Endogenous fines and detection probabilities for cartel deterrence: Experimental evidence

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Abstract

This study experimentally investigates the impact of antitrust enforcement on cartel formation and collusive price decisions when fines and detection probabilities depend on the cartel overcharge, i.e. they are *endogenous*. We impose expected punishments that create two payoff–equivalent collusive price equilibria, but with different levels of riskiness of collusion. Compared to a scenario where expected punishments are exogenous to the cartel overcharge, endogenous punishments see fewer cartels formed on the price with higher riskiness of collusion, but stabilise cartels formed on the price with lower riskiness of collusion, leading to a trade-off between frequency and composition deterrence. As a result, overall welfare effects are ambiguous.

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1. Introduction

The fight against cartels fixing prices remains a priority of antitrust authorities around the globe. The main tool of antitrust authorities to deter cartels is to punish detected cartelists with fines, which consists of both fixed and variable elements. While cartels are usually prosecuted for their wrongdoings *per se*, i.e. they receive an exogenous, fixed fine for the mere attempt to collude irrespective of the actual cartel harm, fines are partially adjusted to the magnitude of cartel harm in some jurisdictions such as the EU and the US. In private damage litigation, damages are directly awarded based on estimated overcharges, and are therefore endogenous. Accordingly, we denote enforcement as *endogenous* when the detection probability and/or the fine depend on cartel overcharge, and as *exogenous*, or fixed, when the detection probability and the fine do not change with cartel overcharge.

While cartel deterrence is often understood as the prevention of cartel formation, it can also imply a reduced cartel overcharge (Harrington, 2005, 2004; Bos *et al.*, 2016). Specifically, *frequency deterrence* is measured as the number of cartels that are not formed in the presence of antitrust laws, but would have formed otherwise; *composition deterrence* is measured by the mitigation of cartel harm caused by those that are formed nonetheless. As the main objective of antitrust authorities is increasing welfare, both types of deterrence are important. Katsoulacos *et al*. (2015) compare different fine regimes, and find that a regime based on cartel overcharge out-performs the other regimes including a fixed one. The intuition is that an overcharge-based punishment changes a cartel's optimisation problem and hence the collusive price, which is causing the damage to consumers. This has led to their recommendation that antitrust authorities should switch to a penalty structure that is overcharge based.

This article seeks to shed light on composition deterrence that is not driven by the standard cartel optimisation problem. Since a cartel is fundamentally a coordination game, its formation and stability crucially depend on the 'trust' among cartelists. Leniency programmes are an example of convicting and deterring cartels through worsening the trust problem: cartelists are uncertain about the actions of others, and each cartelist has an incentive to deviate, or blow the whistle. Such *strategic uncertainty* can also have an impact on the choice of collusive price. When the expected punishment imposed on a cartel varies with the collusive price charged, it is possible that some collusive prices are 'riskier' than others are, *ceteris paribus*, and that some cartelists respond strategically by avoiding those prices. The intuition is that the deviation profit relative to the sucker's payoff varies with the cartel price, and therefore when considering the outcome of being cheated upon by others in an agreement, cartelists may find some price choices less attractive. This can provide a second rationale of composition deterrence.

In this article, we analyse whether enforcement with endogenous punishments can produce composition deterrence through the channel of strategic uncertainty in a market experiment of an infinitely repeated non-cooperative game. For this purpose – unlike in previous experimental literature on collusion – the expected punishment imposed on a detected cartel increases with the cartel price, so that cartels formed on a high price and a low price can have the same expected payoff but different *riskiness of collusion*[1] (Blonski *et al.*, 2011; Blonski and Spagnolo, 2015).

The results show that – consistent with our theoretical predictions – enforcement with endogenous punishments produces composition deterrence through strategic uncertainty. While

[1] By riskiness of collusion, we mean the strategic risk that arises from strategic uncertainty, rather than an exogenous risk.

overall cartel formation does not differ significantly between the baseline treatment (with fixed punishments) and treatments with endogenous punishments, significantly fewer cartels are formed on the high price. However, while enforcement with endogenous punishments produces a composition deterrence effect, deterring cartels from colluding on the high, riskier price to colluding on the low, safer price, it also stabilises collusion on the low price. This unintended consequence leads to a trade-off between frequency and composition deterrence, and therefore overall welfare effects of this enforcement regime are ambiguous.

Our findings have practical implications for the design and evaluation of antitrust enforcement regimes. As it is prohibitively costly for antitrust authorities to deter cartels altogether, composition deterrence may offer the prospect to reduce cartel harm and improve overall welfare, which is the main objective of antitrust policies. The results from our experiment suggest punishments that vary with cartel overcharge to be a promising avenue of deterrence and strategic uncertainty to be a feasible channel through which composition deterrence can come into effect. However, the finding of a trade-off raises the concern that a reduced cartel formation on a high price does not necessarily feed back into increased overall welfare, which is an important consideration to be taken into account when designing enforcement regimes with endogenous punishments.

The remaining of this paper is organised as follows. The next section reviews the related literature. Section 3 describes the experimental design. Section 4 provides the theoretical mechanism, based on which our hypotheses are presented. Section 5 reports and discusses results. Section 6 concludes.

2. Related literature

Despite increased cartel enforcement, including heavier punishments and the relatively more innovative leniency programmes, the empirical evidence suggests limited effectiveness of these polies "as currently designed" (Levenstein and Suslow, 2012). Over the years, the theoretical literature on cartels (e.g. Block et al., 1981; Katsoulacos et al., 2015) argue the prospect of composition deterrence, because it resembles the welfare objective of antitrust policies, and also reflects the consideration that punishments should be "reasonable and proportionate".

While the literature on cartel experiments is growing, it has so far forgone to analyse composition deterrence due to the design of enforcement regimes that features fixed detection probabilities and fines.[2] A few studies feature fines that depend on either the collusive price and/or the preceding collusive history. For example, Apesteguia *et al.* (2007) and Hinloopen and Soetevent (2008) study the effect of leniency programmes, and Fonseca and Normann (2014) study the effect of communication. Yet, they do not examine how the endogeneity of fines affects cartel prices or stability. We contribute to the experimental literature on collusion in the presence of an antitrust authority by proposing a design in which both the detection probability and the fine depend on the collusive price. To our knowledge, this is the first article that studies how collusion depends on the detection probability and the size of the fine, when the two depend directly on the collusive price.

Strategic uncertainty as a channel of cartel deterrence is not new, and has been shown to underlie part of the mechanism of leniency programmes. Bigoni *et al*. (2015) suggest that deterrence can be achieved by worsening the incentive and trust problem faced by cartelists. However, the strategic uncertainty in cartel coordination receives little attention outside the context of leniency

[2] Examples include studies on the effects of leniency programmes (Hamaguchi *et al*., 2009; Bigoni *et al*., 2012, 2015; Clemens and Rau, 2014; Hinloopen and Onderstal, 2014), the substitutability of fines and detection probabilities (Chowdhury and Wandschneider, 2017), cartels' avoidance activities (Chowdhury and Wandschneider, 2016), and tacit collusion induced by previous cartel agreements (Chowdhury and Crede, 2015).

programmes, although a cartel is fundamentally about coordination in non-cooperative games. In the literature of non-cooperative games, strategic uncertainty that arises in a socially interactive decision situation is suggested as an underlying reason for coordination failure (Van Huyck *et al*., 1990; Heinemann *et al*., 2009). As the degree of strategic uncertainty faced by decision makers increases, it becomes more difficult to trust and they tend to choose secure options (Fehr, 2009). Blonski *et al*. (2011) and Blonski and Spagnolo (2015) take an axiomatic approach and introduce a strategic uncertainty based measure of the critical discount factor in infinitely repeated games. In doing so, they take into account cognitive and behavioural determinants with a particular emphasis on the sucker's payoff, i.e. the payoff to a subject who plays a collusive strategy but is cheated upon by others. Their framework allows for a comparison of the riskiness of different cooperative equilibria, which underlies the rationale of composition deterrence in our theoretical model.

To this end, this article links the experimental literature on cartels to the experimental applications of cooperative games to study illegal activities and the optimal design of enforcement. For example, Berninghaus *et al.* (2013) and Tan and Yim (2014) use coordination games to model corruption and tax evasion. Both studies highlight the role of trust and beliefs and find higher degrees of strategic uncertainty to be an effective device to deter illegal activities.

In contrast to the large body of literature that exists on the frequency deterrence of cartels, little is known about how frequency and composition deterrence interact under some enforcement regimes. We are among the first to highlight the trade-off between the two. In relation to this, Pedro *et al*. (2010) studying the deterrence effect of merger policy suggest that, unlike the prevailing assumption of frequency and composition deterrence reinforcing each other, the two may lead to divergent effects on deterrence.

3. Experimental design

3.1 Price competition

In our experiment, each subject represents a firm and repeatedly competes in a market with two other subjects. The market is characterised by homogeneous goods price competition as introduced by Dufwenberg and Gneezy (2000) and with market characteristics similar to those in Gillet *et al.* (2011). Previous experimental evidence (e.g. Wellford, 2002; Fonseca and Normann, 2012) indicates that three firms are sufficient to ensure that collusion can only be sustained effectively with communication.

In each period, the subjects simultaneously choose a price, p, from the choice set $\{40, 41, \ldots, 52\}$. A subject sells one unit of the good and incurs a cost of 40 if her price is not higher than that of any others, and does not sell nor incur any cost otherwise. The subject who sells the good in a period makes a profit of $p - 40$, and the other two subjects make a profit of zero. If two or three subjects choose the same lowest price, the profit is evenly divided among them.

3.2 Cartel formation

Before engaging in price competition as described above, in each period subjects have to decide simultaneously whether they wish to enter a non-binding price agreement, and if so, which price to agree on. There are two cartel prices to choose from: the high cartel price $p_C^h = 52$ and the low cartel price $p_C^l = 46$.[3] Subjects can either suggest one of the two prices, or both if they do not have a

[3] 52 is the highest price in the choice set and 46 is the mean price in the choice set.

preference. When subjects are presented with the two collusive prices on the computer screen, the order of the two is randomised across subjects and periods, to avoid experimenter demand effect.[4]

As shown in Table 1, a cartel is not formed unless the collusive prices suggested by the three subjects have something in common. If subjects reach one common price, a cartel is formed on that price. If they reach two common prices, which only happens when all three suggest both prices, a cartel is formed on a default collusive price,[5] which is 46 in half of the markets in a treatment, and 52 in the other half. The default price remains the same within a market throughout the experiment.

A cartel is formed, if	All three firms wish to agree on prices and they reach one common price	Collusive price is the common price
	All three firms wish to agree on prices and they reach two common prices (when all three choose both 46 and 52)	Collusive price is the default price in that market
A cartel is not formed, if	All three firms wish to agree on prices and they reach no common price	
	At least one firm does not wish to agree on prices	

Table 1. Possible outcomes of communication

3.3 Treatments (designs of enforcement regime)

This experiment has a 2x2 between-subjects design. In all four treatments, an antitrust authority (the computer) can detect cartels and impose a fine on all cartelists. The treatments differ in the parameters of the detection probability and the fine (see Table 2).

	Fixed detection probability	Endogenous detection probability
Fixed fine	***Baseline*** 46: $D = 20\%, F = 12$ 52: $D = 20\%, F = 12$	***EndoD*** 46: $D = 3.3\%, F = 12$ 52: $D = 20\%, F = 12$
Endogenous fine	***EndoF*** 46: $D = 20\%, F = 2$ 52: $D = 20\%, F = 12$	***BothEndo*** 46: $D = 10\%, F = 4$ 52: $D = 20\%, F = 12$

Table 2. Treatments and parameters

Baseline resembles a typical treatment design in the existing literature, where there is a fixed detection probability of cartels and a fixed fine. As such, the expected punishment of forming a cartel is independent from the cartel price, ruling out the effect of composition deterrence. In the other three treatments, the expected punishments are endogenous and different for cartels formed on different prices, in the form of one of the following: 1) a detection probability that increases with cartel price (*Endo D*); 2) a fine that increases with cartel prices (*EndoF*); and 3) both parameters increasing with cartel price (*BothEndo*). This enforcement regime allows for the capture of composition deterrence.

Table 2 also presents the detailed parameters (D and F) in the four treatments. These parameters are chosen so that the expected payoff of collusion is identical for cartels formed on 46 and 52 in each of *EndoD*, *EndoF* and *BothEndo* – a crucial experimental design ensuring that any composition

[4] A computer screenshot of the communication protocol can be found in the instructions in Appendix A.
[5] This device is used to facilitate coordination in our limited-form communication protocol, and we have checked that it does not induce any bias on the treatment effect. We do not use the alternative free-form communication because, given the already complex design of our experiment, we wish to restrict the effects of social dimension on results (see, e.g. Cooper and Kühn, 2014).

deterrence effect observed is not driven by differences in the expected profitability of collusion.[6] We explain this design further in Section 4.

In all treatments, a cartel that is successfully formed triggers detection until detection of that particular agreement takes place (this can be in the period in which the cartel is formed or in any subsequent period), whether or not there is any deviation. A particular cartel agreement can only be detected and fined once. If a market has reached several agreements in different periods before one of them is detected, the expected punishment upon detection depends on the last price agreement. To simplify the decision-making of subjects and the experimental design, a failed attempt to collude (communication *per se*) in our experiment does not trigger detection. This is an obvious limitation, as in the field, a mere attempt to establish collusion is usually illegal.

3.4 Summary of sequence of the game

1. Subjects are simultaneously asked the question "Do you want to agree on prices?". They can choose "Yes, with price 46" or/and "Yes, with price 52" if they want to agree on prices, and "No" if otherwise.
2. Subjects are informed about whether a price agreement is reached, and if so, the agreement price.
3. Subjects simultaneously make price decisions for their goods by choosing a price from the choice set $\{40, 41, \dots, 52\}$. Any price agreements reached in stage 2 are not binding for subjects' price decisions in this stage.
4. Subjects learn about each other's prices and whether they sell a good in the current period.
5. Subjects are informed about whether they are detected if they have reached a price agreement in the current period and/or their agreement in one of the previous periods has not yet been detected.
6. Finally, subjects learn about their profits minus any potential fines in the current period, as well as their accumulated profits.

3.5 Experimental procedure

The experiment was carried out at the Centre for Behavioural and Experimental Social Science (CBESS) at the University of East Anglia, UK. The recruitment of subjects was carried out with hRoot (Bock *et al.*, 2014) and the experiment was programmed and run with zTree (Fischbacher, 2007). 144 students of different nationalities and with no prior experience in oligopoly experiments participated in the experiment. In each of the four treatments, 36 subjects were allocated into groups of three, providing 12 independent market observations. Group composition was fixed throughout an experimental session. Subjects were welcomed and randomly seated at workstations separated by modular walls in the laboratory. At the start of each session, subjects received printed copies of the instructions. The computer screen also displayed the instructions when an experimenter read them aloud. Subjects' understanding of the instructions was tested with a questionnaire before they participated in the main part of the experiment.

[6] The parameters of the detection probability (10% and 20%) are in range of the mean detection probabilities reported in Bryant and Eckard (1991), Hyytinen *et al.* (2011), Ormosi (2014), and Bos *et al.* (2016). The parameter of 3.3% in *EndoD* is arguably low, and it is chosen to satisfy our key experimental design.

The experiment consisted of two parts. In the first part, the risk preferences of subjects were tested with a risk elicitation task similar to that in Eckel and Grossman (2008).[7] In the second part, subjects each represented a firm and played the game (in the sequence 1 to 6 as described above) for 20 regular periods. A random stopping rule (20%) was implemented to avoid end-game effect as described in Dal Bó (2005). At the end of each session, subjects filled out an anonymous demographic survey before being called out of the laboratory and paid in private. Earnings are denoted as "experimental points" and each point was converted into £0.12 for cash payment, which varied from £4.00 to £13.20 with a mean of £8.19. Sessions lasted between 40 to 60 minutes.

4. Theoretical mechanism and hypotheses

In this section, we present the model that underlies our experimental design. Our hypotheses based on the model prediction are summarised at the end.

Consider a homogeneous goods market with $n \geq 2$ firms that face identical unit costs of production c and compete in prices. The demand function is $Q(p)$, where p denotes price and Q is the quantity supplied to the market. The industry profits $\pi(p, c)$ can be expressed as $\pi(p, c) = (p - c)Q(p)$. If price collusion is not possible, competition gives rise to $p^B = c$. If price collusion is possible and all firms agree to collude, then in the absence of antitrust enforcement, each firm sets $p^M = \arg max_p \pi(p, c)$ and yields a profit of π^M/n.

In this context, the existing literature (e.g. Block *et al.*, 1981; Katsoulacos *et al.*, 2015) show that antitrust enforcement can mitigate the harm caused by the illegal activity by imposing an expected punishment, DF, that is increasing in the cartel overcharge. As Figure 1 illustrates, for any function of DF with $\partial DF/\partial p > 0$ and $\partial^2 DF/\partial p^2 \geq 0$, which is weakly convex with respect the cartel price,[8] antitrust enforcement leads to composition deterrence by altering the optimisation problem of the cartel (from π^M to π^{DF}). As a result, the cartel may still form, but at a lower price of p^{DF}. Note that this mechanism assumes that payoff is the only consideration in terms of cartel formation and stability.

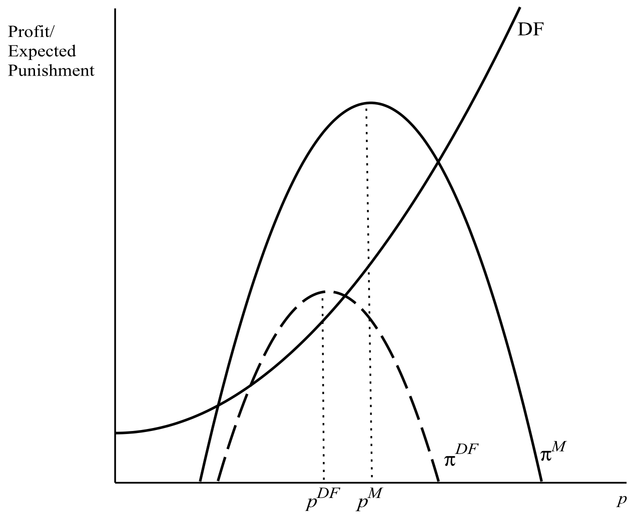

Figure 1. Composition deterrence driven by changes in optimisation problem

In all four treatments in our experimental design, the non-cooperative price equilibrium that tends to dominate in case of coordination failure, i.e. no cartel formed, is characterised by each subject

[7] Sample instructions including those for the risk elicitation task can be found Appendix A.

[8] This is a reasonable assumption given observations from the field. However see Bos *et al.* (2015) for a special scenario in which it does not hold.

choosing $p^B = 41$ and obtaining $\pi^B = (41 - 40)/3 = 0.33$ in each period. Firms having formed a cartel, depending on which price they have agreed on, can each earn a high or a low cartel profit, $\pi_C^h = (52 - 40)/3 = 4$ or $\pi_C^l = (46 - 40)/3 = 2$.

Now recall the different enforcement regimes as described in Table 2. In *Baseline*, DF is fixed at $0.2 \times 12 = 2.4$, leading to the following expected payoffs

$$E(\pi_C^h) = 4 - 2.4 = 1.6 > \pi^B, E(\pi_C^l) = 2 - 2.4 = -0.4 < \pi^B. \quad (1)$$

In *EndoF*, *EndoD*, and *BothEndo*, the size of DF increases with the cartel price; it is 0.4 for price 46 and 2.4 for price 52, leading to

$$E(\pi_C^h) = 4 - 2.4 = 1.6, E(\pi_C^l) = 2 - 0.4 = 1.6. \quad (2)$$

From (1) and (2), we can see that, based the expected payoff, cartels would only be formed on 52 in Baseline, whereas cartels are equally likely to be formed on 46 and 52 in *EndoF*, *EndoD*, and *BothEndo*.

We further characterise the equilibrium conditions. Suppose that firms react to cheating with a Grim-Trigger strategy (see, e.g. Tirole, 1988). The corresponding incentive compatibility constraint (ICC) for sustaining collusion infinitely is given by

$$\frac{\pi_C}{1-\delta} - \frac{DF}{1-\delta(1-D)} > \pi_{dev} + \frac{\delta\pi_B}{1-\delta} - \frac{DF}{1-\delta(1-D)}, \quad (3)$$

where δ denotes the discount factor. Since detection and conviction are triggered by the formation of a cartel, irrespective of whether deviation occurs afterwards or not, the term measuring the expected punishment in the repeated game, $DF/[1 - \delta(1 - D)]$ becomes irrelevant. The discount factor derived from the ICC is given by

$$\delta > \frac{\pi_{dev}-\pi_C}{\pi_{dev}-\pi_B}, \quad (4)$$

which produces almost identical conditions for cartels formed on 52 and 46 in each of *EndoF*, *EndoD*, and *BothEndo*. Therefore, whether a cartel is formed on one of the two prices should not be driven by the relative size of the ICCs.

Both the conditions on expected payoff and ICC suggest that, *ceteris paribus*, when cartels are formed in *EndoF*, *EndoD*, and *BothEndo*, they should be formed equally likely on either of the two cartel prices. That is, due to our design of DF, the composition deterrence effect illustrated in Figure 1 is not present in our model. Thus, we ensure that any composition deterrence effect observed is not driven by differences in the expected profitability of collusion.

In the following, we demonstrate that a cartel price below the monopoly level could also be a reaction to strategic uncertainty in infinitely repeated non-cooperative games. Recall that (3) suggests exogenous risk is irrelevant, but it does not control for strategic risk. Recent theoretical and experimental studies suggest that the riskiness of collusion criterion selects more self-enforcing and sustainable equilibria. We follow *the Prisoner's Other Dilemma* by Blonski and Spagnolo (2015) to compare the riskiness of collusion when firms collude on different prices. The measure of strategic risk of colluding on a particular price is given by the difference between two squared expressions

$$(\pi_B - \pi_S)^2 - (\pi_C - \pi_{dev})^2. \quad (5)$$

This is closely related to the comparison of Nash products in static 2×2 games to determine the risk-dominant equilibrium as proposed by Harsanyi and Selten (1988). The first squared expression captures the difference between the non-cooperative equilibrium profit and the profit obtained in case of being cheated upon (π_S). The second squared expression captures the difference between the collusive profit and the deviation profit. *Ceteris paribus*, the more pronounced the difference between the two Nash products, the higher the riskiness of a collusive equilibrium, which requires a higher discount factor to sustain collusion. The corresponding net present value of the riskiness of collusion in our experiment when the game is infinitely repeated is given by

$$\left(\frac{\pi_B}{1-\delta^*} - \pi_S + \frac{DF}{1-\delta^*(1-D)} - \frac{\delta^* \pi_B}{1-\delta^*}\right)^2 - \left(\frac{\pi_C}{1-\delta^*} - \pi_{dev} - \frac{\delta^* \pi_{dev}}{1-\delta^*}\right)^2. \qquad (6)$$

where δ^* denotes the discount factor incorporating the strategic risk of a collusive equilibrium.

Figure 2 plots the riskiness of collusion at the two cartel prices as a function of the discount factor, using parameters in our treatment design. The riskiness of collusion at price 52 is identical in all four treatments because of the identical parameters associated with it across treatments, whereas the riskiness of collusion for price 46 varies with treatment.[9] The discount factors required to sustain collusion on 46 in different treatments are relatively similar to each other, but are considerably lower than that to sustain collusion on 52. This follows from the fact that collusion on price 52 is associated with a higher deviation incentive than collusion on price 46, whereas the sucker's payoff is zero in both cases.

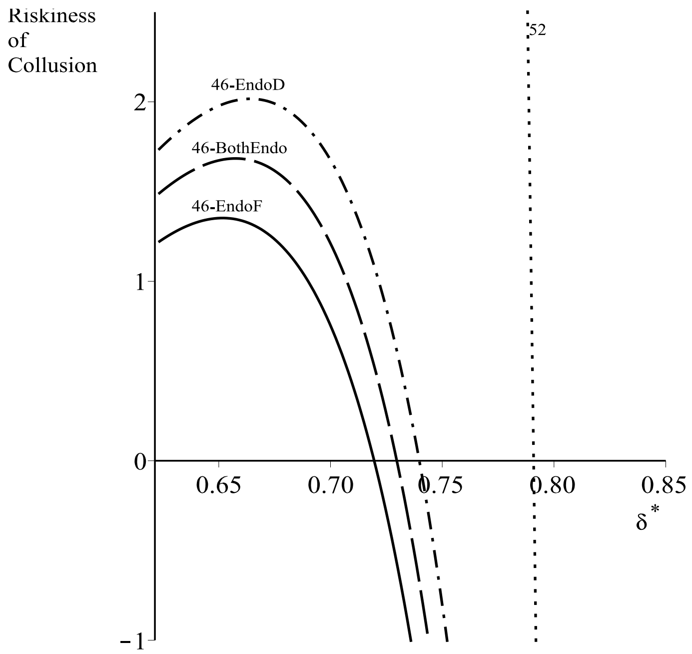

Figure 2**.** The riskiness of collusion

Overall, in *EndoF*, *EndoD*, and *BothEndo*, cartels formed on 46 and on 52 generate the same expected payoff but those on 46 are associated with lower strategic risk. Based on this mechanism, compared to *Baseline* where a cartel can only be profitably formed on 52, the enforcement regimes in *EndoF*, *EndoD*, and *BothEndo* could produce a composition deterrence effect, deterring the cartel price from 52 to 46. This leads to the following testable hypothesis:

Hypothesis 1 Cartels are formed less often on the high cartel price and more often on the low cartel price in *EndoF*, *EndoD*, and *BothEndo* than in *Baseline*.

Any composition deterrence effect obtained in the presence of endogenous punishment regime should contribute to reduced cartel harm, reflected in lower prices:

[9] Figure excludes collusion on price 46 in *Baseline*, because it is an off-equilibrium option.

Hypothesis 2 Market prices are lower in *EndoF*, *EndoD*, and *BothEndo* than in *Baseline*.

5. Results

All reported results are based on the first 20 periods to rule out any end-game effects.[10] Figure 3 shows the proportions of cartelised markets in a period separated by treatment (i.e. *Prop. agreement 46* and *Prop. Agreement 52* in Table 3), and *0* denotes markets with no cartels.

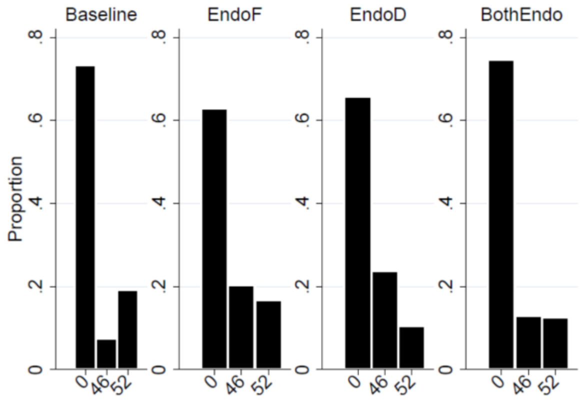

Figure 3. Cartel formation by treatment

At first glance, the observed patterns appear to be in line with the predictions of our theoretical model. Cartels are formed less often on 46 than on 52 in *Baseline*, and are formed more often on 46 than on 52 in *EndoF, EndoD* and (with a very small difference) *BothEndo*. Between treatments, cartels are formed less often on 52 and more often on 46 in *EndoF*, *EndoD* and *BothEndo* than in *Baseline*. These observations are directly relevant to Hypotheses 1 and indicate the possibility of strategic uncertainty driven composition deterrence.

Variable	Baseline	EndoF	EndoD	BothEndo
$Asking\ prices$	43.801	44.133	43.856	43.543
$Market\ prices$	41.817	42.713	42.208	42.038
$Prop. agreement\ 46$	0.075	0.204	0.238	0.129
$Prop. agreement\ 52$	0.192	0.167	0.104	0.125
$Prop. new\ agreement$	0.117	0.167	0.096	0.108
$Prop. cheating\ 46$	1.000	0.429	0.750	0.533
$Prop. cheating\ 52$	0.818	0.684	0.818	0.818
$Prop. detection\ 46$	0.000	0.190	0.000	0.091
$Prop. detection\ 52$	0.227	0.316	0.273	0.200

Table 3. Descriptive statistics

Table 3 reports the relevant market outcomes by treatment. *Asking prices* are the selling prices of goods in each market in each period. *Market prices* denote the prices at which goods are sold, i.e. the lowest asking prices, in each market in each period. *Prop. new agreement* denotes the proportion of markets with newly reached (instead of active) price agreements. *Prop. cheating 46 (52)* reports the proportion of markets with observed occurrence of cheating on an active agreement of 46 (52). Finally, *Prop. detection on 46 (52)* is the observed proportion of markets in which active agreements on 46 (52) are detected by the computer.

[10] Actual sessions lasted between 20 and 25 periods due to the random stoppage rule.

Combining the results in Figure 3 and Table 3, we observe that cheating occurred with 100% probability on the few cartels formed on price 46 in Baseline. This is intuitive because, based the expected payoff, cartels cannot be profitably formed on 46 in Baseline.

To address our hypotheses formally, we first conduct a pairwise comparison on market prices and overall cartel formation.[11] The p-values reported in Table 4 suggest that market prices and overall cartel formation do not differ significantly across the four treatments. This leads to the rejection of our Hypothesis 2, as there is no evidence suggesting market prices to be lower in *EndoF*, *EndoD*, and *BothEndo* than in *Baseline*. Furthermore, this suggests a lack of difference in welfare effects between enforcement regimes with exogenous punishments and with endogenous punishments.

Variable		**EndoF**	**EndoD**	**BothEndo**
$Market\ prices$	**Baseline**	0.386	0.312	0.751
	EndoF		0.840	0.214
	EndoD			0.452
$Prop. new\ agreement$	**Baseline**	1.000	0.702	0.768
	EndoF		0.836	0.883
	EndoD			0.977

Table 4. MWU test p-value matrices for pairwise treatment differences

However, results from Figure 3 and Table 4 do not seem to offer a consistent picture. While there is a clear scope of strategic uncertainty driven composition deterrence, it is not reflected at all in the welfare outcomes. To gain a better understanding of the underlying factors at play, we turn to regression analysis.

We analyse the choice of price agreements at the market level in a multinomial logit model with random effects, with the choices being no agreement (0), an agreement on 46, and an agreement on 52. Table 5 reports the estimated average marginal effects (with cluster-robust standard errors in brackets). *Lag agreement 46(52)* controls for the effect of an active price agreement on 46(52) in the previous period on market's choice in this period. *Lag cheating* indicates whether cheating occurred on a price agreement in the previous period,[12] and *Lag detection 46 (52)* indicates whether detection on the respective price agreement occurred in the previous period. *Period* measure the period effects. *Automatic price 52* is an indicator variable for the markets in which 52 is the default cartel price in case of indifference. *Lag market price* denotes the market price in the previous period. *EndoF*, *EndoD*, and *BothEndo* are treatment indicator variables that measure the treatment effects, with *Baseline* as the baseline.

We start with the treatment effects. The marginal effects of the treatment indicator variables suggest that, compared to *Baseline*, fewer cartels are formed on 52 in *EndoD* and *BothEndo.* Since overall proportions of cartel formation do not differ across treatments (Table 4), we have evidence of strategic uncertainty driven composition deterrence in *EndoD* and *BothEndo*, but not in EndoF.

At first, it appears unclear why such composition deterrence does not lead to lower prices in *EndoD* and *BothEndo* than in *Baseline*. The fact that market prices do not differ significantly implies that there must be an opposing effect driving prices up. However, a closer look at the dynamics of markets' choices over time shows that price agreements on 46 are more stable. The *Lag agreement*

[11] Note that we use the proportion of new cartel agreements for comparing overall cartel formation in this test, but the same results arise with the alternative measure of active cartel agreements.

[12] We do not separate the effects of cheating on agreements on 46 and 52, because covariance matrices for the marginal effects cannot be calculated if both effects are determined separately.

marginal effects indicate that price agreements on 46 are stable and persistent whereas those on price 52 are not. The *Lag detection* variables suggest that detection of an agreement on 46 in the previous period does not reduce the probability of an agreement reached on 46 in this period, but significantly reduces the probability of an agreement reached on 52. Hence, while the enforcement regime with endogenous punishment as featured in our experiment can induce composition deterrence by shifting collusion from the high price to the low price, it also stabilises collusion on the low price. Such an increased stability of cartels represents an adverse effect of frequency deterrence, leading to a trade-off between frequency deterrence and composition deterrence.

	0	46	52
$Lag\ agreement\ 46$	-0.825^{***}	0.743^{***}	0.082
	(0.066)	(0.198)	(0.150)
$Lag\ agreement\ 52$	-0.828^{***}	0.318	0.511
	(0.057)	(0.318)	(0.321)
$Lag\ cheating$	0.138^{***}	-0.067^{***}	-0.071^{***}
	(0.013)	(0.019)	(0.016)
$Lag\ detection\ 46$	0.064^{***}	-0.007	-0.056^{***}
	(0.016)	(0.011)	(0.017)
$Lag\ detection\ 52$	0.093^{***}	-0.051^{***}	-0.042^{**}
	(0.019)	(0.014)	(0.019)
$Period$	0.007^{***}	-0.003^{**}	-0.004^{***}
	(0.002)	(0.001)	(0.002)
$Automatic\ price\ 52$	-0.005	-0.006	0.011
	(0.020)	(0.013)	(0.017)
$Lag\ market\ price$	0.009	-0.008	-0.001
	(0.006)	(0.006)	(0.003)
$EndoF$	-0.030	0.041	-0.011
	(0.041)	(0.036)	(0.017)
$EndoD$	0.002	0.032	-0.034^{**}
	(0.033)	(0.033)	(0.017)
$BothEndo$	0.001	0.026	-0.027^{*}
	(0.033)	(0.032)	(0.016)
Log pseudolikelihood		-290.758	
Observations		912	

Table 5: Multinomial logit on choice of price agreements

*Notes: values represent average marginal effects. Cluster-robust standard errors in parentheses. ***, **, and * denote 1%, 5%, and 10% significance levels.*

Results: we find that cartel enforcement regimes featuring expected punishments that increase with cartel overcharge can produce composition deterrence through strategic uncertainty. Compared to *Baseline* in which expected punishments are fixed, significantly fewer cartels are formed on the high, risker cartel price in *EndoD* and *BothEndo*. However, such strategic uncertainty driven composition deterrence does not lead to lower market prices in these two treatments. We find that this can be explained by the unintended consequence of endogenous punishments: while it deters some cartels from colluding on the high, riskier price to colluding on the low, safer price, it also stabilises collusion on the low price. This unintended consequence leads to a trade-off between frequency and composition deterrence, and overall welfare effects of this enforcement regime are ambiguous.

6. Conclusion

As antitrust enforcement cannot deter cartels altogether because to do so would be prohibitively costly, composition deterrence may offer the prospect to reduce the harm caused by cartels, which resembles the main objective of antitrust authorities of increasing welfare. While the literature on cartel experiments is growing, it has so far forgone to analyse composition deterrence due to the design of enforcement regimes that features fixed detection probabilities and fines.

This article analyses whether enforcement regimes with endogenous punishments (that is, detection probabilities and fines increase with cartel overcharge) can produce composition deterrence through the channel of strategic uncertainty. Strategic uncertainty has been suggested as an underlying reason for coordination failure (Van Huyck *et al*., 1990; Heinemann *et al*., 2009). While cartel is a coordination game, strategic uncertainty as a channel of deterrence has received little attention outside the context of leniency programmes. We seek to establish it as a channel of composition deterrence in a market experiment of an infinitely repeated non-cooperative game.

For this purpose, we design the expected punishment imposed on a detected cartel in a such a way that cartels formed on a high price and a low price can have the same expected payoff but different riskiness of collusion (Blonski et al., 2011; Blonski and Spagnolo, 2015). Results from our experiment show that enforcement regimes with endogenous punishments can produce composition deterrence through strategic uncertainty. Compared to *Baseline* in which expected punishments are fixed, significantly fewer cartels are formed on the high, riskier cartel price in *EndoD* and *BothEndo.* However, such composition deterrence does not lead to lower market prices in these two treatments. We find that this can be explained by the unintended consequence of endogenous punishments: while it deters some cartels from colluding on the high, riskier price to colluding on the low, safer price, it also stabilises collusion on the low price. This unintended consequence leads to a trade-off between frequency and composition deterrence, and overall welfare effects of this enforcement regime are ambiguous.

Our findings have practical implications for the design and evaluation of antitrust enforcement regimes. They suggest punishments that vary with cartel overcharge to be a promising avenue of deterrence and strategic uncertainty to be a feasible channel through which composition deterrence can come into effect. However, the finding of a trade-off raises the concern that reduced cartel formation on a high price does not necessarily feed back into increased overall welfare, which is an important consideration to be taken into account when designing enforcement regimes with endogenous punishments.

More experimental and empirical work on the trade-off between frequency and composition deterrence in the context of cartels is needed. Although a large body of literature exists for cartel deterrence, little is known about how the two factors interact under different enforcement regimes. While our experiment focuses purely on uncertainty-driven effects, the trade-off may differ when profitability-driven effects are present as well.

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Appendix

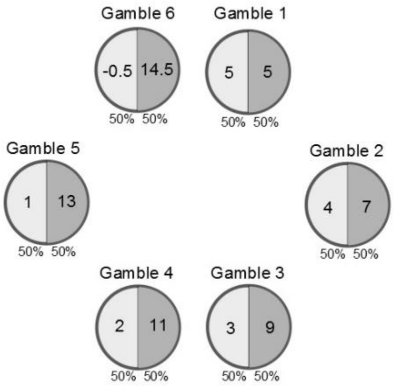
Instructions (BothEndo – automatic price 52)

Welcome and thank you for taking part in this experiment. In this experiment you can earn money. How much money you will earn depends on your decision and on the decision made by other participants in this room. The experiment will proceed in two parts. The currency used in the experiment is experimental points. Each experimental point is worth 12 pence. All earnings will be paid to you in cash at the end of the experiment.
Every participant receives exactly the same instructions. All decisions will be anonymous, that is, your identity will not be revealed to other participants at any time during or after the experiment. It is very important that you remain silent. If you have any questions, or need assistance of any kind, please raise your hand and an experimenter will come to you.

Instructions for Part 1

In the first part of the experiment you will be asked to choose from six different gambles (as shown below). Each circle represents a different gamble and you must **choose the one that you prefer**. Each circle is divided in half. The two numbers in each circle represent the amount of experimental points the gamble will give you.
An experimenter will toss a coin to determine which half of the circle is chosen. A volunteer will come to the front of the room and confirm the result of the coin toss. If the outcome is heads, you will receive the number of points in the light grey area of the circle you have chosen. If the outcome is tails, you will receive the number of points shown in the dark grey area of the circle you have chosen. Note that no matter which gamble you pick, each outcome will occur with a 50% chance.

Please select the gamble of your choice by **entering the number** of your gamble (1, 2, 3, 4, 5, or 6) in the field "I choose Gamble" and press OK.
Once everyone has made their decision, Part 1 will end and we will move on to Part 2 of the experiment.



Instructions for Part 2
In this part of the experiment you will form a group with two other randomly chosen participants in this room. Throughout the experiment you are matched with the same two participants. All groups of three participants act independently of each other. This part of the experiment will be repeated for at least 20 rounds. From the 20th round onwards, in each round there is a **20 out of 100 (20%)** chance that the experiment will end.
Your job:
You are in the role of a firm that is in a market with two other firms. In each round, you will have to set a price for your product. This price must be one of the following prices:
40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52
You will only sell the product if the other firms do not set a lower price than you in that round. If you sell the product, your earnings are equal to the difference between the price and the cost, which is 40:
Earnings = Price - 40.
Therefore, you will not make any profit if you set a price of 40. If you do not sell the product, you will not get any earnings but you will not incur costs either. If two or more firms set the same lowest price, the earnings will be shared equally between them.
Before you set your price, you may decide to agree with the other firms to set the same price and share the earnings. There are two prices you can agree on, **46** and **52**. If you agree with the other two firms to set the price of 46 and all firms set 46, each firm will get a profit of **2** experimental points. If you agree with the other two firms to set the price of 52 and all firms set 52, each firm will get a profit of **4** experimental points.
The picture below shows how this will look on the computer. All firms get asked whether they want to agree on prices.

If you want to agree on prices, you can indicate so by choosing the price you want to agree on. You can choose either 46 or 52, or you can choose both prices. The other two firms will do the same. If all three firms wish to agree on prices, and there exists a common price among the three firms' chosen prices, an agreement is reached on that common price.

If all three firms choose both prices, implying that they are fine agreeing on both prices, then a price agreement on 52 will be reached automatically. If there is no common price among firms' choices, no price agreement is reached. For example, no common price is reached if two firms suggest price 46 and one firm suggest price 52.
If you do not wish to agree on prices with the other two firms, you can indicate so by choosing the option No. If at least one firm chooses No, there will be no price agreement.
The following table summarizes how price agreement can be reached:

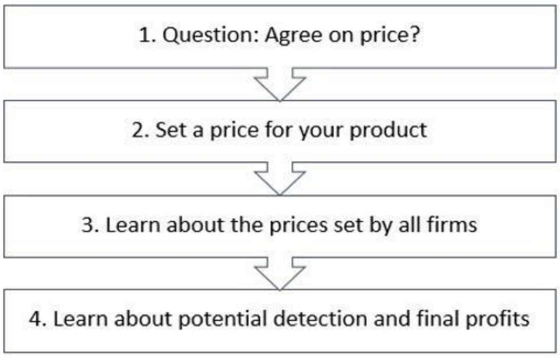
Price agreement is reached, if	All three firms wish to agree on prices and they reach one common price	Agreed price is the common price (46 or 52)
	All three firms wish to agree on prices and they reach two common prices (when all firms choose both 46 and 52)	Agreed price is 52
Price agreement is not reached, if	All three firms wish to agree on prices and they reach no common price	
	At least one firm does not wish to agree on prices	

After deciding whether you would like to form a price agreement, you have to set a price by filling the "Choose a price" box shown below. If a price agreement is reached, a message will appear above the "Choose a price" box showing the price that you agreed on. If no price agreement is reached in that round, no message will appear and you have to set a price without being able to coordinate with the other firms.

However, the agreement is not binding and you are not required to set the agreed price. After your price choice, you will be informed about the prices that you and the other firms set in that round. If you successfully reach a price agreement, the agreement may be discovered by the computer. The computer can discover the agreement on price 46 with a **10 out of 100 (10%)** chance, and can discover the agreement on price 52 with a **20 out of 100 (20%)** chance. If the agreement on price 46 is discovered, a fine of **4** experimental points has to be paid. If the agreement on price 52 is discovered, a fine of **12** experimental points has to be paid. If no price agreement is reached, you cannot be discovered or receive a fine.
The chance of being discovered and the fine depend on the price agreement reached, but not on the prices you set afterwards. The table below summarizes the chance of being discovered by the computer and the associated fines:

	Chance of being discovered	Fine
No price agreement is reached	0%	0
Firms agree on price 46	10%	4
Firms agree on price 52	20%	12

A price agreement can be discovered as long as it has not been discovered in a previous round. Once this has happened, you will not be fined in the future, unless you make a price agreement again. If you and the other two firms had several price agreements and none of them has been discovered, the chance of being discovered and fine always depend on the latest price agreement.
The picture below summarizes the structure of Part 2 of the experiment.



At the end of each round, you will be told the earnings you have made in this round. If you have reached a price agreement, you will also be told whether the agreement has been discovered by the computer.

Final payment:

At the beginning of the experiment you start with an initial endowment of 50 points = 6 GBP. The earnings you make in each round will be converted into cash. Each point is worth 12 pence, and we will round up the final payment to the next 10 pence. We guarantee a minimum earning of 2 GBP.