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Intermittent collusive agreements: antitrust policy and business cycles

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Abstract

In this article we study collusive strategies and the optimal level of fines when firms face random demand fluctuations. Collusive firms can choose to alternate collusive periods with more competitive periods: such an intermittent strategy can be implemented particularly if demand variability is high. Firms then set competitive prices during recessions to cancel the risk of cartel detection and keep the ability to cartelize for the future. If the maximum fine is too low to fully deter cartels, the antitrust authority can influence the choice of collusive agreement by varying the level of fines according to demand states. If the demand is highly variable, the antitrust authority may induce firms to collude in all demand states (by decreasing the fine during recessions), in order to detect and break up cartels more easily. On the other hand, if the demand variability is low the optimal policy may be to reduce the fine when demand is high.

Keywords: Collusion, antitrust policy, business cycles.

JEL: K42, L22, L41.

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1 Introduction

While the fight against cartels is an unrelenting issue for antitrust authorities, the most efficient policy is still intensively researched.¹ In this article, we examine the relevance of implementing optimal fines that depend on the demand state in a sector (so fines adjust to the industry business cycle).

Competition rules have been relaxed several times during periods of general or sector-based economic turmoil.² Nowadays, few economists seem in favor of a total suspension of competition policy in times of crisis. But a temporary relaxation of some rules or reduced sanctions are sometimes offered. For example, state aid control in Europe was eased during the Covid pandemic. In this study, we analyze whether it is desirable to vary the cartel fines according to the sectorial situation. Current legislation does not account for sector-based business cycles. However it may factor in the financial situation of firms, which correlates with the business cycle. Without going so far as to allow cartels, French and European authorities specify that the level of antitrust fines can be adjusted to help companies in financial difficulty survive a temporary crisis. This measure can occur during periods of crisis, but it does not apply to all firms involved in a cartel, but rather only in cases firms are indebted or poorly capitalized. In addition, fines can be indirectly linked to business cycles if they are based on firm turnover (in the European case) or profit (in the U.S.). Relevant turnover as a basis for calculation of antitrust fine is a good way to link fines with the firm size, but the correlation between turnover and sectorial conditions is imperfect. For example, the turnover of a multi-product multinational firm is only weakly correlated with the local market conditions of one of its products. We could even consider cases where the correlation is negative. If the price of an input rises sharply and firms can pass on to consumers only a part of this increasing cost, the firms' sales increase even though the economic conditions worsen.

In this article, we study a novel policy proposal, whereby antitrust fines are adjusted over the sectorial business cycle. We show that this policy can represent a second-best optimum if the maximum level of fines is too low to fully deter collusive agreements. Such policy is not intended to decrease firm bankruptcies, but must change the number of colluding states. Empirical evidence³ suggests that the level of cooperation between firms can vary over time, as collusive periods alternate with more competitive episodes. In our model firms can choose to implement such intermittent collusive strategies when profits vary substantially

¹See Harrington (2017) for a recent survey.

²As a consequence of the financial crisis of 1929, U.S. antitrust authorities put antitrust legislation aside and allowed potential cooperation among competitors in certain cases, as specified in the National Industrial Recovery Act (NIRA) of 1933. During the 1980s the European Commission allowed a capacity reduction agreement on artificial fibres (Barjot and Schröter 2013, Barjot 2014) in response to the structural crisis faced by the European chemical industry at that time. The September 11 attacks in 2001 caused a serious drop in airline demand, particularly in the United States. To address this decline, the U.S. Department of Transportation conferred antitrust immunity to an agreement between two Hawaiian airlines, allowing them to coordinate their air travel capacity and prices (Blair, Mak and Bonham 2007, Kamita 2010). The intended results of these lenient cartel policies were not always the same. The NIRA aimed to halt price deflation and restore the level of margins so as to provide wage increases. In the other two examples, capacities were excessive and the cartel policy sought to facilitate capacity reductions.

The results of these measures were mixed. Cole and Ohanian (2004) present data suggesting that the more lenient cartelization policy was a key factor behind the weak recovery from the Great Depression. Blair, Mak and Bonham (2007) and Kamita (2010) conclude that the collusive airline agreement was not needed to get the companies to reduce their capacity. This cartel led to a sharp price increase that persisted after immunity expired, and only the entry of a new competitor resulted in lower prices. In contrast, the artificial fibers cartel seems to have had positive effects as the sector was reorganized without using government funds (Barjot and Schröter 2013, Barjot 2014).

³See the literature review in the next section.

with demand states. Antitrust authorities can then seek to decrease the number of colluding states by varying fines according to the demand states. Perhaps less intuitively, antitrust authorities may induce firms to extend collusive agreements to demand states for which infringement is less harmful. This possibility generates new opportunities to detect and dissolve the cartel so that the condemned firms do not commit other offenses in the future.

To assess the merits of implementing an optimal level of cartel fines that depends on the business cycle, we need to understand the impact on collusive behavior. A recurring topic in industrial organization is the implementation and the sustainability of collusive agreements under business cycles.⁴ However these previous studies do not include an antitrust authority and consequently do not analyze the effectiveness of optimal antitrust fines. Our article therefore contributes to this literature by incorporating an active antitrust authority which intends to fight collusion into the analysis.

Our model introduces an antitrust authority into the approach pioneered by Rotemberg and Saloner (1986) [RS henceforth]. We assume that once detected, cartels are fined and dissolved forever.⁵ Firms accordingly expect that if they collude during one period, they decrease the collusive opportunities afterwards. An important assumption is the possibility for colluding firms to reduce the risk of detection by setting a price equal to the competitive price, during a low demand period or when fines are high. We successively deal with two cartel enforcement scenarii. Under the first assumption (A1), the collusive price level does not affect the detection probability and the cartel can still be detected even if the cartel price equals the competitive price. Under the more realistic second assumption (A2), firms can reduce the detection probability by temporarily deactivating the cartel. To simplify the model, we assume that, in such situations, the detection probability drops to zero. Then the key assumption is that the cartel is either detectable irrespective of the collusive price (assumption A1) or, in contrast, that the probability of detection drops to zero whenever collusive firms price competitively (assumption A2).

We now defend this key assumption. We could assume that colluding firms have to meet regularly to set cartel price and that the implementation of cartels requires a governance structure in order to ascertain that the agreement is fulfilled by all firms. These activities generate hard evidence which can be found by the antitrust authority. Under the first assumption (A1), the antitrust authority detects collusive activity primarily through meetings and then the collusive price level does not affect the detection probability. Under the second assumption (A2), information exchanges on prices between colluding firms are used to monitor adherence to the agreed price and the antitrust authority can detect this. When firms choose the competitive price, no firm has incentive to deviate, so monitoring cartel activity is useless and may be temporarily suspended. In such situations, the detection probability decreases significantly and we assume that it drops to zero. However when the cartel price is higher than the marginal cost, meetings and cartel governance are required, and we assume that the detection probability is strictly positive and not price-dependent. Cartel

⁴We review major contributions on this topic in the next section.

⁵We could allow that the cartel can reform with some probability in the future and we conjecture many results would not change. The antitrust authority may still induce firms to collude in more demand states to dissolve cartels faster but this result would be weakened (this result persists if recidivism can occur after an extended period of time or with a probability less than 1).

governance and meetings are not explicitly introduced into the model, but assumptions A1 and A2 are shortcuts to capture these ideas.

Under assumption A1, primarily used to provide a benchmark, our results are consistent with RS. In addition to assumption A1, we assume that, during a deviation period, the probability of cartel detection remains unchanged and then expected fines are exactly the same whether firms collude or deviate. Then expected fines do not affect incentive compatibility conditions and, in this case, the model is isomorphic to the original RS. Then firms choose the highest collusive price (the monopoly price or a lower price if demand is high and incentives to deviate are strong) for all demand states and never opt for an intermittent collusive strategy. As in RS, collusive agreements are less likely to occur during booms.

We obtain very different results under assumption A2. In this case, firms can select the intermittent collusive strategy by deactivating the cartel for some demand states. During each period, firms face a trade-off between sustaining collusion with high prices in order to maximize the current cartel profit and setting competitive prices to cancel the risk of cartel detection and retaining the ability to cartelize for the future. If expected collusive profits are similar for both demand states, either because of low demand variability or because the different levels of fines partly offset the demand differences, firms implement a constant collusive strategy. They choose a high level of price for each period until the cartel is detected and dissolved. However firms can choose to implement an intermittent collusive strategy when profits are substantially different depending on demand states. They set the monopoly price only during periods in which the collusive profits are highest and charge the marginal cost if expected collusive profits are low. Contrary to RS, when demand variability is strong firms choose to collude only during booms. When demand variability is weak, firms charge the monopoly price only during economic downturns if the expected fine is significantly lower than during booms. One of the main contributions of our study is to highlight the implementation of such intermittent collusive strategies.

In this article we analyze the optimal level of fines and we obtain the following results. If the upper bound of fines is sufficiently high to fully deter the collusive agreements, it is optimal to set the maximum level of fines for both states. Varying the level of fines according to demand states is then unnecessary. However, if the maximum fine is low, the antitrust authority cannot fully deter cartels but can instead influence the choice of collusive agreement in order to decrease the severity of the offense. This latter point may drive the antitrust authority to vary fines according to business cycles. More precisely, if demand variability is strong, firms tend to select an intermittent collusive strategy with collusive prices only during booms. But cartels are more harmful during booms and the antitrust authority may induce firms to collude during recessions as well (a less harmful strategy) since when collusion occurs at every state of demand, the antitrust authority can more quickly detect and break up cartels. Condemned firms can not commit further offenses, then a cartel conviction has an incapacitation effect. This effect occurs more quickly if firms collude in all demand states. Consequently, the antitrust authority must impose the maximum fine during booms and a minimum fine level during recessions. However, if demand variability is weak, results are reversed. Firms tend to select a constant collusive strategy and the antitrust authority aims to reduce the number of collusive states. In this

case reducing fines during booms can be optimal, in line with some models dealing with marginal deterrence.⁶ The antitrust authority must set the minimal fine level for infringements which cannot be deterred (in this model, during booms periods) and it must set the highest fine otherwise (in this model, for low demand periods). Fines have a marginal deterrence effect: they reduce the number of colluding states. The antitrust authority favors the incapacitation effect when the variance of demand is high and the marginal deterrent effect when this variance is low.

For low maximum fines, varying fines according to business cycles may be welfare improving. In practice, if exogenous markers of business cycles exist, antitrust enforcement guidelines could state that fines vary with the state of the economy and that recessions could be viewed as aggravating (if the antitrust authority tends to choose a higher level of fines during recessions) or attenuating circumstances (lower level of fines during recessions). The competition authorities may also use speeches or press releases to warn, for example, that competition rules will be stricter in the coming months because of the state of the market.

This article is organized as follows. In the next section we survey the related literature. Then we describe our model (section 3). Section 4 reports the results obtained under assumption A1. These serve as a benchmark to present the results obtained with the alternative hypothesis, in section 5. We discuss the optimal level of fines in section 6. Section 7 concludes.

2 Related literature

Surprisingly, although reducing cartel fines during crisis periods is regularly discussed, very few theoretical articles address this issue. To the best of our knowledge, Fabra and Motta (2013) is the main paper which analyzes optimal lower fines during recessions. Our paper contributes also to two strands of literature on collusion. The first is the literature tying collusion sustainability and random fluctuating demand. The second analyzes the effects of fines on collusive strategies.

2.1 Antitrust fines and business cycles

Fabra and Motta (2013) consider an incumbent firm which, facing a potential entrant, can engage in conduct that violates antitrust laws. The antitrust authority can launch investigations and impose corporate and managerial fines. The authors show that both fines must be applied: a reduced corporate fine to decrease the risk of social cost of bankruptcy and a managerial fine to revert to the initial deterrence level. They argue that lower fines during recessions are sometimes optimal. First, it is harder to achieve deterrence in booms (anti-competitive practices are more beneficial) so higher fines must be applied. Second, the risk of bankruptcy for the firm with high fines is lower during booms than during recessions, so optimal fines can be lower during recessions. Finally, the authors show that varying policy according to the demand state can be welfare-maximizing. In contrast to this paper, we consider a dynamic model. Both fines act on collusive sustainability constraints: the fine imposed during recessions may influence collusive strategy in booms, and

⁶See for example Mookherjee and Png (1994).

vice-versa. Another relevant difference pertains to the marginal deterrence and incapacitation effects, which are not present in their model since only one period is considered and only one anti-competitive strategy is achievable.

2.2 Collusion sustainability and business cycles

The relationship between collusion and business cycles is not a new issue. Kleinwächter (1883), the founder of cartel theory, describes cartels as children of distress (“Kinder der Not”) as they might arise as the response to economic downturn in order to offset the drop in the price. The literature on the relationship between cartel sustainability and business cycle is quite extensive. We first review the main theoretical studies, and then discuss some empirical studies.

2.2.1 Theoretical studies

In contrast to the view that cartels arise during economic downturn, Green and Porter (1984) suggest that low demand periods may trigger transitory price wars. Because firms cannot determine whether low demand is induced by the economic situation or by a deviation from the collusive path, periods of weak demand require punishment to dissuade cheaters.⁷ The same dynamic arises in our model, as firms deactivate cartels during low demand periods, but we propose a different explanation from Green and Porter (1984).

Slade (1990) also shows that firms can alternate between collusive and competitive periods in a model where each firm’s marginal cost changes over time and is private information.

Our model is in line with the work initiated by Rotemberg and Saloner (1986) [RS]. These authors argue that cartels are likely to behave more competitively in periods of high demand since deviating from the collusive agreement results in higher profit. This result is partly due to the fact that demands over various periods are uncorrelated, so future expected profit (whether firms keep on colluding or deviate) is independent of current demand, so cartel deviation is more attractive if demand is high.

Several studies check the robustness of the results obtained by RS. Kandori (1991) includes demand correlation over time and demonstrates that if the discount factor tends to unity or is close to $\frac{n-1}{n}$ (n is the number of firms) in which case the no-deviation constraint is binding, prices display the same countercyclical movement as in RS. Haltiwanger and Harrington (1991) allow for cyclical demand instead of random demand. They assume that movements in market demand are fully anticipated but each cycle is composed of finite number of periods. In their model firms can more easily collude during periods of falling demand, which does not necessarily contradict results of RS: the gain from deviation is highest when demand is strongest, and begins to falls when demand decreases.

Bagwell and Staiger (1997) assume that the level of market demand alternates between slow and rapid

⁷In the model presented in Green and Porter (1984), firms cannot observe the demand shock or other firm’s quantity choice. Only the equilibrium price is public information. Since low prices can reflect demand conditions or overproduction by competitors, firms revert to competitive before switching back to collusion in order to ensure that punishment mechanisms are credible.

growth states, and the transition between states is determined by a Markov process. They show that if demand growth rates are strongly (weakly) correlated over time, then collusion is easier to sustain if demand growth rate is strong (low). Bernhardt and Rastad (2016) analyze collusion under demand uncertainty by a risk-averse cartel and overturn the RS results when cartel members are risk-averse and face positive fixed operating costs. Risk aversion implies that marginal gain from cheating on the cartel declines as demand increases. Fixed operating cost strengthens this effect and allows the authors to provide contradictory results of RS for some parameter values.

Staiger and Wolak (1992), Fabra (2006), Knittel and Lepore (2010) and Paha (2017) explore collusive pricing with capacity-constrained firms in the presence of demand uncertainty. Capacity constraints may limit deviation opportunities for colluding firms, but also potential retaliation against a deviating firm. The link between collusive opportunities and demand state depends either on firm capacities (if these are exogenous) or their expenditures (if capacities are endogenous).

Montero and Guzman (2010) analyze collusive agreement under demand uncertainty but the model differs from RS in several ways. In their model collusive agreement is sustained by large firms in the presence of a competitive fringe. Then cartels may lead to two opposite effects. First, members of the cartel may reduce their production so as to increase equilibrium price. Second, cooperation among members may lead to output-expanding strategies with the purpose of decreasing the production of the competitive fringe. The dominant effect depends on the demand state.

These studies assume that the number of firms is fixed, whereas Eswaran (1997) and Bagliano and Dalmazzo (1999) explicitly include in the context of RS the possibility of bankruptcy in recessions. Cartels may then be more difficult to sustain during recessions since the risk of bankruptcy induces firms to place a greater weight on immediate profits. To alleviate this problem, Eswaran (1997) allows for state-dependent market sharing strategies.⁸

Vasconcelos (2008) points out that market growth may trigger future entry.⁹ A potential entrant may alter the sustainability of a collusive agreement. Entry takes place earlier in a growing market as the entrant's profit is higher if the collusive agreement is already sustained than if it is dissolved in response to deviation. Deviation then provides higher current profit, and also delays potential entry. Subsequently collusion may be more difficult to sustain in growing markets when the number of firms is endogenous.

Our article contributes to this literature by including an active antitrust authority. We show that, subject to certain conditions, firms can implement an intermittent collusive strategy: cartels can be deactivated for some periods (often, but not exclusively, when demand is low). Such switching between collusive and competitive periods has been described by Green and Porter (1984) under imperfect monitoring where firms switch to a reversionary episode before switching back to collusion. In our paper, we propose a very different explanation for this phenomenon since firms can deactivate the cartel for some periods to cancel the risk of

⁸The market share adjustment eliminates the risk of bankruptcy for firms with financial weakness since the other producers can curtail their own production if demand is low to ensure their viability. In return, they obtain larger market shares when demand is high.

⁹See also Correia-da-Silva, Pinho and Vasconcelos (2016).

cartel detection and keep the ability to cartelize for the future. These two explanations are complementary since they apply in different contexts.

2.2.2 Empirical evidence

The theoretical literature surveyed in the preceding section identifies many relationships between collusion and business cycles. We now discuss the empirical evidence, whose overall results are mixed.

Many industries have been shown to alternate between collusive and competitive periods. Examples include the railroad industry in the USA (Porter, 1983, and Ellison, 1994),¹⁰ Bromine production (Levenstein, 1997), and the Chinese airline market (Zhang and Round, 2011). Levenstein and Suslow (2006) also mention aluminum, coffee, copper, steel, sugar, sulfur and tin industries. Resende and Zeidan (2016) investigate the price dynamics of thirty different industries in Canada using a nonparametric approach, to assess their resemblance with the Green and Porter model (1984). This turns out to be true for one industry, plastic bottles. The authors conclude that such an intermittent collusive strategy is unusual, nevertheless non-negligible. If alternating collusive and competitive periods have been observed in some industries, their interpretation is subject to debate. Some authors argue that all collusive periods must be viewed as a unique cartel and competitive periods as temporary price wars prescribed by the agreement, as in Green and Porter's (1984) theoretical model. Other studies consider these as separate cartels: a cartel is dissolved following a unilateral deviation of a firm or a detection of the antitrust authority and another one becomes active after the competitive phase. An intermediate explanation relies on the fact that price wars represent periods where profit-sharing rules are renegotiated after a change in industry structure (the entry of a new firm, innovation, an increased production capacity differential after the opening of a new plant, etc.). Our model is consistent with the first interpretation (competitive periods are stipulated in the rules governing the cartel), but our explanation differs from that of Green and Porter (1984).

Our article also contributes to the relationship between collusion and business cycles, which has been widely investigated empirically although results are mixed. In a study analyzing legal cartels between American exporters, Dick (1996b) finds that cartels tend to operate in periods of growing export operations. In a complementary study, Dick (1996a) shows that low demand negatively affects cartel sustainability. Other studies, as Asch and Seneca (1975), suggest that collusion is more likely under recessions where it serves to reverse the decline in prices. Symeonidis (2003), using a dataset of price-fixing incidence across UK manufacturing industries in the 1950s, finds a non-monotonic relationship (inverted U-shape) between market growth and the likelihood of collusion. This is because market growth increases cartel sustainability, but faster growth can have the opposite effect by attracting new competitors. Jacquemin et al. (1981) analyze Japanese export cartels and prove that the growth rate of demand is inversely related to the duration of cartels. Zhang and Round (2011) study China's airline market and show that airlines tended to engage in

¹⁰This cartel, run by the Joint Executive Committee (JEC), controlled eastbound freight shipments from the Midwest to eastern cities in the United States during 1880-1886. It preceded the Sherman Antitrust Act of 1890 and the formation of the Interstate Commerce Commission (1887), operating to increase the price of grain above the competitive price. In addition to the articles of Porter (1983) and Ellison (1994), other studies also provide evidence of reversions to non-cooperative behavior, such as Lee and Porter (1984), Cosslett and Lee (1985), Berry and Briggs (1988), and Hajivassiliou (1990).

collusion when demand was high, but that there is also evidence suggesting collusion during low demand periods. In their literature review, Levenstein and Suslow (2006) point out that periods of price reduction can lead to cartel formation. These price cuts are not always linked to recessions though, and can result from idiosyncratic events (entry of a new firm, increase in production capacities). These authors also emphasize that unanticipated demand shocks undermine cartel stability more than anticipated shocks. Some studies do not find any evidence of the impact of business cycle on collusion, such as Iwand and Rosenbaum (1991) for the US cement industry. Overall, empirical results regarding the impact of business cycles on collusion sustainability are mixed and depend on both the sectors and time periods. In our article, we show that firms can collude either only during booms, or only during recessions or during both types of demand. We can thus provide an explanation for the variety of empirical evidence.

The last point we examine is the impact of the demand variance on the collusion. It is generally agreed that strong demand variance reduces collusion sustainability. For example, Ivaldi et al. (2003) state that “*collusion is less sustainable in markets that are subject to demand fluctuations.*” This idea is based on both theoretical and empirical analysis. Dick (1996a) empirically finds that cartels are less sustainable if export price movements are high. Some other studies however obtain the opposite result. Sjostrom (1989) shows that collusive agreements in ocean shipping are more likely when the standard deviation of total shipments increases. In our article, we obtain such a result for some parameter values. Moreover, it is often argued that cartels leads to decreased price variance. Bolotova, Connor and Miller (2008) examines this relationship in the context of two cartel conspiracies, citric acid and lysine. Empirical results suggest that the variance of prices during the lysine conspiracy decreased, but that it increased during the citric acid cartel. In our model we also obtain an increased price variance when firms choose the intermittent collusive strategy.

2.3 Marginal deterrence of collusion

Articles dealing with the fight against cartels mainly focus on cartel deterrence. Fewer studies analyze the marginal deterrence effect: even if collusive agreements are not fully deterred, the gravity of offense can be reduced with appropriate competition policy and antitrust fines.¹¹

Deterring the formation of collusive agreements requires the maximal level of fines. But if perfect deterrence is not achievable authorities may set fine levels depending on prices in order to decrease their occurrence, and thus the damages suffered by consumers. This issue is studied by Souam (2001) and Pénard and Souam (2002) in static model (disregarding the no deviation constraint) and Houba, Motchenkova and Wen (2010, 2018) in a dynamic setting.

Our contribution differs significantly from the previous papers which mainly focus on the cartel price when the deterrence effect does not prevail. Since we assume that fine is independent of the collusive price, we sidestep this feature. Instead, we consider that fines can depend on business cycles in which case the marginal deterrence effect does not pertain to the cartel price (even if it is indirectly impacted) but to the

¹¹See Stigler (1970), Shavell (1992), Wilde (1992), Mookherjee and Png (1994) and Friehe and Miceli (2014) for generic studies of marginal deterrence applied to crime.

number of demand states in which cartels operate. Another novel feature of our article is that the welfare ranking of collusive strategies on welfare is sensitive to parameter values, unlike in the previous papers where a lower collusive price has a positive effect on welfare.

Our article makes some similar points to those raised by Reuter (2017). He extends Green and Porter (1984) by introducing the possibility of a trade association. This association allows firms to receive a signal about the aggregate demand state, altering the length of price war. However, cartel detection is increased when expected duration of cartel is reduced. As in our article, several collusive strategies are achievable and the expected fines set by antitrust authority (these fines can be discounted or not for cartels which operate outside of the trade association) impact the choice of strategy. Antitrust authorities face a trade-off between inducing collusive firms to avoid participating in the trade association in order to increase the frequency of price wars and decrease expected collusive prices, or inducing firms to fall back on the trade association to boost detection probability and decrease the expected length of collusive agreements. Although our article similarly highlights a trade-off for the antitrust authority, our model parts from Reuter's (2017) analysis in several ways. We assume perfect information, we do not include a trade association, and, more importantly, we focus on fines which are based on business cycles.

3 The Model

We consider an n -firm Bertrand competition setting over an infinite time horizon. Firms produce a homogeneous good with the same marginal cost c . At each period, they can decide to conclude a collusive agreement. Collusive outcomes are supported by grim trigger strategies: as soon a firm deviates from the agreement, all firms play competitively forever.¹²

Demand fluctuates and is described by a function $Q(p, \theta)$, where p is the industry price and θ is a discrete random variable with values in $\{\theta_l, \theta_h\}$. The low [high] shock θ_l [θ_h] occurs with probability μ [$1 - \mu$]. As in RS, we assume that shocks are independently and identically distributed. The following assumptions apply: for all p , $Q(p, \theta_h) \geq Q(p, \theta_l)$; $\frac{\partial Q}{\partial p}(\cdot) \leq 0$; and $\frac{\partial^2 Q}{\partial p^2}(p, \theta)p + 2\frac{\partial Q}{\partial p}(p, \theta) < 0$. The monopoly price and profit, $p^m(\theta)$ and $\pi^m(\theta)$, are therefore well-defined. We keep the demand function in the most general form throughout, but occasionally use the specific form $Q(p, \theta) = \theta(A - p)$ in order to illustrate the results. We choose $\theta_h = \bar{\theta} + \alpha$ and $\theta_l = \bar{\theta} - \alpha$, so $\alpha \in [0, \bar{\theta}]$ parametrizes the magnitude of demand shocks and can be considered as a measure of the demand variance.¹³

We consider an antitrust authority which intends to detect and fight collusion. We assume that firms cannot collude tacitly, but have to explicitly exchange information and achieve an agreement about how to coordinate their conduct. Cartel members agree to fix prices during regular meetings and check that the agreement is fulfilled ex-post. This process generates hard evidence which can be discovered by the antitrust

¹²If firms revert to a Nash equilibrium of static game, at least two firms set price equal to marginal cost and others can choose higher prices. In order to avoid that authority infers such higher prices reflect collusive strategies, we assume that without collusion, all choose $p = c$.

¹³The exact value of the variance is $4\mu(1 - \mu)\alpha^2$, which is increasing in α . It is worth noting that the expected value of θ is $\bar{\theta} + (1 - 2\mu)\alpha$, which depends on α if $\mu \neq 1/2$.

authority.

When colluding firms set prices exceeding marginal cost, the cartel is detected with probability ρ . If colluding firms set prices equal to marginal cost, we distinguish two possible scenarii. In the first scenario, we assume that the detection probability remains ρ (this assumption is labeled A1 henceforth). This assumption applies if the cartel governance structure remains in place and firms continue to meet and debate the price at the beginning of each period. It is mainly such meetings that can lead to the cartel detection. In the second scenario (this assumption is labeled A2 henceforth), we assume that the detection probability drops to zero when colluding firms set prices equal marginal cost. This case may be motivated by recalling that competitive pricing is a Nash equilibrium of the static game. The cartel therefore does not require any pricing check, and can therefore temporarily suspend the exchange of price information between its members, reducing the detection probability. In order to simplify the computations and results we assume that this detection probability is zero, but our main results remain unchanged if we consider any sufficiently big detection differential. We favor assumption A2 which seems more realistic, and assumption A1 is used primarily to provide a benchmark. Apart from the discontinuity of detection probability at $p = c$ we assume that detection probability is not price-dependent.¹⁴

We assume that, during a deviation period, the probability of cartel detection remains equal to ρ and that the deviating firm faces the same expected fine as during collusive period.¹⁵ During deviation periods, governance structure activities remain in place: meetings take place between firms delegates and check are performed ex-post if colluding firms decide to set $p > c$. Furthermore, as noted by Bos et al. (2018), “This assumption reflects the common legal practice that collusion is a *per se* offense. It is the act of communicating to coordinate behavior that is illegal (or taken as evidence of illegality), and not the actual prices that are charged.” In practice, antitrust legislation generally does not provide reduced fines for deviating firms unless they apply for leniency programs, which are not included in our model. Nevertheless we discuss the alternative assumption in the Appendix 8.2 related to Section 4.

If a cartel is detected, the authority launches an investigation which leads to successful prosecution resulting in a fine $f(\theta) \in [0, F(\theta)]$.¹⁶ Prior to starting the game, antitrust authority discloses the amount of fines incurred. Fines can be state-contingent (if $f_l \equiv f(\theta_l)$ differs from $f_h \equiv f(\theta_h)$), but never exceed a

¹⁴This exogenous detection probability can be interpreted as resulting from random inspections without price monitoring (as in Houba et al. 2010). The exogeneity of the parameter ρ eliminates several potential effects of the antitrust policy. If ρ depended on prices (or on price changes), then the collusive firms would adopt complex price patterns (see for examples Block et al. 1981, Harrington 2005, Bos et al. 2018, Emons 2020, or Akyapi and Turner 2022). Assuming an increasing and continuous detection probability function would be prohibitively complex in our model. Indeed, firms would set the cartel price below the monopoly price in order to decrease the detection probability, regardless of the demand state. We could suspect that if fines are the same in both states, the decrease in collusive price would be stronger when demand is low since gain from higher price is less profitable. But a sufficient fine reduction during recessions can offset this effect. The effects of price-dependent detection probability seem to be in line with the effects of the drop of detection probability in case of competitive pricing. Furthermore, if we keep this discontinuity assumption when $p = c$, intermittent collusive strategies may still appear at equilibrium. Then we believe that our main results could be generalized to a price-dependent detection probability.

¹⁵The assumption that a cartel can still be detected in periods of defection is adopted in many other papers, including Spagnolo (2004), Buccirosi and Spagnolo (2007), Chen and Rey (2013), Harrington (2014), Jensen and Sørgaard (2016), Dargaud and Jacques (2015, 2020), and Bos et al (2018).

¹⁶For the sake of generality, we introduce the possibility that the maximum fine depends on the demand state. This is the case for example under EU competition rules, where the maximum level of fine is capped at 10% of the overall annual turnover of the company. For the most part of our study, we assume $F(\theta_h) = F(\theta_l) = F$ but the discussion at the end of Section 6 considers the case where $F(\theta_h) \neq F(\theta_l)$.

statutory maximum $F(\theta)$. Cartels are dissolved once they have been convicted and firms can not collude again. In practice, some detected cartels do form once again, so our assumption may appear extreme. We make the assumption that a condemned cartel can never form again in order to simplify the model. What is important is that a cartel is dissolved with a very high probability after its condemnation and cannot form again until a significant number of periods has elapsed, so there is an incapacitation effect.

Firms, consumers and the antitrust authority have the same discount factor $\delta \in (0, 1)$.

Denote the instantaneous profit and consumer surplus by π and cs and the capitalized flows of discounted profits and consumer surplus by Π and CS . The superscripts m and nc respectively designate the monopoly and non-cooperative situation.

4 Constant detection probability

In this section, primarily as a benchmark, we study collusive strategies under assumption A1, whereby the detection probability remains constant even if the cartel price is equal to the competitive price. In this case, firms have no incentive to temporarily suspend the cartel's activities. As the detection probability and fines do not depend on the cartel price, collusive firms should set the highest possible price, subject to the constraint that the agreement is self-enforcing. We refer to this strategy as the constant collusive strategy or “ C strategy”. As in RS, we first assume that δ is sufficiently high that collusion at the monopoly price is sustainable whatever the state of demand, and then consider a reduced value of δ for which cartel may be sustainable at lower prices if demand is high.

If firms are very patient then any collusive price can be sustained whatever the state of demand, including the monopoly price which maximizes the collusive profit. The associated discounted profits are:¹⁷

$$\begin{aligned}\Pi^C &= \mu \left(\frac{\pi^m(\theta_l)}{n} - \rho f_l \right) + (1 - \mu) \left(\frac{\pi^m(\theta_h)}{n} - \rho f_h \right) + \delta(1 - \rho) \Pi^C \\ \Leftrightarrow \Pi^C &= \frac{\mu \left(\frac{\pi^m(\theta_l)}{n} - \rho f_l \right) + (1 - \mu) \left(\frac{\pi^m(\theta_h)}{n} - \rho f_h \right)}{1 - \delta(1 - \rho)}\end{aligned}$$

This strategy is sustainable for $\delta \geq \max(\delta_l^C, \delta_h^C)$, where δ_l^C and δ_h^C are computed for low and high demand levels respectively and are equal to:¹⁸

$$\begin{aligned}\delta_l^C &= \frac{(n - 1) \pi^m(\theta_l)}{(1 - \rho) \{(\mu + n - 1) \pi^m(\theta_l) - n\mu\rho f_l + (1 - \mu) [\pi^m(\theta_h) - n\rho f_h]\}} \\ \delta_h^C &= \frac{(n - 1) \pi^m(\theta_h)}{(1 - \rho) \{[\mu(\pi^m(\theta_l) - n\rho f_l) - (1 - \mu)n\rho f_h] + (n - \mu) \pi^m(\theta_h)\}}\end{aligned}$$

¹⁷These profits are computed at the beginning of the period. This expression can be negative if the fines incurred are very high, but in such a case, at least one of the no-deviation constraints is violated. When the no-deviation constraints are satisfied, Π^C is necessarily positive.

¹⁸See Appendix 8.1 for proof.

An important theme in this article is whether cartels are less sustainable when demand is high or when it is low. We find that¹⁹ $\delta_h^C \geq \delta_l^C$, so collusive agreements are more difficult to sustain in booms than in recessions, as in RS. We assume that collusive firms can be fined regardless of whether a deviation from collusive strategies actually occurs. The expected fine for the current period then plays the role of a fixed cost and does not directly affect the incentive constraint. Fines also appear in the continuation gains of collusion. However, as we assume uncorrelated demand fluctuations, the expected future fines have the same impact on deviation incentives in both demand states. The ranking of sustainability thresholds is then the same as in RS's model. This ranking could differ if deviating firm could not be fined, for instance in the presence of leniency program.²⁰

Let us now assume lower values of the discount factor for which collusive agreements may be sustainable at a lower price than the monopoly price. If $\delta_l^C < \delta < \delta_h^C$, the monopoly price is sustainable only if demand is low but firms can sometimes sustain a price which is lower than the monopoly price but higher than the competitive price if demand is high, as in RS's model: we denote this collusive strategy by C^* and the collusive profit if demand is high (and without the expected fine) by π^* .

In this case the expected discounted profit is equal to:

$$\Pi^{C^*} = \frac{\mu \left(\frac{\pi^m(\theta_l)}{n} - \rho f_l \right) + (1 - \mu) \left(\frac{\pi^*}{n} - \rho f_h \right)}{1 - \delta(1 - \rho)}$$

with²¹

$$\pi^* = \frac{\delta(1 - \rho) \{ \mu \pi^m(\theta_l) - n \rho [\mu f_l + (1 - \mu) f_h] \}}{n - 1 - \delta(1 - \rho)(n - \mu)}.$$

In order for the denominator to be positive, δ must be sufficiently low: $\delta \leq \bar{\delta}^* \equiv \frac{n-1}{(1-\rho)(n-\mu)}$. As in RS, firms select the collusive strategy C^* if they are not sufficiently patient for the strategy C be sustainable. However, in our model, the collusive strategy C may not be sustainable despite a relatively high value of δ , because of high fines. In such cases, if C is not sustainable, neither is C^* even with a collusive price higher than marginal cost when demand is high.²²

The collusive strategy C^* is necessarily sustainable if demand is high.²³ If demand is low the no-deviation

¹⁹ $\delta_h^C \geq \delta_l^C \Leftrightarrow (1 - \mu) \left(\frac{\pi^m(\theta_h)}{n} - \rho f_h \right) + \mu \left(\frac{\pi^m(\theta_l)}{n} - \rho f_l \right) \geq 0$. This condition always holds if $\Pi^C > 0$. Otherwise collusion is not sustainable and the comparison of discount factors is irrelevant.

²⁰See Appendix 8.2.

²¹See Appendix 8.3.

²²It is well known that, without competition policy and in the absence of fluctuation in demand, if firms producing homogeneous goods and competing by setting prices can sustain a price above marginal cost then the monopoly price can be sustained as cartel prices, and vice versa. Without any competition policy but allowing for demand fluctuations, RS show that some prices above the firms' marginal cost may be sustainable in periods of high demand while firms can not sustain the monopoly price. In such a case, C^* is sustainable whereas C can not be sustained. On the other hand, if a cartel fine is introduced, then, in the absence of fluctuation in demand, the monopoly price may be sustainable, whereas lower prices are not (see for example Dargaud and Jacques, 2015). In such a case, if C is not sustainable, neither is C^* . Our model is close to the RS situation, when the detection probability and the fines are low. If so, C^* is the only sustainable collusive strategy for some values of δ (the threshold value of δ below which C is no longer sustainable is lower than $\bar{\delta}^*$). In contrast, when the detection probability and fines are higher, our model is close to Dargaud and Jacques, 2015. In such a case, if C is not sustainable, neither if C^* (the threshold value of δ below which C is no longer sustainable is higher than $\bar{\delta}^*$).

²³ π^* is computed according to the binding no-deviation constraint if demand is high.

constraint is:

$$\frac{\pi^m(\theta_l)}{n} - \rho f_l + \delta(1 - \rho)\Pi^{C^*} \geq \pi^m(\theta_l) - \rho f_l,$$

or:

$$\delta \geq \delta_l^{C^*} \equiv \frac{1}{(1 - \rho)} \frac{[n - 1 - \delta(1 - \rho)(n - \mu)]\pi^m(\theta_l)}{[(\mu + n - 1) - \delta(1 - \rho)n]\pi^m(\theta_l) - [1 - \delta(1 - \rho)]n\rho[\mu f_l + (1 - \mu)f_h]}.$$

The primary objective of this article is to analyze whether the optimal level of fines should be state-dependent. This is clearly not the case under assumption A1 where the optimal policy is to set the highest achievable fines, as in many studies dealing with the economic analysis of crime. Indeed, δ_h^C increases and π^* decreases in both levels of fines. Even if the fines are too weak to deter collusive agreements, they can cushion their effects by decreasing prices during booms: this is a marginal deterrence effect of fines.

5 Variable detection probability

We now study equilibrium strategies under assumption A2, whereby firms can cancel the risk of the cartel detection by setting the competitive price. Firms can still pursue the constant collusion strategy by setting the monopoly price for each period, regardless of the demand level. However, they may instead opt for an intermittent collusive strategy, setting the monopoly price only if demand is high (H strategy) or low (L strategy), and fixing the competitive price the rest of the time. We characterize and compare these different cartel agreements, and then illustrate the results using a specific demand function.

5.1 Collusive strategies

We analyze three collusive strategies which we denote by C , H and L . Since the expected fine does not depend on price and the detection probability is exogenous, colluding firms choose the highest possible price, which is the monopoly price if it is sustainable.

5.1.1 Constant strategy

If δ is sufficiently high then firms can choose the C strategy. Π^C is the same as in the previous section, but the expected fines ρf_l and ρf_h are now quasi-fixed costs that must only be paid if firms decide to set prices above marginal cost. The firms prefer to switch to the H or L strategies if $\frac{\pi^m(\theta_l)}{n} - \rho f_l < 0$ or $\frac{\pi^m(\theta_h)}{n} - \rho f_h < 0$. Otherwise, the C strategy is the same to the one previously described.

If $\delta_l^C < \delta < \delta_h^C$, the monopoly price cannot be sustained in both states. However, firms can, for some parameter values, opt for the C^* strategy and sustain a price which is lower than the monopoly price when demand is high. The collusive profit without expected fine is then π^* (see previous section). The C^* strategy is sustainable if $\delta \geq \delta_l^{C^*}$, $\frac{\pi^m(\theta_l)}{n} - \rho f_l > 0$, and $\frac{\pi^*(\theta_h)}{n} - \rho f_h > 0$. Furthermore, in order for C^* to be sustainable whereas firm can not sustain the C strategy, the condition $\delta \leq \bar{\delta}^*$ must be satisfied.

5.1.2 Intermittent strategies

When collusion is intermittent, firms playing the H [L] strategy set the monopoly price only if demand is high [low], and set price equal to marginal cost otherwise.

The discounted profits are:

$$\begin{aligned}\Pi^H &= \mu\delta\Pi^H + (1-\mu)\left[\frac{\pi^m(\theta_h)}{n} - \rho f_h + \delta(1-\rho)\Pi^H\right] &\Leftrightarrow \Pi^H &= \frac{1-\mu}{1-\delta+(1-\mu)\delta\rho}\left[\frac{\pi^m(\theta_h)}{n} - \rho f_h\right] \\ \Pi^L &= (1-\mu)\delta\Pi^L + \mu\left[\frac{\pi^m(\theta_l)}{n} - \rho f_l + \delta(1-\rho)\Pi^L\right] &\Leftrightarrow \Pi^L &= \frac{\mu}{1-\delta+\mu\delta\rho}\left[\frac{\pi^m(\theta_l)}{n} - \rho f_l\right].\end{aligned}$$

Firms playing the H [L] strategy may be induced to deviate from the cartel only if demand is high [low]. The collusion sustainability conditions are:

$$\begin{aligned}\frac{\pi^m(\theta_h)}{n} - \rho f_h + \delta(1-\rho)\Pi^H \geq \pi^m(\theta_h) - \rho f_h &\Leftrightarrow \delta \geq \delta^H \equiv \frac{(n-1)\pi^m(\theta_h)}{[n(1-\rho+\mu\rho)-\mu]\pi^m(\theta_h)-n(1-\rho)(1-\mu)\rho f_h} \\ \frac{\pi^m(\theta_l)}{n} - \rho f_l + \delta(1-\rho)\Pi^L \geq \pi^m(\theta_l) - \rho f_l &\Leftrightarrow \delta \geq \delta^L \equiv \frac{(n-1)\pi^m(\theta_l)}{[(1-\mu\rho)n-(1-\mu)]\pi^m(\theta_l)-n(1-\rho)\mu\rho f_l}.\end{aligned}$$

The threshold discount factor for the H [L] strategy is increasing in f_h [f_l] and independent from f_l [f_h].

For lower discount factors, there is no sustainable price higher than the marginal cost for either strategy (see Appendix 8.4 for proof). We obtain the same result as in Bertrand competition with homogeneous products and a stationary demand function. If the monopoly price is not sustainable, then neither is any other price above than marginal cost.

5.2 Strategy choice

We now derive equilibrium collusive choices, for a given level of fines. We suppose that firms choose their collusive strategy before knowing the first value of θ .

If $\delta \geq \max\{\delta^H, \delta_h^C\}$,²⁴ the relevant comparison is:

$$\Pi^H \geq \Pi^C \Leftrightarrow \frac{(1-\mu)\delta\rho}{1-\delta+(1-\mu)\delta\rho}\left(\frac{\pi^m(\theta_h)}{n} - \rho f_h\right) \geq \frac{\pi^m(\theta_l)}{n} - \rho f_l.$$

Observe that $0 < \frac{(1-\mu)\delta\rho}{1-\delta+(1-\mu)\delta\rho} < 1$, so firms consider the H strategy only if $\frac{\pi^m(\theta_h)}{n} - \rho f_h > \frac{\pi^m(\theta_l)}{n} - \rho f_l$. The condition $\Pi^H \geq \Pi^C$ is more likely to hold if f_l is high, f_h is low, $\pi^m(\theta_h)$ is high, $\pi^m(\theta_l)$ is low, or $(1-\mu)$ is high.

If $\delta \geq \max\{\delta^L, \delta_h^C\}$, we obtain the following comparison:

$$\Pi^C \geq \Pi^L \Leftrightarrow \frac{1-\delta+\mu\delta\rho}{\mu\delta\rho}\left(\frac{\pi^m(\theta_h)}{n} - \rho f_h\right) \geq \frac{\pi^m(\theta_l)}{n} - \rho f_l.$$

Note that $\frac{1-\delta+\mu\delta\rho}{\mu\delta\rho} > 1$. The L strategy may only be selected by firms if $\frac{\pi^m(\theta_l)}{n} - \rho f_l > \frac{\pi^m(\theta_h)}{n} - \rho f_h$, which implies that the level of fine f_l has to be lower than f_h since $\pi^m(\theta_h) > \pi^m(\theta_l)$. We find the same comparative static properties as above: the condition $\Pi^C \geq \Pi^L$ is more likely to hold if f_l is high, f_h is low, $\pi^m(\theta_h)$ is high, $\pi^m(\theta_l)$ is low and $(1-\mu)$ is high.

²⁴We have already shown that $\delta_l^C < \delta_h^C$.

If δ is high enough to sustain the C strategy, then the comparison of the H and L strategies is irrelevant.²⁵

We now turn to lower values of δ . In such cases, the C strategy may not be sustainable but firms might implement the C^* strategy if $\delta \leq \bar{\delta}^*$. Note that $\Pi^{C^*} \leq \Pi^C$. We can compare Π^{C^*} with Π^H and Π^L , but the first comparison is uninformative since $\delta^H \leq \delta_h^C \Leftrightarrow \Pi^C \leq \Pi^H$.²⁶ In the region where H is sustainable but not C , firms prefer H to C^* since $\Pi^H \geq \Pi^C \geq \Pi^{C^*}$.

Concerning the other comparison between Π^{C^*} and Π^L , we can prove that²⁷ $\delta^L \geq \delta_l^C$ iff $\Pi^C \geq \Pi^L$ and $\delta^L \leq \delta_l^C \leq \delta_h^C$ if $\Pi^L \geq \Pi^C$. If $\Pi^L \geq \Pi^C$ there are parameter values for which firms must choose between L and C^* , but the inequality $\Pi^L \geq \Pi^C \geq \Pi^{C^*}$ must hold and firms select the L strategy. Moreover, for these values, if L is not sustainable, then neither is C^* . Concerning the other case $\Pi^C \geq \Pi^L$, there may be parameter values for which C can not be sustained whereas L and C^* are sustainable. In such cases we obtain the following condition:

$$\Pi^{C^*} \geq \Pi^L \Leftrightarrow \frac{1 - \delta + \mu\delta\rho}{\mu\delta\rho} \left[\frac{\pi^*}{n} - \rho f_h \right] \geq \frac{\pi^m(\theta_l)}{n} - \rho f_l.$$

We can then identify cases for which either the C , H or L strategies are selected.

If $\Pi^H \geq \Pi^C$ and $\delta > \delta^H$, firms opt for the H strategy. If $\Pi^C < \Pi^L$ and $\delta > \delta^L$, they choose the L strategy. If $\Pi^H < \Pi^C$, $\Pi^C \geq \Pi^L$ and $\delta > \delta_h^C$, they follow the C strategy.

5.3 Equilibria with a specific demand function

To formulate the results in a more intuitive way and represent them graphically, we use the specific demand form $Q(p, \theta) = \theta(A - p)$, choosing $\theta_h = \bar{\theta} + \alpha$ and $\theta_l = \bar{\theta} - \alpha$. This specification highlights the crucial role of demand variance.

Firstly, we focus on the case: $\delta > \bar{\delta}^*$, which produces the most interesting results and new findings compared with existing literature. As pointed out in section 4, the C^* strategy never appears in equilibrium if $\delta > \bar{\delta}^*$, and we therefore compare the C , H and L strategies. At the end of this section, we explore the opposite case: $\delta < \bar{\delta}^*$ where firms can choose the C^* strategy in equilibrium.

The monopoly price $p^m = \frac{A+c}{2}$ does not depend on the demand shock with this demand function. We derive quantity and profits compatible in monopoly equilibrium:

$$\begin{aligned} Q^m(\theta_h) &= (\bar{\theta} + \alpha) \left(\frac{A - c}{2} \right) & ; & \quad \pi^m(\theta_h) = (\bar{\theta} + \alpha) \frac{(A - c)^2}{4} \\ Q^m(\theta_l) &= (\bar{\theta} - \alpha) \left(\frac{A - c}{2} \right) & ; & \quad \pi^m(\theta_l) = (\bar{\theta} - \alpha) \frac{(A - c)^2}{4}. \end{aligned}$$

²⁵If $H \succ C$ then $C \succ L$ and $H \succ L$. If $L \succ C$ then $C \succ H$ and $L \succ H$.

²⁶See Appendix 8.5 for proof.

²⁷See Appendix 8.5 for proof.

Comparisons of collusive profits lead to the following results:

$$\begin{aligned}\Pi^H &\geq \Pi^C \Leftrightarrow \alpha \geq \alpha^{HC} \equiv \frac{\frac{4n\rho}{(A-c)^2} \{(1-\mu)\delta\rho f_h - [1-\delta + (1-\mu)\delta\rho]f_l\} + (1-\delta)\bar{\theta}}{1-\delta + 2(1-\mu)\delta\rho} \\ \Pi^C &\geq \Pi^L \Leftrightarrow \alpha \geq \alpha^{CL} \equiv \frac{\frac{4n}{(A-c)^2}\rho[(1-\delta + \mu\delta\rho)f_h - \mu\delta\rho f_l] - (1-\delta)\bar{\theta}}{1-\delta + 2\mu\delta\rho}.\end{aligned}$$

The two previous inequalities are more easily satisfied if demand fluctuations are large. This is intuitive since the difference between $\pi^m(\theta_h)$ and $\pi^m(\theta_l)$ increases in α , so collusion becomes more attractive during booms and less attractive during recessions. Fines clearly affect the choice of collusive strategy: the two previous inequalities are more easily satisfied for higher [lower] values of f_l [f_h].

Demand variance also affects collusion sustainability:

$$\begin{aligned}H \text{ is sustainable if } \alpha &\geq \alpha^H = \frac{\delta(1-\mu)(1-\rho)\frac{4n\rho}{(A-c)^2}}{(n-n\rho-\mu+\mu n\rho)\delta-n+1}f_h - \bar{\theta} \\ L \text{ is sustainable if } \alpha &\leq \alpha^L = \bar{\theta} - \frac{\delta\mu(1-\rho)\frac{4n\rho}{(A-c)^2}}{(n-1+\mu-\mu\rho n)\delta-n+1}f_l \\ C \text{ is sustainable if } \alpha &\leq \alpha_h^C = \frac{[(1-\rho)n\delta-n+1]\bar{\theta} - (1-\rho)\frac{4n\rho}{(A-c)^2}[\mu f_l + (1-\mu)f_h]\delta}{n-1-(1-\rho)(n-2\mu)\delta}\end{aligned}$$

The H strategy is sustainable if the high demand level ($\bar{\theta} + \alpha$) is sufficiently strong and f_h is not too high. The L strategy is sustainable if the low demand level ($\bar{\theta} - \alpha$) is high and f_l is not too high. In order for C to be sustainable, the demand level ($\bar{\theta}$) must be high whereas its variance must be low, and both fine levels shall not be too large.

We first analyze equilibrium collusive strategies when fines are the same in both states. In this case we know that firms always prefer the C strategy to the L strategy (and the C strategy is sustainable if firms can sustain the L strategy). The choice between H and C depends on demand variability.

Proposition 1 *When fines are the same in both demand states, firms set monopoly price only during booms if demand variability is high and select the constant collusive strategy otherwise. Firms never choose to set monopoly price only during recessions.*

This result is due to two different effects. The first effect relates to the attractiveness of the H and C strategies. Firms know that cartels are dissolved once detected and that they never form again. The lifetime of the cartel is therefore finite. But firms can expect cartels to be dissolved later when they collude only during booms. They therefore waive instantaneous collusive profits when demand is low in order to benefit from better opportunities in the future from high profit levels during booms. The attractiveness of the H strategy, compared to the C strategy, increases with demand variability because the instantaneous collusive profit if demand is low decreases in α whereas the expected collusive profit if demand is high increases with this same parameter. The second effect is related to the sustainability conditions of collusive agreements. The H strategy is more easily sustained if α is high since expected collusive profits increase whereas the

expected fine is the same. However the C strategy is less sustainable if α increases, as highlighted by RS. Large demand shocks make the monopoly price more difficult to sustain and the expected fine does not affect this result (see Section 4). These two effects, though they appear for different parameter values, act in the same direction.

Figure 1 helps to illustrate these results in the (f, α) -plane (with $f = f_l = f_h$). For this and subsequent diagrams (except figure 3 for which the values of δ and μ are different), we set the following values for model parameters: $A - c = 5$, $\rho = 0.01$, $n = 2$, $\bar{\theta} = 5$, $\delta = 0.9$ and $\mu = 0.5$.²⁸ The general shape of the graphs does not depend on these parameter values as long as the different collusive strategies remain sustainable when the fines are low. The solid lines delimit equilibrium strategies. NC is the no-collusion strategy.

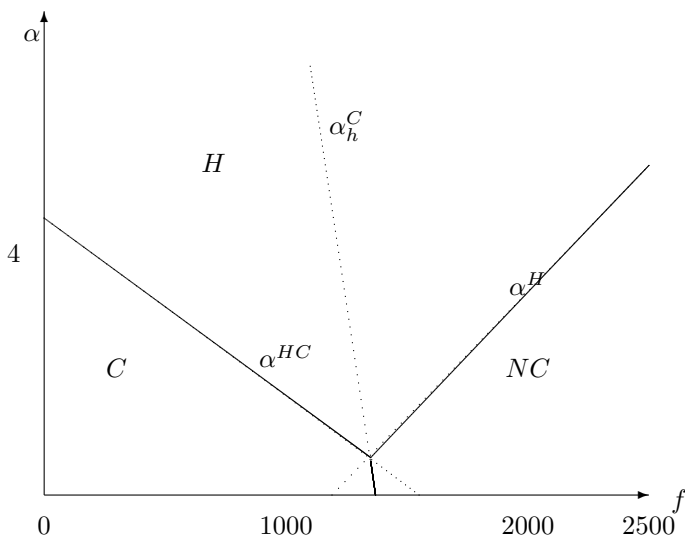


Figure 1: Equilibrium strategies if $f_h = f_l$

A similar reduction in both fine levels may induce firms to switch from the H to the C strategy. A lower value of f implies a larger decrease in the expected fine compared with the collusive profit when demand is low ($\frac{\pi^m(\theta_l)}{n} - \rho f_l$ grows proportionally more than $\frac{\pi^m(\theta_h)}{n} - \rho f_h$).

We next relax the assumption $f_h = f_l$. Lower fines during booms lead to broadly the same results as previously. Firms never select the L strategy and the borders defining where firms choose between the C and H strategies have the same configuration as previously in the (f_h, α) -plane. The border α^H is exactly in the same place (it does not depend on f_l) and α^{HC} remains a decreasing function of f_h .

Equilibrium strategies are more complex if fines are lower during recessions. The L strategy can be an equilibrium choice. To illustrate this possibility (see Figure 2), we take $f_h/(\alpha - c)^2$ to be sufficiently high and set $f_h = 2000$ (other parameter values remains the same).

²⁸Setting $\mu = 0.5$ implies that $\bar{\theta}$ equals the expected value of the demand and α is the standard deviation of the demand.

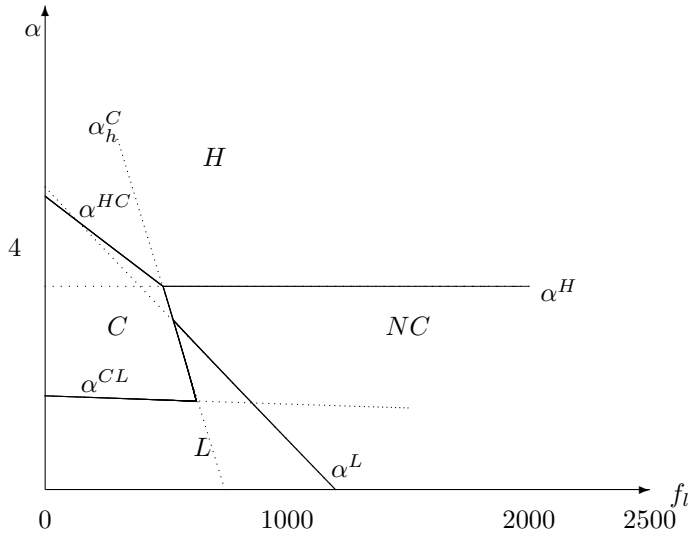


Figure 2: Equilibrium strategies if $f_h > f_l$

For strong demand variability, firms still set the monopoly price only during booms. This is true when $\Pi^H \geq \Pi^C$ and $\delta > \delta^H$. For smaller demand fluctuations, firms pursue this strategy if the level of fines during recessions is high and otherwise they switch to the constant collusive strategy. A decreased value of f_l reduces the gap between the collusive profits obtained in both demand states and counteracts lower production when demand is low, rendering the constant collusive strategy more attractive.

Compared to Figure 1, the most important new features arise if demand variability is low. In this case if the fine levels are very different (with $f_h > f_l$), collusive profit is higher during recessions and firms choose to set the monopoly price only if demand is low.²⁹ For slightly increased demand variability, firms choose the constant collusive strategy if the fine level is low during recessions. Otherwise they choose to set the monopoly price only during recessions, since this is the only sustainable collusive strategy.³⁰ For such demand variability levels, increasing fines during recessions makes the C and L collusive strategies more difficult to sustain but the destabilization of the C strategy is reached more easily.³¹

Proposition 2 *Collusive firms choose to set the monopoly price only during booms when demand variability is high and the expected fine f_h is not too high. They charge the monopoly price only during recessions if f_l is significantly below f_h and demand variability is weak. The constant collusive strategy is an equilibrium choice when collusive gains obtained in both demand states are close (due to the fact that the different levels of fines partly offset the demand differences) and if both fine levels are low.*

One of the contributions of this article is to examine collusive sustainability when firms face random demand fluctuations. RS argue that cartels are likely to behave more competitively during booms since

²⁹This is the case when $\Pi^C < \Pi^L$ and $\alpha < \alpha^L$.

³⁰This is the case when $\alpha_h^C < \alpha < \alpha^L$. This area is always located in the graph. Indeed when α^L intercepts α^{CL} , $\delta^L = \delta_l^C$. In addition, the following inequality applies: $\delta_h^C > \delta_l^C$. Consequently, when $\alpha^L = \alpha^{CL}$, then $\delta^L < \delta_h^C \Leftrightarrow \alpha^L > \alpha_h^C$. This area partially overlaps the zone described in the previous footnote ($\alpha < \alpha^{CL}$). The two effects work simultaneously in the same direction.

³¹A higher value of f_l decreases the expected cartel gain during recessions, and hence the global expected profit when firms opt for the C strategy. It then makes deviation from the C strategy more attractive, particularly during booms.

deviating from cartel results in higher gains. For intermediate discount factors, this mechanism can lead to counter-cyclical prices. Under the first assumption (A1), our results are consistent with RS. However this is not the case with the other assumption (A2). When demand variability is strong, firms in our model tend to opt for the H strategy and collude only during booms, so collusive agreements intensify the pro-cyclical tendency of prices. We therefore get a price dynamic similar to that in Green and Porter (1984),³² overturning the RS results. If demand variability is weak and if the expected fine during recessions is rather low compared to fine during booms, then firms charge collusive prices only during recessions and prices are counter-cyclical (whether the discount factor has an intermediate or high value), as in RS.

Some studies³³ argue that strong demand variability decreases collusion sustainability. Our model runs counter to this result. In the first diagram ($f_h = f_l$) and for sufficiently high fine levels collusive agreements are not sustainable when demand variability is low, and the H strategy is sustainable only if demand variability is high. If demand variability is high, the constant collusive strategy is hard to sustain. However, the intermittent H strategy is easier to implement if demand variability increases. In the second diagram ($f_l < f_h$), the sustainability of a collusive agreement varies non-monotonically with the demand variance. Firms can switch from the L collusive strategy when demand variability is low to the H strategy when variability is high, while avoiding collusion for intermediate values. For strong demand fluctuations the constant collusive strategy is more difficult to sustain, but firms can more easily sustain the H strategy.

We now turn to the case: $\delta < \bar{\delta}^*$ for which firms can implement the C^* strategy. Comparison of collusive profits leads to the following results:³⁴ $\Pi^{C^*} \geq \Pi^L \Leftrightarrow \alpha \leq \alpha^{LC^*}$ with

$$\alpha^{LC^*} = \bar{\theta} - \frac{4n\rho}{(A-c)^2} \frac{[(1-\delta+n\delta\rho)(1-\rho) - (n-1)\rho]\mu\delta f_l + [1-\delta(1-\rho)](1-\delta+\mu\delta\rho)(n-1)f_h}{(1-\delta+\delta\rho)(1-n\rho)\mu\delta}$$

When both strategies are sustainable, firms implement the L strategy only if $f_l < f_h$ (we previously obtained a similar result for the comparison between C and L). Moreover, the condition $\Pi^L \geq \Pi^{C^*}$ is more likely to hold if α is high whereas α must be low in order to obtain the following condition: $\Pi^L \geq \Pi^C$. We can easily explain this result: Π^C increases in α during high demand period (effect 1), but an increase in α renders both collusive strategies C and C^* less sustainable (effect 2). For high values of δ , effect 2 is irrelevant because the sustainability condition is not binding. If δ is lower, the sustainability condition of the C^* strategy is binding: an higher value of α leads to a lower equilibrium price during high demand period. Then firms may switch to the L strategy if f_l is significantly lower than f_h .

For $\delta < \bar{\delta}^*$, both strategies H and L are not sustainable if μ is close to 0.5. When $\mu \approx 0.5$, firms playing the H or L strategy are expected to produce half the time. In order for these two strategies to be sustainable, δ^2 must be sufficiently high, but in such a case, the condition $\delta < \bar{\delta}^*$ is not satisfied. Then the H [L] and C^* strategies can be sustained at equilibrium if μ is sufficiently small [high].

It is more interesting to consider high values of μ since the ranking of L and C^* strategies depends on the parameter values, while H always dominates C^* if both strategies are sustainable (while C is not). To

³²However there is a timing difference between the two models. In Green and Porter (1984), price declines occur after a period of weak demand.

³³See the literature review section.

³⁴We remind that firms prefer H to C^* when these two strategies are sustainable whereas C is not.

illustrate the results considering small values of δ , we set the following values for model parameters: $A - c = 5$, $\rho = 0.01$, $n = 2$ and $\bar{\theta} = 5$ (same values as in figures 1 and 2), a reduced value of δ : $\delta = 0.6$ and an increased value of μ : $\mu = 0.8$. Considering $f_l = f_h$ is not really interesting because firms always implement the C^* strategy if C^* and L are sustainable. Then we illustrate the case: $f_l \neq f_h$ and we fix $f_h = 400$. Figure 3 illustrates the results.

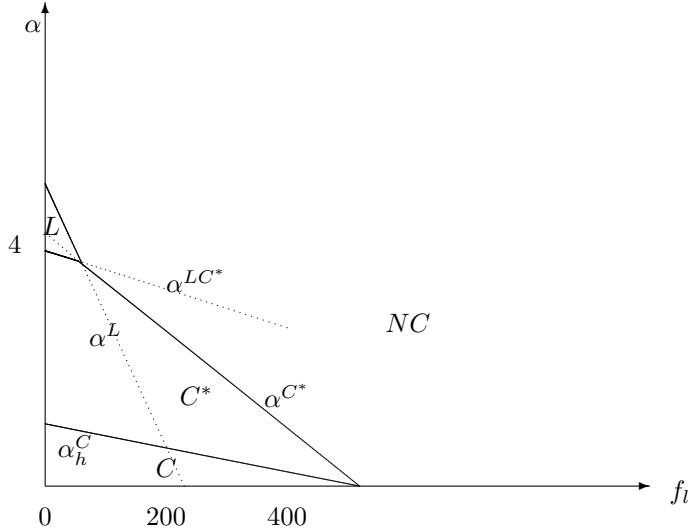


Figure 3: Equilibrium strategies if $f_h \neq f_l$ and δ is low

For these low values of δ , we obtain similar results as RS. When the C strategy is no longer sustainable (this occurs when α or f_l is high), firms switch to the C^* collusive strategy. Then collusive prices display a countercyclical movement: prices are higher during recessions than during high demand periods. The intermittent collusive strategy L can still emerge, but only under certain conditions: the demand variability must be very strong, the cartel fine must be significantly lower during recessions than during booms, and the probability of low shock on demand must be very high.

Simply put, the interesting and novel results of this paper occur for high values of δ , whereas we obtain similar results as RS if δ is lower.

6 Optimal policy

In the previous section we study collusive strategy for a fixed set of fines. We now consider the optimal choices of fines. In practice, antitrust fines have an upper bound. The competition authority must therefore set the level of fines such that $f_l \in [0, F_l]$ and $f_h \in [0, F_h]$. Unless otherwise stated, we assume that $F_l = F_h = F$. We analyze the optimal policy of an antitrust authority that seeks to maximize either consumer surplus or welfare. We first rank collusive strategies according to these two standards and then we discuss the optimal level of fines. In this section, we assume $\delta > \bar{\delta}^*$ to simplify presentation of the results and focus on the most interesting cases. The opposite case is, however, discussed in the last paragraph.

6.1 Consumer surplus and social welfare

Consumer surplus and social welfare are difficult to rank. The price effect and the length of cartel play important roles and impact strategies differently (for example if demand is low, firms compete if they play the H strategy and consumer surplus should be higher compared to the C strategy, except that the cartel duration is different).

The expected consumer surplus following cartel dissolution is:³⁵

$$CS = \sum_{t=0}^{\infty} \delta^t [\mu cs^{nc}(\theta_l) + (1-\mu) cs^{nc}(\theta_h)] = \frac{1}{1-\delta} [\mu cs^{nc}(\theta_l) + (1-\mu) cs^{nc}(\theta_h)].$$

We deduce the expected consumer surplus for various strategies:

$$CS^i = \begin{cases} \frac{\mu cs^m(\theta_l) + (1-\mu) cs^m(\theta_h) + \delta \rho CS}{1-\delta(1-\rho)} & \text{for } i = C \text{ strategy} \\ \frac{\mu cs^{nc}(\theta_l) + (1-\mu) cs^m(\theta_h) + (1-\mu)\delta \rho CS}{1-\delta + (1-\mu)\delta \rho} & \text{for } i = H \text{ strategy} \\ \frac{\mu cs^m(\theta_l) + (1-\mu) cs^{nc}(\theta_h) + \mu \delta \rho CS}{1-\delta + \mu \delta \rho} & \text{for } i = L \text{ strategy} \end{cases}$$

Proof. See Appendix 8.6. ■

Social welfare consists of consumer surplus, producer surplus and antitrust fines (the fine transfer is welfare neutral). We accordingly have:

$$W^i = \begin{cases} \frac{\mu[cs^m(\theta_l) + \pi^m(\theta_l)] + (1-\mu)[cs^m(\theta_h) + \pi^m(\theta_h)] + \delta \rho CS}{1-\delta(1-\rho)} & \text{for } i = C \text{ strategy} \\ \frac{\mu cs^{nc}(\theta_l) + (1-\mu)[cs^m(\theta_h) + \pi^m(\theta_h)] + (1-\mu)\delta \rho CS}{1-\delta + (1-\mu)\delta \rho} & \text{for } i = H \text{ strategy} \\ \frac{\mu[cs^m(\theta_l) + \pi^m(\theta_l)] + (1-\mu) cs^{nc}(\theta_h) + \mu \delta \rho CS}{1-\delta + \mu \delta \rho} & \text{for } i = L \text{ strategy} \end{cases}$$

Comparing consumer surpluses yields the following inequalities, where $\Delta cs(\theta) = cs^{nc}(\theta) - cs^m(\theta)$:

$$\begin{aligned} CS^H &\geq CS^C \Leftrightarrow \Delta cs(\theta_l) \geq \frac{(1-\mu)\delta \rho}{1-\delta + (1-\mu)\delta \rho} \Delta cs(\theta_h) \\ CS^C &\geq CS^L \Leftrightarrow \Delta cs(\theta_l) \geq \frac{1-\delta + \delta \rho \mu}{\delta \rho \mu} \Delta cs(\theta_h) \\ CS^H &\geq CS^L \Leftrightarrow \Delta cs(\theta_l) \geq \frac{1-\mu}{\mu} \frac{1-\delta + \mu \delta \rho}{1-\delta + (1-\mu)\delta \rho} \Delta cs(\theta_h). \end{aligned}$$

We deduce the following welfare comparisons:

$$\begin{aligned} W^H &\geq W^C \Leftrightarrow \Delta cs(\theta_l) - \pi^m(\theta_l) \geq \frac{(1-\mu)\delta \rho}{1-\delta + (1-\mu)\delta \rho} (\Delta cs(\theta_h) - \pi^m(\theta_h)) \\ W^C &\geq W^L \Leftrightarrow \Delta cs(\theta_l) - \pi^m(\theta_l) \geq \frac{1-\delta + \delta \rho \mu}{\delta \rho \mu} (\Delta cs(\theta_h) - \pi^m(\theta_h)) \\ W^H &\geq W^L \Leftrightarrow \Delta cs(\theta_l) - \pi^m(\theta_l) \geq \frac{1-\mu}{\mu} \frac{1-\delta + \mu \delta \rho}{1-\delta + (1-\mu)\delta \rho} (\Delta cs(\theta_h) - \pi^m(\theta_h)) \end{aligned}$$

The first point emerging from these computations is that the surplus ranking depends on parameter values. The H strategy seems to be less harmful than the C strategy since it is limited to only one state

³⁵As with previous notations, $cs(\theta)$ denotes the period surplus and $CS(\theta)$ the discounted surplus. Recall that the superscript nc designates the non-cooperative situation.

of demand. However, the H strategy is expected to be detected later. This collusive strategy does not therefore impact consumers when demand is low, but consumers are expected to suffer from collusion longer when demand is high. The most damaging collusive strategy for consumers and global welfare depends on parameter values. This last observation contrasts with most models dealing with marginal deterrence, where the ranking of offenses according to their harmfulness does not vary with parameters. This divergence stems from the incapacitation effect, which is generally not included in these models.

The second point is that these comparisons differ from borders defining firms' strategy choices. The equilibrium strategies diverge from the socially optimal choices, which is to be expected since firms can make collusive agreements. The choice of equilibrium collusive strategies depends on expected fines, which is not the case for consumer surplus and social welfare. Antitrust fines can thus be used to influence the choice of collusive strategies so as to reduce gravity of offense.

We now illustrate the above results and obtain further comparisons using the specific demand function. The expressions for consumer surplus are then:

$$\begin{aligned} cs^{nc}(\theta_h) &= \frac{1}{2}(\bar{\theta} + \alpha)(A - c)^2 & ; & \quad cs^{nc}(\theta_l) = \frac{1}{2}(\bar{\theta} - \alpha)(A - c)^2 \\ cs^m(\theta_h) &= \frac{(\bar{\theta} + \alpha)}{8}(A - c)^2 & ; & \quad cs^m(\theta_l) = \frac{(\bar{\theta} - \alpha)}{8}(A - c)^2. \end{aligned}$$

Therefore:

$$cs^{nc}(\theta_h) - cs^m(\theta_h) = \frac{3}{8}(\bar{\theta} + \alpha)(A - c)^2 \quad ; \quad cs^{nc}(\theta_l) - cs^m(\theta_l) = \frac{3}{8}(\bar{\theta} - \alpha)(A - c)^2.$$

A higher demand level amplifies the negative impact of cartels, so collusion is more harmful during booms.³⁶

The comparisons of consumer surplus and social welfare yield:

$$\begin{aligned} W^H &\geq W^C \Leftrightarrow CS^H \geq CS^C \Leftrightarrow \alpha \leq \alpha_W^{HC} = \frac{1 - \delta}{1 - \delta + 2(1 - \mu)\delta\rho} \bar{\theta} \\ W^C &\geq W^L \Leftrightarrow CS^C \geq CS^L \Leftrightarrow 0 \geq (1 - \delta)\bar{\theta} + (1 - \delta + 2\mu\delta\rho)\alpha \\ W^H &\geq W^L \Leftrightarrow CS^H \geq CS^L \Leftrightarrow \frac{(2\mu - 1)(1 - \delta)}{(1 - \delta) + 2(1 - \mu)\mu\delta\rho} \bar{\theta} \geq \alpha \end{aligned}$$

The social welfare and consumer surplus comparisons are identical. This is because the effects of collusion on consumer surplus and profit are proportional (with this demand function), and monopoly harm to consumers is stronger than the positive impact on firm profits.

The L strategy always yields greater surplus than the constant collusive strategy.³⁷ Collusion is less harmful if demand is low, so extending cartels for both demand levels does not improve welfare although constant collusive strategies are expected to be dissolved earlier. On average firms collude during $1/\rho$ periods

³⁶We could obtain opposite result by looking at income effect that could lead to higher marginal willingness to pay for low demand. In this article we consider partial equilibrium and ignore income effects, so consumer surplus is measured by the area below the downward-sloping demand curve.

³⁷The RHS of the second inequality is positive.

under both strategies, but collusion is less harmful for consumers during low demand periods and collusive periods occur later under the L strategy.

As noted previously, the comparison of W^C and W^H is ambiguous. Firms are expected to collude during $1/\rho$ periods. The H strategy is more harmful during collusive periods since collusion occurs when demand is high but these collusive periods are expected to occur later than under the C strategy. The H strategy is the least harmful if the demand variance is weak, if $1 - \mu$ is low (expected collusion is delayed) or if δ is small (the advantage to delay collusion is stronger).

We still have to compare the two intermittent collusive strategies. The L strategy yields higher surplus than the H strategy if recessions occur less frequently than booms ($\mu < 1/2$), due to the combination of two effects. First, collusive periods are less harmful during low demand periods. Second, if $\mu < 1/2$, the L strategy delays collusive periods relatively to the H strategy. If $\mu > 1/2$, these effects point in the opposite direction and the second effect can be larger if μ is high and δ is low.

The main points can be summarized as follows:

Proposition 3 *When demand variability is high, the most harmful collusive strategy is to set the monopoly price only during booms. When the demand variability is low, the constant collusive strategy is the most harmful.*

6.2 Optimal fine level

We now compare the equilibrium strategies with the social welfare (or consumer surplus) ranking in order to analyze the optimal level of fines.

We first consider that fines are the same in both states and add the boundary α_W^{HC} (previously defined for the surplus ranking) in Figure 1, since it is the only relevant one. Figure 4 illustrates the results.

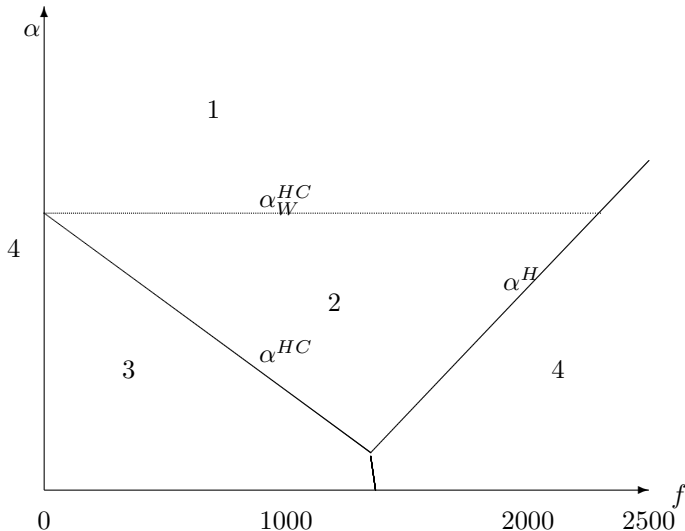


Figure 4: Equilibrium strategies and welfare ranking if $f_h = f_l$.

We identify four specific zones:

Zone	Equilibrium	Welfare ranking
1	H	$C \succ H$
2	H	$H \succ C$
3	C	$H \succ C$
4	NC	irrelevant

Table 1: Equilibrium strategies and welfare ranking if $f_h = f_l$.

The comparison of α_W^{HC} and α^{HC} plays a key role:³⁸

$$\alpha^{HC} - \alpha_W^{HC} = \frac{4n\rho}{(A-c)^2} \frac{(1-\mu)\delta\rho f_h - [1-\delta + (1-\mu)\delta\rho] f_l}{1-\delta + 2(1-\mu)\delta\rho}$$

When both fines are zero, the two thresholds are equal ($\alpha^{HC} = \alpha_W^{HC}$). Firms always select the most harmful collusive strategy: the H [C] strategy if the demand variability is strong [weak]. If the level of fines is increased, firms switch from the C strategy to the H strategy for intermediate demand variability (Zone 2). In such a case firms' choices are consistent with welfare maximization. Fines have a marginal deterrence effect: firms do not collude during recessions. For even higher fines, firms never collude. If the competition authority has to set the same level of fines in both states, it must choose: $f_h = f_l = F$. Proposition 4 follows.

Proposition 4 *When collusive agreements are liable to the same penalty in both demand states, the antitrust authority must apply the maximum fine.*

Hereafter we relax the assumption $f_h = f_l$ and first consider lower fines during booms ($f_h < f_l$). As previously outlined, equilibrium collusive strategies are similar to the case $f_h = f_l$, and Figure 4 can still be used to capture the effects of a lower fine during booms. The x-axis should be read as the level of fine F . Therefore, the graph reflects the situation in which the competition authority chooses $f_h = f_l = F$. Starting from this initial situation, we analyze the impact of a reduced fine f_h (while maintaining $f_l = F$). The effect clearly depends on the value of F .

If the maximum fine is low, a decreased value of f_h moves the α^{HC} boundary down. Some firms then switch from the constant collusive strategy (Zone 3) to the H strategy (Zone 2). In such cases collusion is less harmful for welfare. Consequently, for a low maximum fine level F , a fine structure $f_h < f_l = F$ is welfare-improving compared to the case $f_h = f_l = F$. If the authority chooses a design with $f_h < f_l$, it should choose $f_h = 0 < f_l = F$ if F is low.

For a large maximum fine F , the reduced value of f_h produces very different effects. The α^H boundary moves downward. Zone 2 expands at the expense of Zone 4. The deterrence effect is reduced. The reduction of the fine f_h leads to the formation of new cartels, decreasing welfare. If F is high, $f_h = f_l = F$ is socially preferable to $f_h < f_l = F$.

We now consider the alternative case where the antitrust authority set larger fines during booms and illustrate the result in the Figure 5. More specifically, we add the threshold α_W^{HC} to Figure 2 (illustrating the

³⁸The general results discussed below only depend on the specific demand function, not on the parameter values.

equilibrium strategies), which is the same straight line as in the Figure 4. The boundary α_W^{HC} necessarily crosses α^{HC} .³⁹

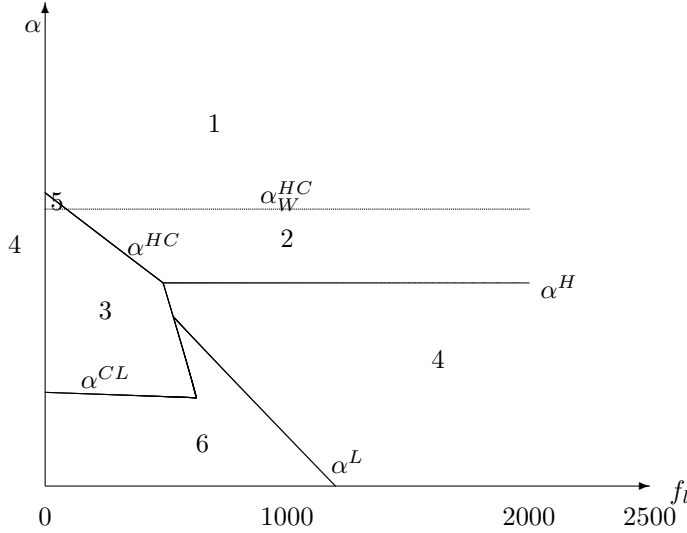


Figure 5: Equilibrium strategies and welfare ranking if $f_h > f_l$

We identify six regions:

Region	Equilibrium	Welfare ranking
1	H	$L \succ C \succ H$
2	H	$L \succ H \succ C$
3	C	$L \succ H \succ C$
4	NC	irrelevant
5	C	$L \succ C \succ H$
6	L	$L \succ H \succ C$

Table 2: Equilibrium strategies and welfare ranking if $f_h > f_l$.

There is a range of α values, above α_W^{HC} , in which firms choose to set the collusive prices during booms only when f_l is high (Region 1) and switch to the constant collusive strategy for lower fine values (Region 5). For such values of α , setting the lowest fine $f_l = 0$ is welfare-improving compared with setting $f_l = F$, since the value of the maximum fine is too low to deter collusion. But the fine levels can modify the choice of collusive strategy. The antitrust authority must set the lowest fine f_l if demand variability is high in order for firms to choose the constant collusive strategy. When collusion occurs at every state of demand, the incapacitation effect is enhanced, and the antitrust authority detect and break off cartels more easily.

However, if demand variability is less than α_W^{HC} , setting the maximum level of f_l is optimal. Two cases must be distinguished. If $\alpha > \alpha^H$ the level of the maximum fine F is too low to deter collusion, but f_l may induce firms to collude either under the C (Region 3) or H (Region 2) strategy. Increasing the fine f_l creates a marginal deterrence effect. Firms give up collusion when demand is low. Below α_W^{HC} , the H strategy is socially optimal and the antitrust authority must set a sufficiently high value of f_l to induce firms

³⁹ $\alpha^{HC} - \alpha_W^{HC} > 0$ if $f_h > 0$ and $f_l = 0$ and $\alpha^{HC} - \alpha_W^{HC}$ is a monotonically decreasing function in f_l .

to choose this intermittent collusive strategy. Below α^H , the antitrust authority can deter collusion by setting f_l sufficiently high.

The main results described above do not seem to depend on parameter values, except for the value of F which determines if collusive agreements can be fully deterred. The following proposition recapitulates the main results.

Proposition 5 *If the maximum fine F is sufficiently high to fully deter the collusive agreements, it is optimal to set the maximum fine level for both states ($f_h = f_l = F$). In the opposite case, the antitrust authority must set $f_l = 0 < f_h = F$ if demand variability is high ($\alpha > \alpha_W^{HC}$) and $f_h = 0 < f_l = F$ if the demand variability is low ($\alpha < \alpha_W^{HC}$).*

Remark: setting the maximum level of fines for both states ($f_h = f_l = F$) when F is high is not the only way to fully deter collusion. For very high values of F , setting high fines which still lie below F can be enough to fully deter collusion. It can then also be optimal to set $f_h < f_l$ or $f_h > f_l$.

The last diagram suggests, for low value of fine during recessions, an increased value of this fine cannot fully deter collusion but firms may switch from the C (Region 3) to the L (Region 6) strategy, leading to an increase in welfare. However the opposite switch can occur as the value of f_l increases for other parameter values, since the threshold α^{CL} is decreasing in f_l . For a small range of α values, welfare is no longer a monotonic function in f_l in this case. However, the optimal policy is to set a sufficiently high value for f_l in order to deter collusive agreements. But if this value can not be reached since F is too low, the marginal deterrence effects highlighted in the fourth diagram may apply and another structure of optimal fines may be preferred. We performed many numerical simulations, and this effect never appeared if $F_l = F_h$. Indeed, if we decrease F in order for the C and L strategies not to be fully deterred by setting $f_l = f_h = F$, the threshold α^{CL} moves down and falls below zero. Then it is no longer possible to create incentives for firms to select the L strategy by setting $f_l = 0 < f_h = F$. Nevertheless, we only reach the intended effect if F_l is substantially lower than F_h . This can be observed in the Figure 5 if we set $f_h = F_h = 2000$ and $F_l = 500$. For some parameter values, firms can switch from the C to the L strategy if we reduce f_l below F_l (α^{CL} is a decreasing function), and welfare therefore increases.

Up to now, we have considered the case: $\delta > \bar{\delta}^*$ in which the H and L strategies can more easily appear. We briefly consider the opposite case: $\delta < \bar{\delta}^*$. As already mentioned, for these values of δ , the H and L strategies are not sustainable if $\mu \approx 0.5$, and firms can only sustain the C or C^* strategy. The optimal policy is then to set $f_h = f_l = F$. If F is sufficiently high, the expected fines deter cartel formation. If F is somewhat lower, the fines have a marginal deterrence effect: they induce firms to reduce p^* .⁴⁰ If μ is substantially different from 0.5, the H or L strategies may appear, but this is the case only for a small range of parameter values, as suggested by Figure 3. According to this graph, to create incentives for firms to select the L strategy, the variance of demand must be very high (which suggests that such cases are very rare in

⁴⁰If F is very small, fines does not impact firms' behavior and $f_h = f_l = F$ remains an optimal solution, even if it is no longer the unique solution.

practice) and f_l must be very low. If the fine F is not very small, collusion can be fully deterred for all the values of α for which firms can implement the L strategy. To conclude, the case: $\delta < \bar{\delta}^*$ seems similar to the other case if we consider a high value of F . The optimal policy seems to be $f_h = f_l = F$ for almost all possible parameter values when $\delta < \bar{\delta}^*$.

7 Conclusion

In this article we examine firms behavior and cartel enforcement when colluding firms face random demand fluctuations.

Regarding firms behavior, we obtain the following results. If a cartel is detectable irrespective of the collusive price (assumption A1), then we obtain similar results to those RS obtain without antitrust policy. Specifically, collusive agreements are less stable in booms than in recessions and prices can be counter-cyclical. In contrast, if the probability of detection is zero whenever collusive firms price competitively (assumption A2), then firms may choose to implement an intermittent collusive strategy. With such a strategy, firms set the monopoly price only during periods where collusion is most profitable and charge marginal cost otherwise. If the antitrust authority is active, then cartels do not last forever and firms cannot collude anew if cartels are dissolved. Firms then prefer to avoid the risk of cartel detection for any period in which collusion is less profitable. Collusive prices are pro-cyclical if firms play the strategy H . Firms set the monopoly price only during booms and charge marginal cost if demand is low. By contrast they charge counter-cyclical collusive prices if they play the L strategy. Finally, if collusive profits are relatively similar for both demand states, then firms collude until the cartel is dissolved and cartel prices are weakly pro-cyclical⁴¹ if the discount rate is high (C strategy) and counter-cyclical for lower values of the discount rate (C^* strategy).

Our main results relate to the optimal level of fines when firms face random demand fluctuations. Under Assumption A1, antitrust authorities aim to deter collusive agreements or at least minimize their negative impact. This leads them to set the highest achievable fines. Under assumption A2, if the upper bound of fines is sufficiently high to fully deter the collusive agreements, the antitrust authority should set the maximum level of fines for both states. However, if the highest fine level is low, the antitrust authority should vary fines according to business cycles. If demand variability is strong, the authority may wish to reduce the fine when the demand is low to induce firms to collude during recessions. In this case the antitrust authority can more easily detect and break up cartels, because of the incapacitation effect. On the other hand, if demand variability is weak, the authority can sometimes increase social welfare by reducing the fine incurred during booms. Firms are then induced to behave competitively if demand is low and to collude only if demand is strong, due to the marginal deterrence effect.

We conjecture that these results still hold if we relax some of our assumptions. First, we assume that condemned cartels can never form again. If this assumption is relaxed, the incapacitation effect would persist if cartels can reform, but only after a significant number of periods. We also assume that the detection

⁴¹In our example collusive prices are constant since they do not depend on demand. For a more general demand function these prices will be pro-cyclical.

probability drops to zero during periods when firms set the competitive price. A strong reduction would be sufficient in order for firms to select intermittent collusive strategies. We assume that during a deviation period, the detection probability remains the same. The alternative hypothesis would not change our main results, even if the sustainability thresholds for the different collusive strategies would be modified. On the other hand, our comparisons of the different strategies would not be affected. The marginal deterrence and the incapacitation effects would remain. It would therefore still be optimal to vary the fines according to the demand state when the upper bound of fines is too low to fully deter collusive agreements. Assuming an increasing and continuous detection probability function of prices would be burdensome. Our main results stem from a jump in the detection probability when the price varies from $p = c$ to $p > c$. The results would remain unchanged assuming a price-dependent detection probability as long as the $p = c$ discontinuity remains.

In this article we have focused exclusively on the level of fines used to fight cartels facing demand fluctuations. But the antitrust authority may also adapt detection efforts to economic situations and we plan to incorporate leniency programs in future research. We also intend to address the role of the financial situation of firms. Reducing fines during recessions may help firms to fight bankruptcy and invest even during reduced availability of financing caused by economic crisis. However, in this article, we demonstrate that financial trouble is not the only possible justification for lowering fines during recessions.

8 Appendix

8.1 Computations of δ_l^C and δ_h^C

Low demand: Collusion on the monopoly price is sustainable iff:

$$\frac{\pi^m(\theta_l)}{n} - \rho f_l + \delta(1 - \rho)\Pi^C \geq \pi^m(\theta_l) - \rho f_l$$

$$\Leftrightarrow \delta \geq \delta_l^C \equiv \frac{(n-1)\pi^m(\theta_l)}{(1-\rho)\{(\mu+n-1)\pi^m(\theta_l) - n\mu\rho f_l + (1-\mu)[\pi^m(\theta_h) - n\rho f_h]\}}.$$

High demand: The collusion sustainability condition is:

$$\frac{\pi^m(\theta_h)}{n} - \rho f_h + \delta(1 - \rho)\Pi^C \geq \pi^m(\theta_h) - \rho f_h$$

$$\Leftrightarrow \delta \geq \delta_h^C \equiv \frac{(n-1)\pi^m(\theta_h)}{(1-\rho)\{[\mu(\pi^m(\theta_l) - n\rho f_l) - (1-\mu)n\rho f_h] + (n-\mu)\pi^m(\theta_h)\}}.$$

8.2 Deviating firms are not fined

Throughout this article, we consider that collusive firms can be fined independently of whether a defection from the agreement occurs. We explore the alternative assumption in this appendix: a deviating firm is not fined (this assumption could be supported if we introduced leniency programs for instance).⁴²

⁴²A deviating firm applies for leniency, with a possible timing lag to profit from the deviation payoff before revealing the cartel.

The discounted profits of the C strategy remain the same:

$$\Pi^C = \frac{\mu \left(\frac{\pi^m(\theta_l)}{n} - \rho f_l \right) + (1 - \mu) \left(\frac{\pi^m(\theta_h)}{n} - \rho f_h \right)}{1 - \delta(1 - \rho)}.$$

However deviation profits increase and the no-deviation constraints are therefore as follows.

If demand is low,

$$\begin{aligned} \frac{\pi^m(\theta_l)}{n} - \rho f_l + \delta(1 - \rho) \Pi^C &\geq \pi^m(\theta_l) \\ \Leftrightarrow \delta \geq \delta_l^C &= \frac{(n - 1) \pi^m(\theta_l) + n \rho f_l}{(1 - \rho) [(n + \mu - 1) \pi^m(\theta_l) + (1 - \mu) \pi^m(\theta_h) - n(1 - \mu) \rho f_h + n(1 - \mu) \rho f_l]}. \end{aligned}$$

If demand is high,

$$\begin{aligned} \frac{\pi^m(\theta_h)}{n} - \rho f_h + \delta(1 - \rho) \Pi^C &\geq \pi^m(\theta_h) \\ \Leftrightarrow \delta \geq \delta_h^C &= \frac{(n - 1) \pi^m(\theta_h) + n \rho f_h}{(1 - \rho) [\mu \pi^m(\theta_l) - n \mu \rho f_l + (n - \mu) \pi^m(\theta_h) + n \mu \rho f_h]}. \end{aligned}$$

Comparing these two thresholds is more complex than under the other assumption and much depends on the parameter values. We analyze the case: $n = 2$ and $\mu = 1/2$.

In this case the following comparison applies:

$$\delta_h^C \geq \delta_l^C \Leftrightarrow \pi^m(\theta_h) - \pi^m(\theta_l) \geq 2\rho(f_l - f_h).$$

The LHS of the above expression is positive. If the level of fine during booms is higher than during recessions, the above inequality is achieved and we find again the same result as in RS. However if f_l is significantly higher than f_h we may find the opposite result: collusion is less sustainable during recessions.

8.3 Computations of π^*

Expected discounted profit is equal to:

$$\Pi^{C^*} = \frac{\mu \left(\frac{\pi^m(\theta_l)}{n} - \rho f_l \right) + (1 - \mu) \left(\frac{\pi^*}{n} - \rho f_h \right)}{1 - \delta(1 - \rho)}.$$

Firms should choose the highest value for π^* . However, they must respect the no-deviation constraint when demand is high. π^* is computed by binding this constraint:

$$\frac{\pi^*}{n} - \rho f_h + \delta(1 - \rho) \Pi^{C^*} = \pi^* - \rho f_h.$$

Then we obtain:

$$\pi^* = \frac{\delta(1 - \rho) \{ \mu \pi^m(\theta_l) - n \rho [\mu f_l + (1 - \mu) f_h] \}}{n - 1 - \delta(1 - \rho)(n - \mu)}.$$

8.4 Non-sustainability of the intermittent collusive strategies for intermediate values of δ

H strategy (collusion during booms): Firms charge the marginal cost if demand is low. During booms the individual collusive profit is: $\frac{\pi^*}{n}$. Firms only have the incentive to deviate during booms. Collusion is sustainable iff:

$$\frac{\pi^*}{n} - \rho f_h + \delta (1 - \rho) \Pi^* \geq \pi^* - \rho f_h + \delta \times 0,$$

with:

$$\Pi^* = \mu [0 + \delta \Pi^*] + (1 - \mu) \left[\frac{\pi^*}{n} - \rho f_h + \delta (1 - \rho) \Pi^* \right] \Leftrightarrow \Pi^* = \frac{1 - \mu}{1 - \delta + (1 - \mu) \delta \rho} \left[\frac{\pi^*}{n} - \rho f_h \right].$$

Replacing for Π^* in the previous condition allows us to re-write the no-deviation condition during booms as:

$$\begin{aligned} \frac{\pi^*}{n} - \rho f_h + \delta (1 - \rho) \frac{1 - \mu}{1 - \delta + (1 - \mu) \delta \rho} \left[\frac{\pi^*}{n} - \rho f_h \right] &\geq n \frac{\pi^*}{n} - \rho f_h \\ \Leftrightarrow \delta &\geq \delta^{H^*} \equiv \frac{(n - 1)}{[n(1 - \rho + \mu \rho) - \mu] - n(1 - \rho)(1 - \mu) \rho \frac{f_h}{\pi^*}}. \end{aligned}$$

$\frac{f_h}{\pi^*}$ decreases in π^* . Then $[n(1 - \rho + \mu \rho) - \mu] - n(1 - \rho)(1 - \mu) \rho \frac{f_h}{\pi^*}$ increases and δ^{H^*} decreases in π^* . The minimum value of δ^{H^*} is therefore reached for the monopoly price.

The H strategy is easier to sustain when firms set the monopoly price rather than a lower price. If $\delta < \delta^H$ the H strategy is not sustainable.

L strategy (collusion during recessions): Firms charge the marginal cost if demand is high. During recessions firms the individual collusive profit is: $\frac{\pi^*}{n}$. Firms have incentives to deviate only during recessions. Collusion is sustainable iff:

$$\frac{\pi^*}{n} - \rho f_l + \delta (1 - \rho) \Pi^{L^*} \geq \pi^* - \rho f_l + \delta \times 0 \Leftrightarrow \delta \geq \delta^{L^*} \equiv \frac{(n - 1)}{[(1 - \mu \rho) n - (1 - \mu)] - n(1 - \rho) \mu \rho \frac{f_l}{\pi^*}}.$$

The minimum value of δ^{L^*} is reached for the monopoly price. Then the L strategy is easier to sustain when firms set the monopoly price rather than a lower price. If $\delta < \delta^L$ the L strategy is not sustainable.

8.5 Comparison of sustainability thresholds

If demand is high, the collusive strategy $i \in \{C, H\}$ is sustainable iff:

$$\frac{\pi^m(\theta_h)}{n} - \rho f_h + \delta (1 - \rho) \Pi^i \geq \pi^m(\theta_h) - \rho f_h.$$

Deviation and current collusive profits are the same with the C and H strategies. But the discounted expected collusive profit is different, and the following inequality applies:

$$\delta^H \geq \delta_h^C \Leftrightarrow \Pi^C \geq \Pi^H.$$

If demand is low, the collusive strategy $i \in \{C, L\}$ is sustainable iff:

$$\frac{\pi^m(\theta_l)}{n} - \rho f_l + \delta(1-\rho)\Pi^i \geq \pi^m(\theta_l) - \rho f_l.$$

From which we deduce:

$$\delta^L \geq \delta_l^C \Leftrightarrow \Pi^C \geq \Pi^L.$$

8.6 Computations of expected consumer surplus

C strategy: Consumer surplus is $cs^m(\theta_k)$ throughout the collusive period and $cs^{nc}(\theta_k)$ afterwards, $k \in \{l, h\}$.

$$\begin{aligned} CS^C &= \mu cs^m(\theta_l) + (1-\mu) cs^m(\theta_h) + \delta [(1-\rho) CS^C + \rho CS] \\ \Leftrightarrow CS^C &= \frac{\mu cs^m(\theta_l) + (1-\mu) cs^m(\theta_h) + \delta \rho CS}{1 - \delta(1-\rho)}. \end{aligned}$$

H strategy: Consumer surplus is $cs^m(\theta_h)$ or $cs^{nc}(\theta_l)$ throughout the collusive period and $cs^{nc}(\theta_k)$ afterwards, $k \in \{l, h\}$.

$$\begin{aligned} CS^H &= \mu [cs^{nc}(\theta_l) + \delta CS^H] + (1-\mu) \{sc^m(\theta_h) + \delta [(1-\rho) CS^H + \rho CS]\} \\ \Leftrightarrow CS^H &= \frac{\mu cs^{nc}(\theta_l) + (1-\mu) cs^m(\theta_h) + (1-\mu) \delta \rho CS}{1 - \delta + (1-\mu) \delta \rho}. \end{aligned}$$

L strategy: Consumer surplus is $sc^{nc}(\theta_h)$ or $sc^m(\theta_l)$ throughout the collusive period and $sc^{nc}(\theta_k)$ afterwards, $k \in \{l, h\}$.

$$\begin{aligned} CS^L &= \mu \{sc^m(\theta_l) + \delta [(1-\rho) CS^L + \rho CS]\} + (1-\mu) [sc^{nc}(\theta_h) + \delta CS^L] \\ \Leftrightarrow CS^L &= \frac{\mu sc^m(\theta_l) + (1-\mu) sc^{nc}(\theta_h) + \mu \delta \rho CS}{1 - \delta + \mu \delta \rho}. \end{aligned}$$

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