2)}. \end{aligned}$$

Quite tedious, but fairly straightforward algebra allows for checking that the only possible ways in which these three numbers can be ordered are the two considered in the proposition. ■

Proof of Proposition 3. First it is shown how the four outputs in the proposition can be most efficiently implemented and the corresponding welfare levels determined. Then it will be shown that the other two possible outputs can never be optimal.

1. The perfectly competitive output (q_1,q_2,q_3) can be implemented by setting

$$\beta_2 = \frac{\pi(q_2,\theta_1)}{(1-\alpha)A} \text{ and } \beta_3 = \max\left\{\frac{\pi(q_3,\theta_1)}{(1-\alpha)A}, \frac{\pi(q_3,\theta_2) + \frac{\alpha}{1-\alpha}\pi(q_2,\theta_1)}{(1-\alpha)A}\right\}.$$

Welfare follows as $W(q_1, q_2, q_3) =$

$$\gamma_1 [V(q_1) - \theta_1 q_1] + \gamma_2 \left[V(q_2) - \theta_2 q_2 - \frac{1}{1-\alpha} \frac{K}{A} \pi(q_2, \theta_1) \right] + \gamma_3$$
$$\times \left[V(q_3) - \theta_3 q_3 - \frac{1}{1-\alpha} \frac{K}{A} \max \left\{ \pi(q_3, \theta_1), \pi(q_3, \theta_2) + \frac{\alpha}{1-\alpha} \pi(q_2, \theta_1) \right\} \right].$$

2. The output (q_2, q_2, q_3) can be implemented by taking $\beta_2 = 0$ and $\beta_3 = \frac{\pi(q_3,\theta_2)}{(1-\alpha)A}$. Welfare is

$$\begin{aligned} W(q_2, q_2, q_3) &= \gamma_1 [V(q_2) - \theta_1 q_2] + \gamma_2 [V(q_2) - \theta_2 q_2] \\ &\quad + \gamma_3 \left[V(q_3) - \theta_3 q_3 - \frac{1}{1-\alpha} \frac{K}{A} \pi(q_3, \theta_2) \right]. \end{aligned}$$

3. The (new) output (q_1, q_3, q_3) requires

$$\beta_2 \geq \frac{\pi(q_2, \theta_1)}{(1-\alpha) A} \text{ and } \beta_3 = \frac{\pi(q_3, \theta_1)}{(1-\alpha) A},$$

to deter type 1 industries from colluding. Furthermore, in order to allow type 2 industries to collude and given β_3, one needs

$$\beta_2 \geq \frac{\pi(q_3, \theta_1) - \pi(q_3, \theta_2)}{\alpha A}.$$

Clearly, β_2 should be smaller than or equal to 1, which requires $\alpha \geq \alpha^*$. The final implementation now is

$$\beta_2 = \max \left\{ \frac{\pi(q_2, \theta_1)}{(1-\alpha) A}, \frac{\pi(q_3, \theta_1) - \pi(q_3, \theta_2)}{\alpha A} \right\},$$

with corresponding welfare level

$$\begin{aligned} W(q_1, q_3, q_3) &= \gamma_1 [V(q_1) - \theta_1 q_1] + \gamma_2 \left[V(q_3) - \theta_2 q_3 - \frac{1}{1-\alpha} \frac{K}{A} \pi(q_3, \theta_1) \right] \\ &\quad + \gamma_3 \left[V(q_3) - \theta_3 q_3 - \frac{1}{1-\alpha} \frac{K}{A} \pi(q_3, \theta_1) \right]. \end{aligned}$$

4. The policy $\beta_2 = \beta_3 = 0$ implements the fully collusive output and welfare

$$W(q_2, q_3, q_3) = \gamma_1 [V(q_2) - \theta_1 q_2] + \gamma_2 [V(q_3) - \theta_2 q_3] + \gamma_3 [V(q_3) - \theta_3 q_3]$$

is attained.

Finally, it is shown that the remaining outputs (q_3, q_2, q_3) and (q_3, q_3, q_3) can never be optimal. It is easily seen that the most efficient way to implement (q_3, q_2, q_3) is by

$$\beta_2 = \frac{\pi(q_2, \theta_1) - \pi(q_3, \theta_1) + \pi(q_3, \theta_2)}{(1-\alpha) A} \text{ and } \beta_3 = \frac{\pi(q_3, \theta_2)}{(1-\alpha) A},$$

resulting in a welfare level of $W(q_3, q_2, q_3) =$

$$\begin{aligned}
&\gamma_1 \left[V(q_3) - \theta_1 q_3 - \frac{1}{1-\alpha} \frac{K}{A} \pi(q_3, \theta_2) \right] \\
&+\gamma_2 \left[V(q_2) - \theta_2 q_2 - \frac{1}{1-\alpha} \frac{K}{A} \left(\pi(q_2, \theta_1) - \pi(q_3, \theta_1) + \pi(q_3, \theta_2) \right) \right] \\
&+\gamma_3 \left[V(q_3) - \theta_3 q_3 - \frac{1}{1-\alpha} \frac{K}{A} \pi(q_3, \theta_2) \right] < W(q_2, q_2, q_3).
\end{aligned}$$

That (q_3, q_3, q_3) cannot be optimal is immediate from noting that the policy $\beta_2 = \beta_3 = 0$ returns the fully collusive output with higher welfare. ■

Proof of Proposition 4. Define a set of bounds Ψ_a^α, Ψ_b^α, Ψ_c^α, Ψ_d^α, Ψ_e^α, and Ψ_f^α as follows.

$$\begin{aligned}
W(q_1, q_2, q_3) &\geq W(q_2, q_2, q_3) \Leftrightarrow \frac{K}{A} \leq \Psi_a^\alpha = \begin{cases} \underline{\Psi}_a^\alpha & \alpha \leq \alpha^{**} \\ \overline{\Psi}_a^\alpha & \alpha > \alpha^{**} \end{cases}; \\
W(q_1, q_2, q_3) &\geq W(q_2, q_3, q_3) \Leftrightarrow \frac{K}{A} \leq \Psi_b^\alpha = \begin{cases} \underline{\Psi}_b^\alpha & \alpha \leq \alpha^{**} \\ \overline{\Psi}_b^\alpha & \alpha > \alpha^{**} \end{cases}; \\
W(q_2, q_2, q_3) &\geq W(q_2, q_3, q_3) \Leftrightarrow \frac{K}{A} \leq \Psi_c^\alpha; \\
W(q_1, q_2, q_3) &\geq W(q_1, q_3, q_3) \Leftrightarrow \frac{K}{A} \leq \Psi_d^\alpha = \begin{cases} \underline{\Psi}_d^\alpha & \alpha \leq \alpha^{**} \\ \overline{\Psi}_d^\alpha & \alpha > \alpha^{**} \end{cases}; \\
W(q_1, q_3, q_3) &\geq W(q_2, q_2, q_3) \Leftrightarrow \frac{K}{A} \leq \Psi_e^\alpha; \text{ and} \\
W(q_1, q_3, q_3) &\geq W(q_2, q_3, q_3) \Leftrightarrow \frac{K}{A} \leq \Psi_f^\alpha.
\end{aligned}$$

Standard algebra delivers

$$
\begin{aligned}
\underline{\Psi}_a^\alpha &= (1-\alpha)\,\Psi_a; \\
\overline{\Psi}_a^\alpha &= (1-\alpha)^2 \frac{\gamma_1 \left([V(q_1)-\theta_1 q_1] - [V(q_2)-\theta_1 q_2]\right)}{\left((1-\alpha)\gamma_2 + \alpha\gamma_3\right)\pi(q_2,\theta_1)}; \\
\underline{\Psi}_b^\alpha &= (1-\alpha)\,\Psi_b; \\
\overline{\Psi}_b^\alpha &= (1-\alpha) \frac{\gamma_1 \left([V(q_1)-\theta_1 q_1] - [V(q_2)-\theta_1 q_2]\right) + \gamma_2 \left([V(q_2)-\theta_2 q_2] - [V(q_3)-\theta_2 q_3]\right)}{\gamma_2 \pi(q_2,\theta_1) + \gamma_3 \left(\pi(q_3,\theta_2) + \frac{\alpha}{1-\alpha}\pi(q_2,\theta_1)\right)}; \\
\Psi_c^\alpha &= (1-\alpha)\,\Psi_c; \\
\underline{\Psi}_d^\alpha &= (1-\alpha) \frac{V(q_2)-\theta_2 q_2 - [V(q_3)-\theta_2 q_3]}{\pi(q_2,\theta_1) - \pi(q_3,\theta_1)}; \\
\overline{\Psi}_d^\alpha &= (1-\alpha) \frac{\gamma_2 \left([V(q_2)-\theta_2 q_2] - [V(q_3)-\theta_2 q_3]\right)}{\gamma_2 \pi(q_2,\theta_1) + \gamma_3 \left(\pi(q_3,\theta_2) + \frac{\alpha}{1-\alpha}\pi(q_2,\theta_1)\right) - (\gamma_2+\gamma_3)\pi(q_3,\theta_1)}; \\
\Psi_e^\alpha &= (1-\alpha) \frac{\gamma_1 \left([V(q_1)-\theta_1 q_1] - [V(q_2)-\theta_1 q_2]\right) - \gamma_2 \left([V(q_2)-\theta_2 q_2] - [V(q_3)-\theta_2 q_3]\right)}{\gamma_2 \pi(q_3,\theta_1) + \gamma_3 \left(\pi(q_3,\theta_1) - \pi(q_3,\theta_2)\right)}; \\
\Psi_f^\alpha &= (1-\alpha) \frac{\gamma_1}{1-\gamma_1} \frac{[V(q_1)-\theta_1 q_1] - [V(q_2)-\theta_1 q_2]}{\pi(q_3,\theta_1)}.
\end{aligned}
$$

The result for $\alpha < \alpha^{**}$ follows straightforwardly. Now consider the case where $\alpha > \alpha^{**}$. The objective now is to order $\overline{\Psi}_a^\alpha$, $\overline{\Psi}_b^\alpha$, $\overline{\Psi}_c^\alpha$, $\overline{\Psi}_d^\alpha$. The last number can be skipped by assumption. The only feasible ways in which the other three numbers can be ordered are (again) $\overline{\Psi}_a^\alpha < \overline{\Psi}_b^\alpha < \Psi_c^\alpha$ and $\overline{\Psi}_c^\alpha < \overline{\Psi}_b^\alpha < \overline{\Psi}_a^\alpha$. ■

Proof of Proposition 5. For (q_1, q_3, q_3) to be optimal, it is necessary that $\frac{K}{A}$ is larger than Ψ_d^α but smaller than Ψ_e^α and Ψ_f^α. First consider $\alpha < \alpha^{**}$. In order for an interval of $\frac{K}{A}$ values for which (q_1, q_3, q_3) to exist, it is needed that $\Psi_e^\alpha \geq \Psi_d^\alpha$ and $\Psi_f^\alpha \geq \Psi_d^\alpha$. For $\alpha \leq \alpha^{**}$ these inequalities reduce to

$$
\begin{aligned}
\gamma_1 &\geq \frac{\gamma_2 \left(\pi(q_2,\theta_1) + \pi(q_3,\theta_2) - \pi(q_3,\theta_1)\right) + \left(\pi(q_3,\theta_1) - \pi(q_3,\theta_2)\right)}{\left(\pi(q_2,\theta_1) - \pi(q_3,\theta_1)\right)\frac{V(q_1)-\theta_1 q_1 - [V(q_2)-\theta_1 q_2]}{V(q_2)-\theta_2 q_2 - [V(q_3)-\theta_2 q_3]} + \left(\pi(q_3,\theta_1) - \pi(q_3,\theta_2)\right)}, \\
\frac{\gamma_1}{1-\gamma_1} &\geq \frac{\pi(q_3,\theta_1)}{\pi(q_2,\theta_1) - \pi(q_3,\theta_1)} \frac{V(q_2)-\theta_2 q_2 - [V(q_3)-\theta_2 q_3]}{V(q_1)-\theta_1 q_1 - [V(q_2)-\theta_1 q_2]}.
\end{aligned}
$$

Note that there always exist a γ_1 satisfying these inequalities (as can be verified by letting γ_1 approach 1). Now consider $\alpha > \alpha^{**}$. It is easily verified that $\overline{\Psi}_d^\alpha \leq \underline{\Psi}_d^\alpha$ for $\alpha \geq \alpha^{**}$. Hence the above conditions also suffice for the case $\alpha > \alpha^{**}$. The interval of $\frac{K}{A}$ values for which (q_1, q_3, q_3) then is optimal is given by

$$
\left[\Psi_d^\alpha, \min\left\{\Psi_e^\alpha, \Psi_f^\alpha\right\}\right].
$$

■

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