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The effects of endogenous enforcement on strategic uncertainty and cartel deterrence

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Keywords
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1 Introduction

The fight against cartels fixing prices or allocating customers 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 feature both fixed and variable elements. On the one hand, cartels are 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. On the other hand, parts of the fines are adjusted to the magnitude of harm induced by the cartel. Furthermore, a substantial part of costs of detection for cartelists stems from private damage actions, in which damages are awarded based on estimated overcharges, and therefore are endogenous.

The deterrent effect of antitrust enforcement can be decomposed into two elements: frequency and composition deterrence. Frequency deterrence refers to the prevention of cartel formation and is often measured as the number of cartels that are not formed in the presence of antitrust laws, but would have formed otherwise. Composition deterrence refers to the mitigation of harm caused by the cartels that are formed through a reduced cartel overcharge (Block *et al.*, 1981; Harrington, 2004, 2005; Bos *et al.*, 2016). This effect follows from a change in the cartel's optimisation problem in the presence of endogenous enforcement and is usually treated as profitability–driven. Yet, cartel behaviour may not only be influenced by profitability concerns, but also by strategic responses of cartelists to uncertainty about the actions of the other cartel members – we define this as *strategic uncertainty.* As *ex ante* the probabilities for the actions of other cartel members are unknown, strategic uncertainty cannot influence decisions based on the expected profitability as enforcement by the competition authorities does. However, such uncertainty between cartel members might be affected by endogenous enforcement as well, which potentially adds an indirect effect of overcharge–dependent punishment to cartel deterrence.

In this study, we seek to determine whether endogenous enforcement can induce composition deterrence through strategic uncertainty in an non–cooperative infinitely–repeated game market experiment. In doing so, we abstract from the direct profitability–driven effects and focus on the indirect effects induced by antitrust law on strategic uncertainty. We contribute to the experimental literature on collusion in the presence of an antitrust authority by proposing a framework that allows us to study the impact of endogenous enforcement on equilibrium cartel price selection. For this purpose, we allow the expected punishment to increase with the cartel price, so that cartels formed on a high price and a low price are identical in expected profitability but different in the *riskiness of collusion* (Blonski *et al.*, 2011; Blonski and Spagnolo, 2015) or in the *level of trust required* for collusion (Bigoni *et al.*, 2015). As a result, the two collusive equilibria are equally payoff–dominant, but the low cartel price is the equilibrium with the riskiness of collusion.

Yet, while we expect endogenous enforcement to induce composition deterrence, it may produce adverse effects on frequency deterrence. The enforcement regime featured in our design renders the low cartel price a more desirable collusive equilibrium, and thus may encourage more collusive agreements on the low cartel price as well as stabilise such agreements. Therefore, endogenous enforcement may produce frequency and composition deterrence that go in opposite directions. This potential trade–off may have important consequences for the optimal design of antitrust enforcement, which warrants the study of the overall effect of endogenous enforcement.

The results show that, consistent with our theoretical predictions, endogenous enforcement produces composition deterrence through its effect on strategic uncertainty. As a result, cartel prices shift from the high cartel price to the low cartel price with the lower riskiness of collusion. Yet, we find an adverse effect on frequency deterrence due to the increased stability of cartels formed on the low price. The overall effect of endogenous enforcement on market outcomes is unclear, as the strategic uncertainty aggravated by endogenous enforcement, *ceteris paribus*, largely mitigates the adverse effect on frequency deterrence. Furthermore, our results show that subjects' preferences over cartel prices are not driven by their risk attitudes, suggesting that subjects behave strategically in such repeated cooperative games. Moreover, cartel price choices are insensitive to different combinations of fines and detection probabilities that feature the same expected punishment.

The article proceeds as follows. Section 2 reviews the relevant literature. Section 3 describes the experimental design, and provides the theoretical background as well as the hypotheses. Section 4 presents the results. Section 5 concludes.

2 Literature review

Until now, most cartel experiments have relied on exogenous fines and detection probabilities, i.e. they are fixed within a treatment, to examine frequency deterrence. Examples include the studies on the effects of leniency programmes by Hamaguchi *et al.* (2009), Bigoni *et al.* (2012, 2015), Clemens and Rau (2014), and Hinloopen and Onderstal (2014), but also on other aspects such as the substitutability of fines and detection probabilities (Chowdhury and Wandschneider, 2015), avoidance activities of cartels (Chowdhury *et al.*, 2016), and tacit collusion induced by previous cartel activities (Chowdhury and Crede, 2015). Exceptions are the studies of Apesteguia *et al.* (2007) and Hinloopen and Soetevent (2008) on the effect of leniency programmes and of Fonseca and Normann (2014), who study how firm numbers affect the necessity to engage in repeated communication to preserve collusion. In these three studies, fines are endogenous and depend on either the chosen cartel price and/or the preceding collusive history. Yet, they do not study how the endogeneity of fines affects cartel prices or stability such that the issue of composition deterrence remains unaddressed. To the authors' knowledge, endogenous detection probabilities (apart from detection triggered by leniency applications) have not yet been experimentally implemented or studied in the context of cartels. However, in the field, cartelists decide not only whether to collude, but also which price to collude on. Although it is reasonable to assume that the risk of detection of cartels increases with the magnitude of their price changes (Harrington, 2004, 2005; Harrington and Chen, 2006), cartel experiments so far have forgone to analyse composition deterrence due to the exogenous design of implemented enforcement regimes.

Although the breakdown of all–inclusive cartels is, in general, either triggered internally by coordination failure of cartelists or externally through the detection by antitrust authorities, the experimental literature on cartels tends to focus on the latter channel. Recently, Bigoni *et al.* (2015) have suggested that deterrence can be achieved not only through imposing severe punishments, but also by worsening the incentive and the trust problems faced by cartelists. As a cartel is a type of collective crime, when making decisions, each member cares not only about the expected profitability of a collusive agreement, but also its stability and sustainability. As severe coordination complexity might itself render collusion infeasible, whether a cartel can be profitably formed fundamentally depends on the cartelists' ability to reach and sustain cooperative equilibria.

The literature of coordination games can loosely be divided into two classes: finitely or infinitely–repeated non–cooperative games and cooperative coordination games that are classified according to the access of information. Both strands of literature point out that the Nash equilibrium concept fails to predict a unique outcome in such games (e.g., Cooper *et al.*, 1990; Fudenberg and Maskin, 1993; Dal Bó and Fréchette, 2011). Coordination failure may arise not only from the absence of a payoff–dominant cooperative equilibrium, but also from Nash equilibria that are not self–enforcing (Van Huyck *et al.*, 1990). The multiplicity of equilibria calls for equilibrium refinement criteria to select equilibria that are most likely to arise. While Harsanyi and Selten (1988) suggest payoff dominance should take precedence over alternative deductive selection criteria, more recent theoretical and experimental studies (e.g. Van Huyck *et al.*, 1990) tend to support the risk dominance criterion. The underlying reason for coordination failure, as suggested by Van Huyck *et al.* (1990) and developed by Heinemann *et al.* (2009), is strategic uncertainty that arises in a socially interactive decision situation.

Knight (1921) distinguishes between risk and uncertainty. The former is usually referred to as Knightian uncertainty or exogenous certainty, whereas the latter is referred to as strategic uncertainty or endogenous certainty. Heinemann *et al.* (2009, p.182) define exogenous uncertainty as "*a priori* given and known probabilities for all possible states of the world". In the context of cartel experiments, the detection probability by the competition authority belongs to this source of uncertainty. Strategic uncertainty, on the other hand, describes situations in which the probabilities with which the states occur are not exogenously given or known *a priori*. Each subject is uncertain about the strategies and actions of the others within the same group, and thus has to make decisions according to subjectively assigned probabilities based on beliefs. This is where the trustworthiness of the others becomes crucial. Fehr (2009) suggests based on the behavioural definition of trust and betrayal aversion that trust is captured by preferences and beliefs of individuals as well as those generated from social interactions. Intuitively, as the degree of strategic uncertainty faced by decision makers increases, it becomes more difficult to trust, hence actions converge to inefficient but secure ones.

In the evolutionary game theory literature, Dal Bó and Fréchette (2011) conclude that the games' fundamentals, which are structural determinants contributing to exogenous uncertainty such as the attractiveness and riskiness of alternative action choices, length of the games, form of communication and subjects' experience, may affect cooperative behaviour. However, although repeated play of the game allows for inductive selection and learning, selected long run stochastically stable equilibria tend to be those satisfying the concept of risk dominance (Kandori *et al.*, 1993; Young, 1993). Blonski *et al.* (2011) and Blonski and Spagnolo (2015) introduce the concept of riskiness of collusion of a cooperative equilibrium in non–cooperative infinitely repeated games which is heuristically related to the concept of risk dominance.[1] In doing so, they consider strategic uncertainty by taking cognitive and behavioural determinants into account with a particular emphasis on the sucker's payoff. They take an axiomatic approach and offer a strategic uncertainty based measure of the critical discount factor, which allows for a comparison of the riskiness of several cooperative equilibria.

Cooperative games have been applied in the lab 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 uncertainty to be an effective device to deter illegal activities. However, as unlike tax evasion, a cartel is a type of collective crime, the incentive and trust issues are more relevant. Bigoni *et al.* (2015) suggest that a crucial part of the deterrent effect offered by leniency programmes is driven by the "distrust" that they create, which is an idea similar to betrayal aversion. They measure the level of trust needed to sustain collusion: the minimum level of trust required is higher as the strategic uncertainty of collusion increases, thus collusion is less likely to be reached.

3 Experiment

3.1 Experimental procedure

The experiment was carried out at the Centre for Behavioural and Experimental Social Science (CBESS) at the University of East Anglia, UK, in February and March 2015. 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 from a variety of backgrounds and nationalities and without prior experience in oligopoly experiments participated in the experiment. 36 subjects were allocated in groups of three, providing 12 independent market observations in each of the four treatments. Group composition was fixed throughout the session. At the start of each session, subjects were randomly seated in the laboratory at workstations separated by modular walls. Each subject received a printed copy of the instruction, which was also read aloud by an experimenter and displayed on each computer screen at the beginning of each session. Subjects' understanding of the instructions was tested with a questionnaire before they had to reach decisions. 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

[1]The riskiness of cooperation measured by Blonski and Spagnolo (2015) is related to strategic uncertainty that we discuss above, rather than exogenous risk, although the term they follow is "strategic risk".

Grossman (2008).[2] Subjects indicated the choices of their preferred lotteries on their computers, and then an experimenter determined the outcome of the lottery with a coin toss monitored by a volunteering subject. In the second part, subjects each represented a firm and played an oligopoly game in markets of three firms, as described below in Section 3.2 for 20 regular periods. A random stopping rule was implemented to avoid end–game effects as described in Dal Bó (2005): there was a 20% chance in each additional period that the experiment ends after the regular periods. 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 12 pence for cash payment. Based on subjects' performance, payments varied from £4.00 to £13.20 with a mean of £8.19. Sessions lasted between 40 to 60 minutes. Sample instructions can be found in the appendix.

3.2 Experimental design

In the experiment, subjects, each representing a firm, engage in competition in a market with two other subjects. The market is defined as a homogeneous goods Bertrand triopoly with (discontinuous) inelastic demand as introduced by Dufwenberg and Gneezy (2000) and market characteristics similar to those in Gillet *et al.* (2011). Each market consists of three firms because it has been found that three firms are sufficient to ensure that collusion cannot be sustained effectively without communication (Dufwenberg and Gneezy, 2000; Wellford, 2002), but with communication (Fonseca and Normann, 2012).

In each period all firms simultaneously make price decisions by choosing any price p from the choice set $p \in \{40, 41, ..., 52\}$. A firm sells one unit of the good and incurs a production cost of 40 if its price is lower than that of any other firm, and does not sell anything nor incur any production cost otherwise. The firm that sells the good at a price lower than its two competitors in a period therefore makes a profit of $p - 40$ whereas the other two firms make zero profit. In case that two or three firms choose the same lowest price, the profit is evenly divided among these firms. Before firms engage in Bertrand competition as described above, in each period they first have to simultaneously decide whether they wish to enter a non–binding price agreement, and if so, which price to agree on. There are two price agreements to choose from: one on the high cartel price $p_C^h = 52$ or one on the low cartel price $p_C^l = 46$.[3] We allow two cartel prices to facilitate the identification of effects in the econometric analysis of price agreements and to ensure that fines and detection probabilities are transparent to the subjects. Firms wishing to cooperate can choose to suggest their preferred cartel price, or they can suggest both prices if they are indifferent between the two. However, such a price agreement can be detected by the computer with positive probability resulting in a fine to be deducted from the profits.

Firms need to indicate their decisions to cooperate by answering the question "Do you want to agree on prices?". If all three firms wish to agree on prices and a unique common price exists

[2] The risk elicitation task can be found in the instructions for the subjects in the appendix.
[3] 52 is the highest possible price and 46 is the mean price in the choice set.

among the three firms' suggested cartel prices, an agreement is reached on that price. If all three firms choose both prices, implying that they wish to agree on either price, then in half of the groups in each treatment a price agreement on 46 is reached automatically and in the other half a price agreement on 52 is reached automatically. This is done to control for any potential effect of this protocol on cartel price choice. It is shown in Section 4 that this default agreement price rule does not affect subjects' price choices. The default price remains the same within a group throughout the experiment. If there is no common price among the firms' chosen cartel prices, no price agreement is reached, e.g. if two firms choose 46 and one firm chooses 52. If firms do not wish to cooperate, they can express so by choosing the option "No". If at least one firm chooses "No", no price agreement is reached in that period. To avoid potential effects arising from the order of items on the screen on subjects' choices, their order is randomized across periods.[4]

With our design, we expect coordination complexity arising from endogenous enforcement to render reaching price agreements more difficult. Although a free–form communication protocol may help to facilitate price agreements, we restrict communication to a limited–form protocol for several reasons. First, our focus is to obtain clear measures on subjects' desired price choices rather than to facilitate collusion. Second, limited–form communication prevents the social dimension to influence results (see, e.g. Cooper and Kühn, 2014) and ensures that communication is limited to pure signalling and cheap talk. Furthermore, it allows for a clear identification and econometric analysis of how strategic uncertainty increases the complexity of cartel coordination. Given that in our experiment bargaining is only possible through signalling over the course of several periods of the game, observations on cartel price choices at the subject level may not directly translate into similar patterns at the market level. To study the uncertainty–driven behavioural pattern of subjects, we focus primarily on individual subjects' decisions.

The sequence of the market experiment is summarised below:

1. Firms simultaneously indicate their decisions to cooperate by answering the question "Do you want to agree on prices?" Firms willing to cooperate choose "Yes" and the price(s) they wish to agree on and "No" otherwise.

2. Firms learn about whether a price agreement is reached, and if so, the agreement price.

3. Firms simultaneously make price decisions for their goods by choosing a price from the choice set $p \in \{40, 41, ..., 52\}$. Any price agreements reached are not binding for the firms' price decisions in this stage.

4. Firms learn about each others' prices and whether they sell a good in the current period.

5. Firms learn about whether they are detected by the computer given that they have reached a price agreement in the current period and/or their price agreements in previous periods have not yet been detected.

[4]A computer screenshot of the communication protocol can be found in the instructions in the appendix.

6. Finally, firms learn about their profits in the current period minus any potential fines, as well as about their accumulated profits.

This experiment is based on a 2x2 between–subject design. Baseline is the control treatment and serves to capture coordination failure that occurs because certain cooperative actions are not supported by an equilibrium. The other treatments assess the explanatory power of the concept of riskiness of collusion when two cooperative equilibria are payoff equivalent, which is useful to determine the uncertainty–driven channel of composition deterrence. We then compare the three treatments with endogenous enforcement to examine, given a constant expected profitability, whether there is a limited substitutability between fines and detection probabilities that might affect cartel pricing as well as deterrence. The detection probabilities (D) and the fines (F) differ in different treatments as shown in Table 1.

Table 1: Treatment and key parameters

	Exogenous detection prob.	**Endogenous detection prob.**
Exogenous fine	**Baseline** 46: $D = 20\%,\ F = 12,\ E(\pi) = -0.4$ 52: $D = 20\%,\ F = 12,\ E(\pi) = 1.6$	**EndoD** 46: $D = 3.3\%,\ F = 12,\ E(\pi) = 1.6$ 52: $D = 20\%,\ F = 12,\ E(\pi) = 1.6$
Endogenous fine	**EndoF** 46: $D = 20\%,\ F = 2,\ E(\pi) = 1.6$ 52: $D = 20\%,\ F = 12,\ E(\pi) = 1.6$	**BothEndo** 46: $D = 10\%,\ F = 4,\ E(\pi) = 1.6$ 52: $D = 20\%,\ F = 12,\ E(\pi) = 1.6$

In Baseline, the detection probability (20%) and the fine (12 experimental points) are the same for collusion on the high price of 52 and the low price of 46. It represents a typical homogeneous goods Bertrand cartel experiment with exogenous fines and detection parameters independent of the cartel price. In EndoF, the detection probability is held fixed but fine is endogenous. The magnitude of the fine is a function of the agreed cartel overcharge: collusion on price 52 yields a higher per period profit and hence requires a higher potential fine of 12, whereas collusion on price 46 face a lower potential fine of 2. Similarly, in EndoD the fine is held fixed but the detection probability increases with the cartel overcharge: collusion on the low price 46 and on the high price 52 feature detection probabilities of 3.3% and 20%, respectively. In BothEndo, the fine and detection probability attached for collusion on 52 are the same as in Baseline, whereas those attached to collusion on 46 are lower at $F = 4$ and $D = 10\%$, i.e., both elements are endogenous in this treatment. The overcharge is about 27% when firms collude on cartel price 52 is close to the mean overcharge of 29% of the cartels studied in Connor and Bolotova (2006). Detection probabilities of 10% and 20% are in range of those reported in Ormosi (2014) for cartels prosecuted by the European Commission between 1984 and 2009.

Parameters and the experimental design are chosen such that the expected profitability and the ICCs are equal across the treatments with endogenous enforcement and the two cartel prices. This is crucial for answering the research questions: it rules out the profitability–driven effects of endogenous enforcement on cartel behaviour as analysed in Katsoulacos *et al.* (2015), and allows us to focus on the uncertainty–driven effects.

3.3 Theoretical background

Before we provide the theoretical model that underlines our framework and experimental design, we briefly discuss the main insights from the theoretical literature on endogenous punishment on cartel prices. Consider a homogeneous goods market with $n \geq 2$ firms that face the identical unit costs of production c and compete in prices and with the demand function $Q(p)$, where p denotes price and Q is the quantity supplied to the market. The industry profits $\pi(p, c)$ is

$$\pi(p, c) = (p - c)Q(p). \tag{1}$$

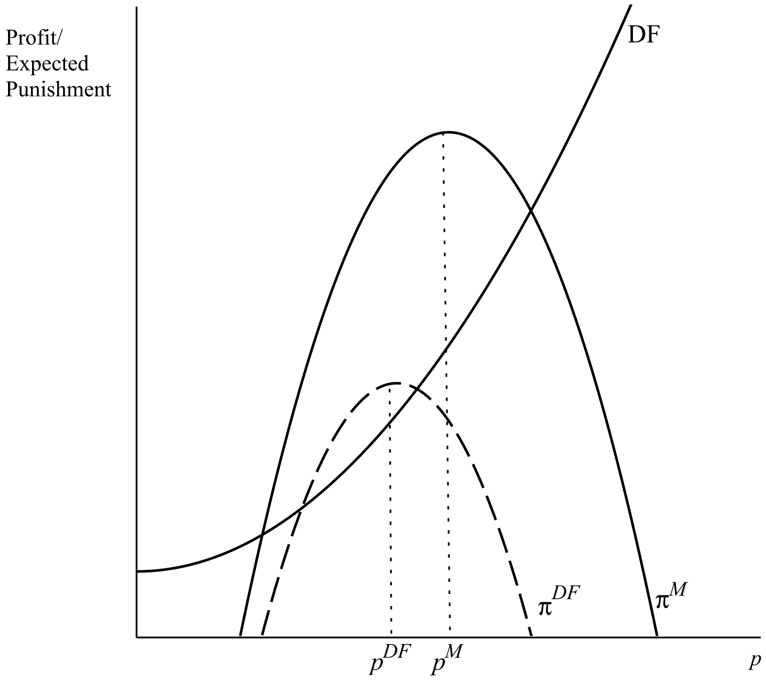
When price collusion is not possible, price competition gives rise to the competitive price $p^B = c$. When price collusion is possible and all firms agree to collude, then in the absence of antitrust enforcement, each firm sets $p^M = arg\ max_p\ \pi(p, c)$ yielding each firm a profit of π^M/n.

In this context, the existing literature (e.g. Block *et al.*, 1981; Katsoulacos *et al.*, 2015) has shown that antitrust enforcement that is increasing in cartel overcharge can mitigate the harm caused by the illegal activity by producing composition deterrence. To illustrate this result, we include an expected punishment of DF where D is the detection probability and F is the penalty imposed upon detection. Let DF be a function of cartel prices and assume $\partial DF/\partial p > 0$ and $\partial^2 DF/\partial p^2 \geq 0$ such that it is weakly convex.[5] With this general functional form, we allow either the fine, the detection probability, or both elements to increase with the cartel overcharge, which is a reasonable assumption given observations from the field. Figure 1 plots the cartel gross profit against the price in the absence of the expected punishment (π^M) as well as the net profit under consideration of the expected punishment presence (π^{DF}). As can be seen, such endogenous antitrust enforcement leads to composition deterrence by altering the expected profitability of a cartel. As a result, cartels may not be deterred altogether, but they are formed at lower prices, i.e. at p^{DF} instead of p^M.

Changing the cartel's optimisation problem, however, is not the only channel through which composition deterrence can be achieved by endogenous enforcement. Price collusion is in nature a cooperative problem. Therefore, in this study we wish to assess whether pricing below the monopoly level could be an optimal reaction to strategic uncertainty in non–cooperative infinitely repeated games. For this purpose, we introduce an antitrust regime with endogenous punishment in which several cartel prices are equally profitable but carry different levels of riskiness of collusion. As such, we rule out any incentive that arises from the relative size of the expected profitability of the cartel, and makes sure that cartelists' collusive price choices are driven by their decisions when facing strategic uncertainty. As mentioned in Section 3.2, this constitutes the crucial property of our experimental design, which is explained further below.

[5]We consider our findings based on this assumption, in particular the counteracting effects of frequency and composition deterrence, to hold in most cases. However, special scenarios may exist in which the assumption does not hold. See Bos *et al.* (2015) for an example in which antitrust punishment benefits cartels.

Figure 1: Profitability–driven composition deterrence



In this framework, there are many equilibria. Yet, the predominant noncooperative equilibrium that tends to dominate choices in case of coordination failure is characterized by each firm choosing $p^B = 41$ and obtaining a competitive profit of $\pi^B = (41 - 40)/3 = 0.33$ in each period. However, firms reaching price agreements, 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 $\pi_C^l = (46 - 40)/3 = 2$, both of which are strictly higher than π^B. In Baseline, the expected punishment is exogenous and fixed at $0.2 \times 12 = 2.4$, therefore the relevant expected payoffs of forming cartels are given by

$$E(\pi_C^h) = 4 - 0.2 \times 12 = \quad 1.6 > \pi_B \tag{2}$$

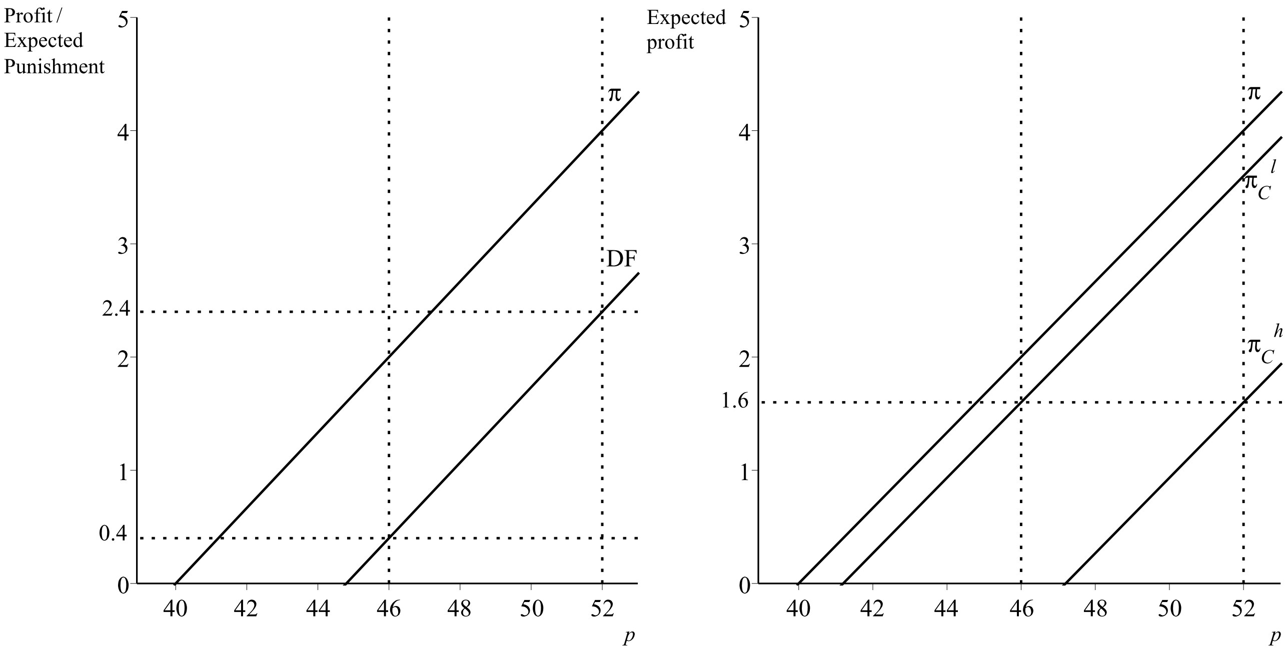
$$E(\pi_C^l) = 2 - 0.2 \times 12 = -0.4 < \pi_B. \tag{3}$$

The expected payoff of colluding on p_C^h is strictly larger than the payoff associated with the predominant noncooperative equilibrium, whereas it is negative on p_C^l. Hence cartels can only be profitably formed on price 52 in expected terms, and rational cartels would – absent other strategic considerations – either collude on price 52 or not collude at all. In treatments EndoF, EndoD and BothEndo, the expected punishment of forming a cartel increases in the cartel price, i.e. it is endogenous. Figure 2 offers the experimental version of the general cartel optimisation problem as shown in Figure 1. Figure 2a shows the gross profits as well as the expected punishment as functions of the cartel price. Figure 2b displays the net expected profitability for collusion on both the high (π_C^h) and the low (π_C^l) cartel prices. As shown in Figure 2, the expected punishment DF is now different for the two cartel prices: it is lower (0.4) for 46 and higher (2.4) for 52. Consequently, the expect payoffs of colluding on the high and the low cartel prices are the same,

$$E(\pi_C^h) = 4 - 2.4 = 1.6, \tag{4}$$
$$E(\pi_C^l) = 2 - 0.4 = 1.6. \tag{5}$$

The two cartel prices thus represent two payoff–equivalent Pareto–dominant collusive equilibria. In the following, we characterize the equilibrium conditions, which may vary under different treatments and with different cartel prices.

Figure 2: Profits and expected punishment in the experiment



(a) Gross profits and exp. punishment **(b)** Expected profits

Suppose that firms react to cheating with a grim–trigger strategy. Thus, a firm slightly undercutting the cartels' price obtains a one shot deviation profit π_{dev}, while the others earn zero profit. The corresponding incentive compatibility constraint (ICC) of sustaining collusion infinitely is given by

$$\frac{\pi_C}{1-\delta} - \frac{DF}{1-\delta(1-D)} \geq \pi_{dev} + \frac{\delta\pi_B}{1-\delta} - \frac{DF}{1-\delta(1-D)}, \tag{6}$$

where δ denotes the discount factor. Note that the punishment is linked to the agreed cartel price in the experiment, irrespective of whether deviation occurs afterwards or not.[6] As such, the term measuring expected punishment, $DF/1-\delta(1-D)$, appears on both sides of the ICC and cancels out. Thus, the ICC is not affected by the variations in fines and detection probabilities and the discount factor derived from the ICC is given by

$$\delta \geq (\pi_{dev} - \pi_C)/(\pi_{dev} - \pi_B), \tag{7}$$

which is almost identical for p_C^h and p_C^l (0.656 and 0.642). Therefore, cartel formation should

[6]Absence of the sensitivity of fines to cheating is in line with fining practices in the field in most jurisdictions, in which the mere attempt to collude is illegal and is fined.

not be driven by the relative size of the ICCs: when firms are able to cooperate, they should be equally likely to collude on either of the two cartel prices.

However, although the ICCs ensure the existence of a cooperative equilibrium and that firms' incentives are not affected by variations in the exogenous uncertainty DF, the cooperative difficulties and trust issues arising from strategic uncertainty may render collusion infeasible. Thus, firms may not stick to a price agreement even if it represents an equilibrium.

The recent theoretical and experimental literature tends to suggest that the riskiness of collusion criterion selects more self–enforcing and sustainable equilibria. Thus, assessing the standard ICCs is not sufficient to explain equilibrium selection in the lab. To exemplify this, we can use Blonski and Spagnolo (2015)'s prisoner's other dilemma to compare the riskiness of collusion when firms collude on different prices. This measure of risk can be calculated for each cartel price as difference between two squared expressions

$$(\pi_B - \pi_S)^2 - (\pi_C - \pi_{dev})^2. \tag{8}$$

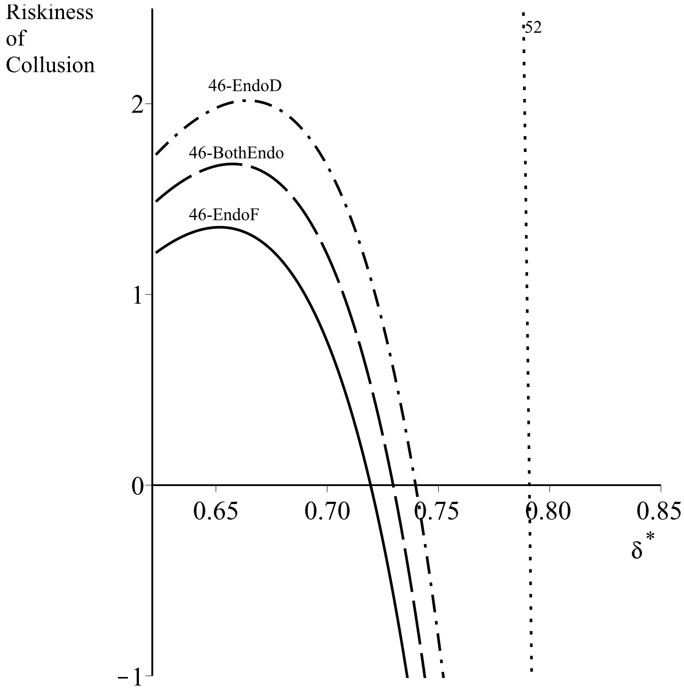
This is closely related to the comparison of Nash products in static 2x2 games to determine the risk–dominant equilibrium as proposed by Harsanyi and Selten (1988). Inside the first squared expression is the difference between the predominant noncooperative equilibrium profit and the profit obtained in case of being cheated upon (π_S). Inside the second squared expression is the difference between the collusive profit and the deviation profit. Therefore, the riskiness of collusion is measured by comparing the cheating incentives in the collusive equilibrium to the incentives of acting noncooperatively to avoid being cheated upon. *Ceteris paribus*, the larger the difference between the deviation and collusion profits, the higher is the riskiness of a collusive equilibrium, which requires a higher discount factor sustain collusion. The corresponding net present value of the riskiness of collusion when the game is repeated infinitely is given by

$$\left(\frac{\pi_B}{1-\delta^*} - \pi_S + \frac{DF}{1-\delta^*(1-D)} - \frac{\delta^*\pi_B}{1-\delta^*}\right)^2 - \left(\frac{\pi_C}{1-\delta^*} - \pi_{dev} - \frac{\delta^*\pi_{dev}}{1-\delta^*}\right)^2 \tag{9}$$

where δ^* denotes the discount factor incorporating the riskiness of each collusive equilibrium. Eq. 9 can be used to calculate the riskiness of collusion at different cartel prices and in different treatments for any given discount factor of the firms.

Figure 3 illustrates the riskiness of collusion on the two cartel prices as a function of the discount factor. The riskiness of collusion is identical for price 52 in all treatments because of the identical fine and detection probability attached to it across treatments, whereas the riskiness of collusion for price 46 varies. Note that we do not consider collusion on 46 in Baseline, as it is an off–equilibrium option. Given an identical payoff, the risk constraint is the tightest for collusion on 52, whereas it does not differ much for collusion on 46 across the included treatments. The high riskiness of collusion on price 52 follows from the fact that collusion on 52 is associated with higher cheating incentives than collusion on 46, whereas the sucker's payoff of 0 remains constant.

Figure 3: The riskiness of collusion



We therefore derive the following predictions for the presence of endogenous enforcement on cartel behaviour. First, subjects' cartel price choices converge to the price 46 with a lower riskiness of collusion, which indicates the uncertainty–driven scope for composition deterrence. Second, collusion is more stable on price 46 than on price 52. Although we do not model frequency deterrence explicitly, the predicted increase in the stability of cartels on price 46 implies the trade–off between frequency and composition deterrence. This is evident from the reduced required discount factors for price 46 in Figure 3 . Third, subjects' preference over cartel price 46, as well as the levels of cartel formation and stability on price 46, do not differ substantially across treatments.

3.4 Hypotheses

As we primarily seek to examine how endogenous enforcement may produce deterrence effects through affecting strategic uncertainty in non–cooperative infinitely–repeated games, the bulk of the hypotheses relate to the behaviour of subjects rather than to markets. This follows from the focus of the experimental design on identifying individuals' preferences, which might not translate to the same behaviour at a group level due to coordination difficulties. Nevertheless, market outcomes are important for the assessment of the overall effect of endogenous enforcement and are briefly addressed. Based on the existing literature and our theoretical predictions, we derive the following hypotheses.

First, given the prediction that collusion on price 46 is not a payoff–dominant collusive equilibrium in Baseline, we want to verify that subjects do not choose to collude on 46 in Baseline. The potential failure of (stable) collusion on price 46 provides evidence that payoff dominance is an important equilibrium selection criterion and fundamentally affects subjects' decisions. As the only feasible collusive equilibrium in Baseline is to collude on price 52, subjects who are willing to collude should do so on 52.

> **Hypothesis 1**: In Baseline, the low cartel price is rarely chosen and does not produce stable cartels.

In itself this is not a very interesting hypothesis to test, as the existing literature has already shown the importance of payoff dominance in equilibrium selection (see, e.g. Dal Bó and Fréchette, 2011). Yet, providing evidence for Hypothesis 1 is necessary for confirming subjects' understanding of the game and for the interpretation of other results later on.

Next, we wish to examine the role of strategic uncertainty in the choice of cartel prices. In treatments EndoF, EndoD and BothEndo, endogenous enforcement equalises the expected payoff of colluding on both prices, whereas the expected punishment is imposed in a way such that collusion on 46 is the equilibrium with the lower riskiness of collusion. As shown in Figure 3, collusion on 46 is subject to a significantly lower level of riskiness than on 52. If strategic uncertainty plays a role in collusive decisions, then as predicted in Section 3.3, cartel prices should converge to the low price 46. Further, disruptions of collusion by previous cheating of cartelists and detection by the antitrust authority should discourage collusion on price 52 in favour of 46. We therefore expect subjects to show a tendency to shift from the high to the low cartel price, but not vice versa.

> **Hypothesis 2**: Subjects' suggested cartel prices converge to the low cartel price in EndoF, EndoD and BothEndo.

Limits to the substitutability between fines and detection probabilities in antitrust deterrence have been a topic of interest in antitrust economics. These limits are important for the efficient and effective allocation of resources of antitrust authorities. The issue has been studied before experimentally with respect to frequency deterrence. Bigoni *et al.* (2015) and Chowdhury and Wandschneider (2015) study how variations of the fine and detection probability given the same expected punishment influence cartel stability both in the presence and absence of leniency programmes. Both studies find the two enforcement elements to be substitutes without leniency programmes, but fines to be more important with leniency programmes. Given that there is no leniency programme in this experiment and that the riskiness of collusion on price 52 stays the same across treatments and that of collusion on price 46 appears to be similar in treatments with endogenous enforcement, subjects' price choices should not significantly differ across treatments with endogenous enforcement.

> **Hypothesis 3**: Subjects' suggested cartel prices do not differ significantly between EndoF, EndoD and BothEndo.

As cartels formed on prices 46 and 52 yield identical expected payoffs, but differ in the risk of detection, it renders the choice between the two prices similar to a choice between two lotteries with different exogenous risks. Therefore, *ceteris paribus*, risk averse subjects might be more likely to choose the cartel price 46 or not to join a cartel at all, as opposed to choosing price 52 or being indifference between both prices. Studies on the relationship between risk aversion and cooperation do not provide conclusive findings. Sabater-Grande and Georgantzis (2002) suggest the relationship to be negative. Reuben and Suetens (2012) show that the majority of subjects behave strategically in infinitely–repeated games. Dreber *et al.* (2014) conclude that the primary determinant of subjects' behaviour in these games is payoff maximization and find no conclusive pattern between cooperation and risk attitude.[7]

Recent studies that distinguish between subjects' risk attitudes towards exogenous uncertainty and their beliefs driven by strategic uncertainty measure both elements separately (Heinemann *et al.*, 2009; Berninghaus *et al.*, 2013; Tan and Yim, 2014). Tan and Yim (2014) emphasise the role of strategic uncertainty over exogenous uncertainty and Berninghaus *et al.* (2013) find that beliefs rather than risk attitude explain subjects' choices. The importance of beliefs for cooperation in infinitely–repeated games has also been stressed by Dal Bó and Fréchette (2011). Similarly, as we highlight the difference between exogenous and strategic uncertainty, and provided that Hypothesis 3 holds that subjects' price choices are not significantly different across treatments with endogenous enforcement, we conjecture that strategic uncertainty is the main driver of subjects' choices and that risk attitude only plays a minor role.

> **Hypothesis 4**: Risk attitude does not strongly affect subjects' suggested cartel prices.

An important problem of cartels, both in the lab and in the field, is to reach a consensus on the cartel price. Levenstein and Suslow (2006) show that disagreement on the collusive outcome is a major source of cartel breakdown. Our experimental design allows us to explicitly distinguish between attempts to propose a specific cartel price for collusion, and to be indifferent between both possible prices. Indifference may be due to a lack of preference for a particular price, i.e. being different is actually a preferred choice, or it may be used to facilitate agreement as other members in the same group might prefer a particular cartel price. We expect to observe both factors varying within and between subjects over time.

> **Hypothesis 5**: Subjects show a persistence in their suggested cartel prices, but are willing to become indifferent between different cartel prices if neccessary to facilitate collusion.

This bargaining–driven phenomenon might produce cartel prices that oppose movements towards the collusive equilibrium of 46 as conjectured in Hypothesis 2. However, the econometric analysis conducted in Section 4 simultaneously controls for both effects such that they can be separated

[7]There are two major differences between the experiment of Dreber *et al.* (2014) and ours, which might affect the results with respect to risk attitudes. First, the average cooperation period in our experiment (23.3 rounds) is significantly longer than that in theirs (10.7-11.5 rounds). Second, one feature in their experiment is that in all analysed treatments, an "execution error" occurs with 12.5% probability and alters subjects' chosen strategies. This makes it difficult for subjects to form beliefs about each other. Our experiment does not feature such a design. Thus, subjects in our experiment are more likely to be able to form beliefs on their opponents and make informed decisions based on the history of cooperation and cheating.

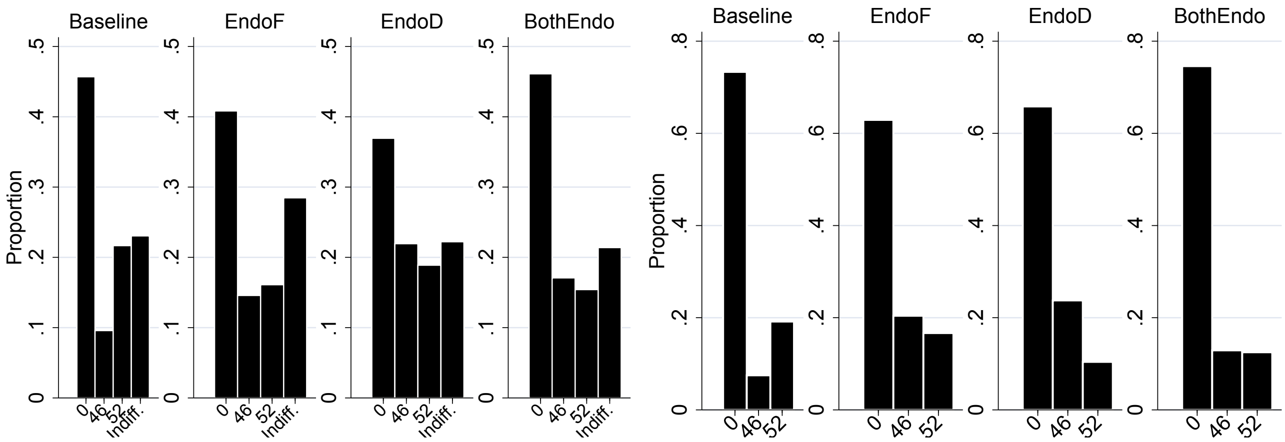
and assessed *ceteris paribus*. Thus, such opposing effects do not hinder inference in our analysis.

The five hypotheses above focus on each subject's desired cartel prices. Yet, the overall welfare effects of endogenous enforcement, which we conjecture to be determined by a trade–off between frequency and composition deterrence, is important in assessing the efficiency of endogenous enforcement and for potential policy implications. Thus, we further assess the welfare effects of endogenising enforcement in our experiment. To examine the welfare effects, we compare market prices and cartel formation in Baseline with exogenous enforcement to those in treatments with endogenous enforcement. *Ex ante*, it is unclear which of the deterrence effects dominates.

4 Results

As a preliminary to the regression analysis, we provide some descriptive statistics.[8] All reported results are based on the first 20 periods to avoid potential end–game effects affecting the results and to consider all markets based on the same number of observations. Figure 4a shows the proportions of suggested cartel prices across all subjects separated by treatment, where 0 denotes subjects' preference of not to engage in price agreements and *Indiff.* refers to instances in which subjects suggest both prices for an agreement; Figure 4b shows the proportions of actual price agreements reached across all markets, and 0 indicates that no agreement is reached.

Figure 4: Choice of agreements by treatment



(a) Subjects' suggested cartel prices **(b)** Price agreements reached

At first glance, observed patterns appear to be in line with the predictions of the theoretical model. The first observation is relevant to Hypothesis 1: among all treatments, the collusive price 46 is suggested and agreed on the least often in Baseline. As such, expected profitability represents an important driver of cartel price choice. The second observation is relevant to Hypothesis 3: the distributions of suggested cartel prices and price agreements reached do not seem to vary significantly across treatments with endogenous enforcement. However, as the (suggested) cartel prices are driven by a substantial number of factors, we draw any inference based on the regression analysis below.

[8]Figures on the distribution of asking prices and market prices, as well as of the asking prices conditional on cheating in the previous round can be found in the appendix.

Table 2: Descriptive statistics

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

Table 2 provides means or proportions for selected variables that are used as regressors below. *Asking prices* represent the selling prices that subjects individually set in each market in each period. *Market prices* represents the prices at which goods are sold and consists of the lowest asking prices in each market in each period. *Prop. agreement on 46 (52)* measures the proportion of the markets and periods in which an active price agreement of 46 (52) is in place. An agreement is defined as active if it is either reached in the current period or reached in previous periods but has not yet been detected or cheated upon. *Prop. new agreement* denotes the proportion of markets with newly reached (instead of active) price agreements irrespective of the chosen cartel price in the previous period. *Prop. cheating on 46 (52)* reports the proportion of the 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 agreements on 46 (52) are detected by the computer.

Several observations can be obtained from Table 2. First, asking and market prices do not differ substantially across treatments, and they both appear to be above the predominant noncooperative equilibrium price of 41. This implies that prices rise with firms' attempts to collude. Second and in line with Figure 4, agreements on 46 are relatively rare (7.5%) in Baseline, compared to the treatments with endogenous enforcement (20.4%, 23.8%, and 12.9%, respectively). Strikingly, for the few agreements reached on 46 in Baseline, cheating occurred with 100% probability. This suggests that subjects appear to have a clear understanding about the fact that collusion on 46 is not an equilibrium in Baseline. Furthermore, no cartel formed on price 46 was detected in EndoD because of the low detection probability of 3.3% in this treatment.

4.1 Subjects' suggested cartel prices

We now turn to the main analysis based on regression models. First, we examine individual subjects' suggested cartel prices in a multi-level multinomial logit model with random-coefficients at the subjects' level and report results in Table 3. Columns II to V present the estimated average marginal effects (with their cluster–robust standard errors in brackets) of the regressors on subjects' choices of price agreements, with the choices being no agreement (0), an agreement on 46, an agreement on 52, or an agreement on either price (indifference between 46 and 52). *Lag asking price* denotes the price that a subject set in the previous period. *Lag lowest seller* is an indicator variable showing whether the subject set the lowest price in the previous period (such that she made a positive profit). *Lag agreement 46 (52)* controls for the effects of previous periods' active price agreement on 46 (52) on subjects' suggested cartel prices in this period. *Lag choice 46, 52* and *46/52* are indicator variables of a subject's suggested agreement price in the previous period, with no agreement (0) serving as the baseline. Given that a price agreement was in place in the previous period, *Lag cheating 46 (52)* and *Lag detection 46 (52)* indicate whether cheating or detection occurred on the respective agreement. *EndoF*, *EndoD* and *BothEndo* are treatment indicator variables that measure the treatment effects, and Baseline serves as the baseline. *Period* measures the period effects. *Automatic price 52* is an indicator variable for the markets in which a price of 52 is chosen automatically if all three subjects in the group are indifferent between both cartel prices. Finally, *Risk attitude* measures subjects' risk attitudes elicited in the risk elicitation task in the spirit of Eckel and Grossman (2008). This variable contains discrete values between 1 and 6 where value 1 represents the highest level of risk aversion and serves as the baseline.

We first address Hypothesis 1. The observations obtained from Table 2 suggest that relatively fewer price agreements are reached on 46 in Baseline and that all of them are cheated upon. The regression analysis confirms that the result is driven by subjects' suggested agreement prices. As shown in Table 3, the treatment dummies indicate that, *ceteris paribus*, subjects are between 9.1% to 15.4% more likely to suggest the low price 46 in the treatments with endogenous enforcement than in Baseline. Taken together, we have strong evidence for Hypothesis 1.

> **Result 1**: In Baseline, the low cartel price is rarely chosen and results in unstable price agreements.

The intuition behind Result 1 is straightforward: the low cartel price does not produce stable cartels in Baseline because it is not a payoff–dominant collusive equilibrium. It follows that, *ceteris paribus*, payoff dominance is a necessary, although not sufficient condition for collusion to arise. Furthermore, it confirms that subjects show an understanding of the game. However, the fact that the majority of subjects did not choose the payoff–dominant collusive price 52 indicates that subjects have other considerations and face additional constraints when agreeing on prices.

Unlike in Baseline, in EndoF, EndoD, and BothEndo, endogenous enforcement renders collusion on price 46 not only payoff equivalent to collusion on 52, but also the equilibrium with the lower riskiness of collusion. If subjects care only about the expected payoff, 46 and 52 are equally likely to be chosen in these three treatments. However, as discussed above, issues of stability and sustainability are fundamental in cartel coordination, in which strategic uncertainty may hinder cooperative behaviour. If these considerations are taken into account, then given the theoretical predictions, subjects are more likely to choose 46 in the treatments with endogenous

Table 3: Suggested cartel agreement – Multi-level multinomial logit results

	0	46	52	46/52
Lag asking price	0.003	0.001	0.006*	−0.010**
	(0.003)	(0.001)	(0.003)	(0.004)
Lag lowest seller	−0.046*	0.010	0.016	0.020
	(0.026)	(0.016)	(0.019)	(0.022)
Lag agreement 46	−0.150	−0.033	0.097	0.085
	(0.151)	(0.059)	(0.102)	(0.124)
Lag agreement 52	−0.075	−0.086***	0.087	0.074
	(0.087)	(0.023)	(0.062)	(0.074)
Lag choice 46	−0.231***	0.143***	−0.010	0.098***
	(0.042)	(0.033)	(0.031)	(0.037)
Lag choice 52	−0.309***	0.058**	0.146***	0.105***
	(0.026)	(0.025)	(0.037)	(0.033)
Lag choice 46/52	−0.427***	−0.053***	−0.069**	0.549***
	(0.040)	(0.018)	(0.029)	(0.050)
Lag detection 46	0.169**	−0.028	−0.024	−0.118***
	(0.068)	(0.035)	(0.057)	(0.033)
Lag detection 52	0.150**	−0.030	−0.056	−0.064
	(0.071)	(0.030)	(0.034)	(0.048)
Lag cheating 46	0.186	0.026	−0.115***	−0.097
	(0.160)	(0.104)	(0.034)	(0.075)
Lag cheating 52	0.015	0.127*	−0.091***	−0.051
	(0.069)	(0.070)	(0.020)	(0.057)
EndoF	−0.068	0.091*	−0.070	0.047
	(0.076)	(0.053)	(0.044)	(0.054)
EndoD	−0.099	0.154**	−0.016	−0.040
	(0.072)	(0.063)	(0.046)	(0.055)
BothEndo	−0.005	0.098*	−0.046	−0.047
	(0.065)	(0.058)	(0.048)	(0.047)
Period	0.014***	−0.001	−0.008***	−0.006***
	(0.002)	(0.002)	(0.002)	(0.002)
Automatic price 52	−0.042	0.029	−0.035	0.049
	(0.048)	(0.025)	(0.038)	(0.039)
Risk attitude – 2	−0.084	0.011	0.080	−0.007
	(0.115)	(0.056)	(0.089)	(0.070)
Risk attitude – 3	0.007	−0.005	0.047	−0.049
	(0.104)	(0.068)	(0.089)	(0.072)
Risk attitude – 4	−0.202	0.073	0.164	−0.034
	(0.127)	(0.075)	(0.126)	(0.069)
Risk attitude – 5	−0.009	−0.015	0.030	−0.006
	(0.117)	(0.072)	(0.097)	(0.067)
Risk attitude – 6	−0.039	−0.003	0.034	0.008
	(0.110)	(0.061)	(0.080)	(0.075)
Pseudo-LL	-2135.055			
Observations	2736			

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

enforcement.

As shown in Figure 4b, price agreements on 46 occur more often in the treatments with endogenous enforcement than those on 52. Regression results in Table 3 allow to study the dynamics of subjects' price choices. First, the *Lag cheating* variables suggest that cheating in the previous period strongly discourages subjects from choosing 52 as the agreement price choice in this period. However, cheating on an agreement on 52 in the previous period increases the probability of subjects choosing 46 in this period. Hence, subjects learn about the different levels of riskiness and their choices converge to the collusive equilibrium with the lower riskiness of collusion. Second, the *Lag choice* variables suggest that, *ceteris paribus*, subjects show a 5.8% probability to switch from price 52 to 46, but no such substitution pattern can be observed for the opposite direction. This adds to the above finding that subjects' choices converge towards the equilibrium with the lower riskiness of collusion. Note that we obtain this finding given that we have controlled for the effects of events such as cheating, detection and previously reached price agreements. Thus, we find evidence in support of Hypothesis 2, which constitutes composition deterrence in line with the model predictions.

> **Result 2**: Subjects' suggested cartel prices converge to the low cartel price with the lower riskiness of collusion in the treatments with endogenous enforcement.

As our analysis is limited to the first twenty periods of the game, the existence of this effect shows that it does not necessarily take several dozen periods for subjects to adjust choices towards the equilibrium with the lower riskiness of collusion.[9]

Next, we examine subjects' choices further by studying how subjects' historical preferences affect their suggested cartel prices in this period. The *Lag choice* marginal effects in Table 3 indicate two main effects. First, subjects show persistence in their preferences for a particular cartel price: they are 14.3% (14.6%) more likely to choose 46 (52) as their suggested cartel price in this period if they did so in the previous period. Second, subjects have the tendency to switch from their suggested cartel price to be indifferent between both cartel prices, but not vice versa: on average, subjects switch from 46 (52) to indifference with 9.8% (10.5%) probability. As such, we find strong evidence supporting Hypothesis 5. It follows that subjects' suggested cartel price choices are not random, but show two distinct strategic elements.

> **Result 3**: Subjects show a persistence in their suggested cartel prices, and are willing to facilitate collusion by agreeing on other cartel prices as well.

The substitutability between fines and detection probabilities in the treatments with endogenous enforcement is addressed next. There are no significant treatment effects with respect to the probability of choosing cartel price 52. This is in line with the experimental design, in which the fines and detection probabilities for price 52 are identical across treatments. Further, there are no significant differences between treatments for subjects' choices not to collude or to be

[9]Yet, the effect might be more pronounced in longer games (see Dal Bó and Fréchette, 2011).

indifferent between the two cartel prices. The only significant treatment effects remain to be compared are those on price choice 46.

As shown before, subjects choose cartel price 46 more often in treatments with endogenous enforcement than in Baseline. In order to assess whether the probabilities of subjects choosing cartel price 46 vary with the different combinations of fines and detection probabilities across the treatments with endogenous enforcement, we compare the marginal effects of choosing price 46 in the previous period across those treatments. Whereas the probabilities to choose price 46 in EndoF (9.1%) and BothEndo (9.8%) do not seem to differ from each other, the marginal effect is about 1/3 higher in EndoD (15.4%). This is reflected in Figure 4 as well, which shows that subjects choose 46 more often and agreements are reached on 46 more often in EndoD than in EndoF or BothEndo. To formally compare the treatment effects, we conduct pairwise Wald tests of the treatment indicator coefficients. The test results do not reject the Null hypothesis of equality of coefficients with p–values of 0.169 (EndoF/EndoD), 0.765 (EndoF/BothEndo), and 0.103 (EndoD/BothEndo). As such, different combinations of fines and detection probabilities given the same expected punishment offer the same deterrence effect.

As Baseline serves as the baseline in the regressions, concerns may arise due to the different design and unique collusive equilibrium in Baseline such that the coefficients for this treatment might differ from those in the other treatments. Hence, to ensure the robustness of the regression results, we re–estimate the multi–level multinomial logit model but exclude Baseline and use EndoF as the baseline. This potentially provides a more homogeneous sub–sample, increases data precision, and reduces the standard errors of the estimates. The results of this robustness check can be found in Table 6 in the appendix. Note that almost all qualitative findings shown in Table 3 are supported by the regression estimates based on the sub–sample in Table 6, and that the quantitative results only change marginally. As such, the estimated marginal effects are not driven by pooling all treatments for the estimations but are robust to this sub–sample composition.[10] Therefore, Hypothesis 3 is supported by the data.

> **Result 4**: Subjects' suggested cartel prices are not sensitive to variations in the fines and detection probabilities that feature the same expected punishment.

We then test Hyphothesis 5 relating to the impact of risk attitude on subjects' suggested cartel prices. In order to rule out potential biases resulting from the specification of the functional form of the risk attitude measure, we include indicator variables for the different degrees of risk aversion. Recall that we measure 6 different degrees of risk aversion using an Eckel and Grossman (2008) style risk elicitation task, and that the measure is negatively correlated with risk aversion (value 1 indicates the highest level of risk aversion). Strikingly, despite this very conservative approach of including the different levels as dummies, not a single effect is significant. Yet, it has

[10] Note that we obtain the above result in a framework that is relevant to the field and features an overproportionate increase in punishment compared to an increase in cartel profit resulting from higher overcharge. The result may therefore not be generalized to enforcement regimes that have different punishment strategies, i.e. punishment that increases linearly or underproportionately to the increase in cartel profit, which have little relevance for the field.

to be tested whether the different coefficients are jointly significant. For this, we conduct joint F–tests of the coefficients for the risk attitude indicator variables for all outcome regressions. However, in each case the joint F–test reports that the variables are jointly insignificant with p–values of 0.252 for outcome regression 46, 0.327 for 52, and 0.790 for 46/52.[11] Therefore, Hypothesis 4 can be confirmed.

Result 5: Risk attitude does not determine subjects' cartel price choices.

A possible explanation for the above result may be the length of interaction of 20 periods, which enables subjects to engage in learning about their partners' strategies through repeated interactions. This learning and the associated effects on beliefs might dominate the effects of risk attitude on choice. However, when information is limited and learning could not take place yet, subjects actions in the presence of coordination difficulties may be affected by their risk attitudes. This might be the case especially at the beginning of the game. Therefore, we re–run the same model again, but limit it to the first three periods of the game. The results stay the same and joint F–tests again indicate that the coefficients are jointly insignificant.[12]

4.2 Cartel prices reached and welfare effects

In the final part of this section, the welfare effects of endogenous enforcement are analysed both at the subject and market levels. First, we conduct a pairwise comparison of market prices and the overall proportions of cartel formation using MWU tests.[13] Although Table 2 reports that average market prices are slighlty higher in the treatments with endogenous enforcement (in particular in EndoF), the p–values shown in Table 4 suggests no significant difference in market prices across all treatments.

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

Variable		**EndoF**	**EndoD**	**BothEndo**
Market prices	**Baseline**	0.368	0.312	0.751
	EndoF		0.840	0.214
	EndoD			0.452
Prop. new agreements	**Baseline**	1.000	0.702	0.768
	EndoF		0.836	0.883
	EndoD			0.977

[11]Similarly, the risk attitude coefficients are jointly insignificant in the specification that excludes Baseline, with p–values of 0.144 for 52 and 0.579 for 46/52. Only for the choice of 46, the risk indicator variables are jointly significant (p–value 0.038). This result is driven by a single significant coefficient of Risk attitude – 4. If risk attitude indeed plays a role, then the other coefficients should be individually significant as well. We therefore do not consider this as sufficient evidence for the significance of risk attitude for price choices.

[12]The results can be found in Table 7 in the appendix.

[13]Given the instability of agreements observed in Table 2, we regard the proportion of markets with newly reached price agreements as a more insightful measure of cartel formation for this purpose. Yet, the same results arise with the alternative measure of active cartel agreements.

Similarly, the p–values suggest that the proportions of cartel formation do not differ across the treatments. Recall that with exogenous enforcement in Baseline and endogenous enforcement in the other treatments, a lack of overall differences might provide evidence for the absence of significant welfare changes induced by endogenous enforcement. Yet, this lack of differences might be due to the trade–off between frequency and composition deterrence.

To address the factors underlying this lack of difference, regression analysis on cartel price agreements reached is conducted using a multinomial logit model with random effects. The estimated average marginal effects and cluster–robust standard errors are reported in Table 5. Unlike the multi–level multinomial logit model used to analyse subjects' cartel price choices, the regression table of cartels' price choices does not feature a column for indifference between the two prices, as price agreements can only be reached on a single price. Most of the regressors in Table 5 are introduced before in the discussion of Table 3. Nevertheless, as the new regression is based on market level observations, we use *Lag market price* to instead of *Lag asking price* included in Table 3. Further, due to the market level observations, it cannot be controlled for individual subjects' past suggested cartel prices.[14]

We start with the uncertainty–driven composition deterrence, as it is our primary focus. The treatment indicator marginal effects in Table 5 suggest that, compared to Baseline, fewer cartels are formed on the high cartel price 52 in EndoD and BothEndo. As the overall proportions of cartel formation do not differ across treatments, this indicates that more cartels are formed on the low cartel price 46 in these two treatments. As such, we observe that endogenous enforcement leads to composition deterrence that, on average, reduces the cartel overcharge. A similar treatment effect is missing in EndoF, which is in line with the observation from Figure 4a that there are no large differences in the choice of 52 between Baseline and EndoF. Yet, the coefficient is only missing, *ceteris paribus*, i.e. it is possible that the treatment effect of EndoF is merely captured by other coefficients.

Given the evidence of composition deterrence in EndoD and BothEndo, *ceteris paribus*, market prices should be lower in these treatments than in Baseline. The fact that market prices do not differ significantly implies that there must be an opposing effect driving market prices up. Recall Result 1 that subjects are significantly more likely to suggest cartel price 46 in the treatments with endogenous enforcement than in Baseline. It appears that endogenous enforcement renders collusion on 46 so attractive that additional cartels are formed on 46 resulting in an adverse effect on frequency deterrence.

We now move on to discuss the dynamics of actual cartels prices. As shown in Table 5, the *Lag agreement* marginal effects indicate that price agreements on price 46 are persistent whereas those on price 52 are not. Furthermore, the *Lag detection* variables suggest that detection of an agreement on 46 in the previous period does not reduce the probability that an agreement is reached on 46 in this period, but significantly reduces the probability of reaching an agreement

[14]Unlike in Table 3, we do not include separate effects of cheating on prices 46 and 52 in Table 5, as covariance matrices for the marginal effects cannot be calculated if both effects are determined separately.

Table 5: Choice of price agreements - Multinomial Logit

	0	46	52
Lag Agreement on 46	-0.825^{***}	0.743^{***}	0.082
	(0.066)	(0.198)	(0.150)
Lag Agreement on 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	

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

on 52. Hence, while endogenous enforcement induces composition deterrence towards the low price with the lower riskiness of collusion, it also stabilises collusion on this price. This increased stability of collusion on price 46 constitutes a second source of adverse effects on frequency deterrence.

To conclude, we find strong evidence in support of the trade–off generated by endogenous enforcement on deterrence and welfare. First, it reduces cartel overcharges and leads to composition deterrence. Second, it increases the complexity of cartel coordination and renders reaching cartel agreements more difficult. Third, it leads to an adverse effect on frequency deterrence as it encourages additional collusion on the low cartel price. Finally, it leads to a second adverse effect on frequency deterrence as stabilises collusion on the low cartel price. The first two effects are positive for cartel deterrence and welfare, whereas the latter two are negative. As the result of these counteracting effects, market prices and the proportions of cartel formation do not differ significantly between treatments with exogenous and endogenous enforcement, and the effects of endogenous enforcement on overall cartel harm are unclear.

There are additional reasons for this lack of a clear result to arise. First, as mentioned in Section 3.2, the experiment is designed to examine the effects of strategic uncertainty on cartel price choices. Fines and detection probabilities are chosen such that the expected profitability between cartel prices 46 and 52 is equal, which allows us to focus purely on the uncertainty–driven incentives. Yet, one would expect stronger effects of endogenous enforcement if it imposes a penalty regime that leads to a relatively higher expected profitability for collusion on price 46 than on 52. Thus, as a result of the focus of this study on the indirect effects of endogenous enforcement on cartel price choices through strategic uncertainty, only lower bounds for potential overall effects of endogenous punishment on cartels are estimated. Second, the communication protocol is designed to clearly capture individual subjects' preferences for cartel prices and to measure the effects of strategic uncertainty on decision–making. This comes at the cost of rendering coordination more difficult. Alternative communication protocols such as free–form chat may be more effective in establishing and sustaining collusion, as they allow bargaining to precede cartel price choices. This is in contrast to our experimental design, in which bargaining is only possible through signalling over the course of several periods of the game.

5 Conclusion

As antitrust enforcement cannot deter cartels altogether because to do so would be prohibitively costly, composition deterrence might reduce the harm caused by cartels and therefore represents an important determinant of the overall welfare effects of antitrust laws. To better understand the properties of endogenous antitrust enforcement, this study seeks to establish its effects on composition deterrence that stem from its impact on strategic uncertainty on cartel prices. For this purpose, we conduct a laboratory experiment on non–cooperative infinitely–repeated games in which subjects engage in price competition in homogeneous goods Bertrand triopoly markets. Subjects can coordinate on prices but face the risk of being detected and fined if they collude. The experimental design and chosen parameters allow us to abstract from the profitability–driven incentives induced by endogenous enforcement and focus on the indirect effects of strategic uncertainty on subjects' decision–making. The implemented endogenous enforcement regime features an overproportionate increase in punishment compared to an increase in cartel profit resulting from higher overcharge, and gives rise to payoff–equivalent collusive equilibria that bear different levels of riskiness of collusion.

The results confirm that payoff dominance is a necessary but insufficient criterion to explain cartel prices in the presence of endogenous punishment. In line with the prisoner's other dilemma framework of Blonski *et al.* (2011) and Blonski and Spagnolo (2015), subjects' choices are found to converge to the collusive equilibrium with the lower riskiness of collusion in the presence of two Pareto–dominant collusive equilibria. This highlights the role of strategic uncertainty in a cartel's coordination problem. Overproportionately increasing punishment steers cartels towards a lower cartel price. In addition, we find that cartel price selection is insensitive to different combinations of fines and detection probabilities and is not driven by subjects' risk attitudes. Further, the results show a trade–off between increased composition deterrence and reduced frequency deterrence in the presence of endogenous enforcement. On the one hand, we find strong evidence of the strategic uncertainty–driven overcharge reducing composition deterrence. On the other hand, the frequency deterrence properties of the enforcement are reduced. This follows from the fact that cartels can self–select themselves into weaker expected enforcement by colluding on low prices only. As a result of these opposing effects and the study's focus on the indirect effects through strategic uncertainty, the overall welfare effects of endogenous enforcement remain unclear.

Future research should study the trade–off between frequency and composition deterrence in the context of cartels further. Although a large body of literature exists for the two forms of deterrence, little is known about how they interact under different enforcement regimes. For example, while the enforcement featured in our study focuses purely on uncertainty–driven effects, the trade–off may differ when profitability–driven effects are present as well. Several studies (e.g. Alm *et al.*, 1992, 1995) have found that subjects do not react to punishment in accordance to its functional form. Therefore, the observed behaviour might differ from the best behaviour as predicted by theory.

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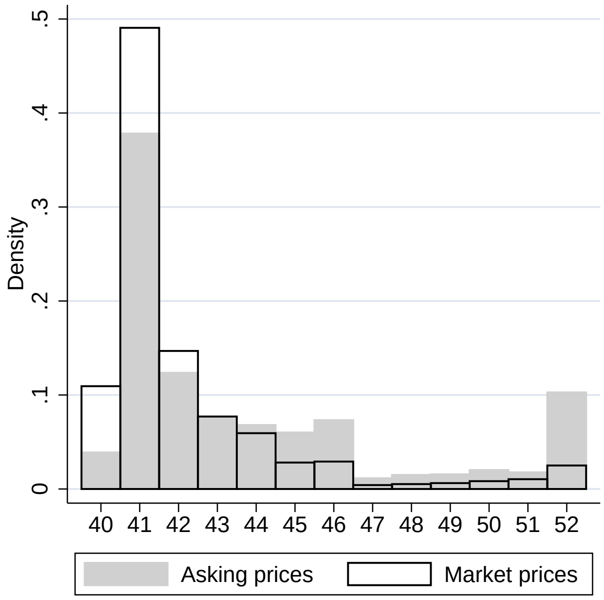
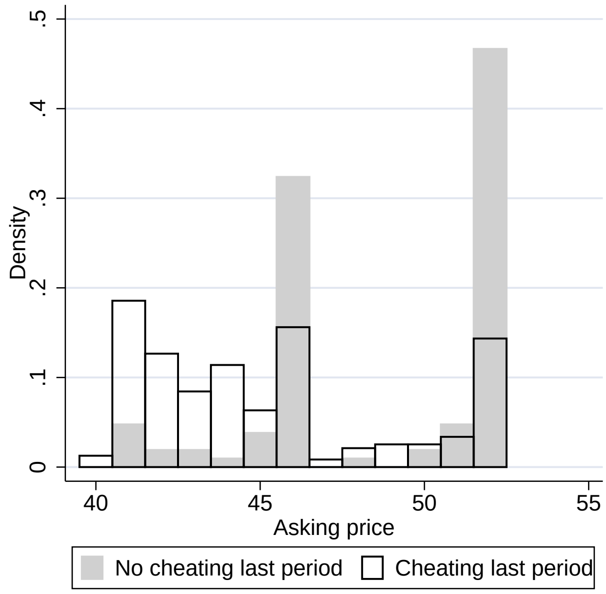
6 Appendix

6.1 Figures

Figure 5: Choice of prices



(a) Asking and market prices



(b) Asking prices and previous cheating

Figure 5a plots the distribution of both asking and market prices across treatments in the first 20 periods. As can be seen, homogeneous goods price competition and cheating leads market prices to be below the asking prices. As stated above, the predominant price set by individuals is 41, which is the non-cooperative equilibrium marked by coordination failure that yields positive payoffs for all subjects. Despite the cartel prices of 46 and 52 that can be agreed on, other prices such as 45 or 51 are set as well. The reason for this becomes clear in Figure 5b, which plots the asking prices dependent on whether cheating occurred in the previous period on a price agreement that was reached in the same period. Remarkably, although many agreements were reached on 52, cheating primarily leads subjects to charge prices in the range between 41 and 45. In other words, subjects that deviate from agreements on price 52 tend to undercut prices by charging prices below the low cartel price of 46.

6.2 Tables

Table 6: Suggested cartel agreement excluding Baseline – Multi-level multinomial logit results

	0	46	52	46/52
Lag asking price	0.004	0.002	0.004	-0.010^{**}
	(0.003)	(0.001)	(0.003)	(0.004)
Lag lowest seller	-0.045	0.018	0.000	0.027
	(0.033)	(0.020)	(0.022)	(0.023)
Lag agreement 46	-0.126	-0.039	0.101	0.064
	(0.147)	(0.074)	(0.100)	(0.107)
Lag agreement 52	0.039	-0.109^{***}	0.039	0.031
	(0.076)	(0.025)	(0.036)	(0.074)
Lag choice 46	-0.227^{***}	0.172^{***}	-0.028	0.082^{**}
	(0.046)	(0.032)	(0.034)	(0.036)
Lag choice 52	-0.321^{***}	0.063^{*}	0.120^{***}	0.138^{***}
	(0.030)	(0.027)	(0.037)	(0.056)
Lag choice 46/52	-0.443^{***}	-0.072^{***}	-0.058^{*}	0.573^{***}
	(0.052)	(0.023)	(0.035)	(0.068)
Lag detection 46	0.140^{**}	-0.029	-0.013	-0.098^{***}
	(0.068)	(0.044)	(0.059)	(0.033)
Lag detection 52	0.106	-0.035	-0.041	-0.066
	(0.084)	(0.035)	(0.029)	(0.060)
Lag cheating 46	0.181	0.033	-0.109^{***}	-0.104
	(0.166)	(0.121)	(0.037)	(0.069)
Lag cheating 52	-0.095^{*}	0.197^{**}	-0.066^{***}	-0.035
	(0.055)	(0.083)	(0.018)	(0.056)
EndoD	-0.029	0.055	0.055	-0.081^{*}
	(0.074)	(0.041)	(0.057)	(0.046)
BothEndo	0.070	-0.003	0.020	-0.086^{**}
	(0.070)	(0.041)	(0.056)	(0.040)
Period	0.015^{***}	-0.002	-0.008^{***}	-0.005
	(0.003)	(0.002)	(0.002)	(0.002)
Automatic price 52	-0.010	0.011	-0.041	0.040
	(0.054)	(0.033)	(0.042)	(0.045)
Risk attitude – 2	-0.019	0.022	0.031	-0.034
	(0.112)	(0.052)	(0.079)	(0.068)
Risk attitude – 3	0.037	0.026	0.027	-0.090
	(0.107)	(0.084)	(0.085)	(0.075)
Risk attitude – 4	-0.278^{**}	0.213^{**}	0.121	-0.056
	(0.085)	(0.085)	(0.115)	(0.074)
Risk attitude – 5	0.007	0.058	-0.009	-0.056
	(0.152)	(0.118)	(0.100)	(0.070)
Risk attitude – 6	-0.004	0.048	-0.056	0.012
	(0.112)	(0.078)	(0.052)	(0.087)
Pseudo-LL		-1587.218		
Observations		2052		

Notes: Values represent average marginal effects. Cluster-robust standard errors in parentheses. ***, **, and * denote 1%, 5%, and 10% significance levels. Includes only the first three periods.

Table 7: Suggested cartel agreement in the first three periods– Multi-level multinomial logit results

	0	46	52	46/52
Lag asking price	0.017*	−0.016*	−0.007	0.006
	(0.010)	(0.009)	(0.013)	(0.009)
Lag lowest seller	0.061	−0.053	−0.095*	0.086
	(0.062)	(0.053)	(0.054)	(0.060)
Lag agreement 46	0.059	−0.188***	0.297**	−0.168**
	(0.120)	(0.018)	(0.102)	(0.065)
Lag agreement 52	−0.065	−0.222***	0.361***	−0.073
	(0.104)	(0.020)	(0.127)	(0.088)
Lag choice 46	−0.227***	0.067	0.011	0.149**
	(0.049)	(0.058)	(0.073)	(0.066)
Lag choice 52	−0.355***	0.030	0.279***	0.046
	(0.043)	(0.058)	(0.066)	(0.068)
Lag choice 46/52	−0.387***	−0.136***	−0.168***	0.691***
	(0.042)	(0.036)	(0.056)	(0.060)
Lag detection 52	0.406***	−0.107**	−0.149*	−0.150**
	(0.125)	(0.045)	(0.082)	(0.066)
Lag cheating 46	−0.194***	0.709***	−0.286***	−0.229***
	(0.028)	(0.020)	(0.031)	(0.075)
Lag cheating 52	−0.215***	0.658***	−0.239***	−0.204***
	(0.035)	(0.022)	(0.036)	(0.032)
EndoF	0.076	−0.020	−0.088	0.032
	(0.068)	(0.066)	(0.065)	(0.056)
EndoD	0.011	0.161**	−0.075	−0.098*
	(0.068)	(0.076)	(0.054)	(0.054)
BothEndo	0.001	0.203***	−0.117*	−0.086**
	(0.075)	(0.077)	(0.067)	(0.044)
Period	0.073	−0.082**	−0.015	0.025
	(0.048)	(0.037)	(0.057)	(0.044)
Automatic price 52	0.004	−0.003	−0.047	0.046
	(0.040)	(0.039)	(0.046)	(0.042)
Risk attitude – 2	0.009	0.059	0.019	−0.087
	(0.070)	(0.083)	(0.081)	(0.060)
Risk attitude – 3	0.068	−0.056	−0.038	0.026
	(0.087)	(0.072)	(0.076)	(0.080)
Risk attitude – 4	−0.196***	0.146	0.101	−0.052
	(0.066)	(0.102)	(0.090)	(0.059)
Risk attitude – 5	−0.020	0.063	0.008	−0.051
	(0.076)	(0.095)	(0.104)	(0.061)
Risk attitude – 6	0.019	0.086	−0.022	−0.083
	(0.084)	(0.094)	(0.077)	(0.058)
Pseudo-LL		-296.673		
Observations		288		

Notes: Values represent average marginal effects. Cluster-robust standard errors in parentheses. ***, **, and * denote 1%, 5%, and 10% significance levels. Includes only the first three periods.

6.3 Instructions: BothEndo treatment – automatic price of 52

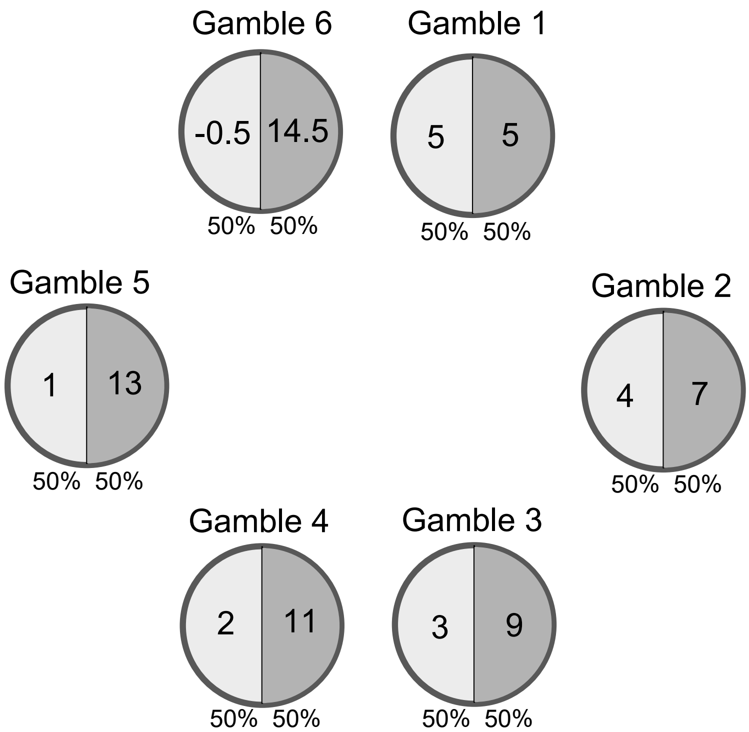
Instructions

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

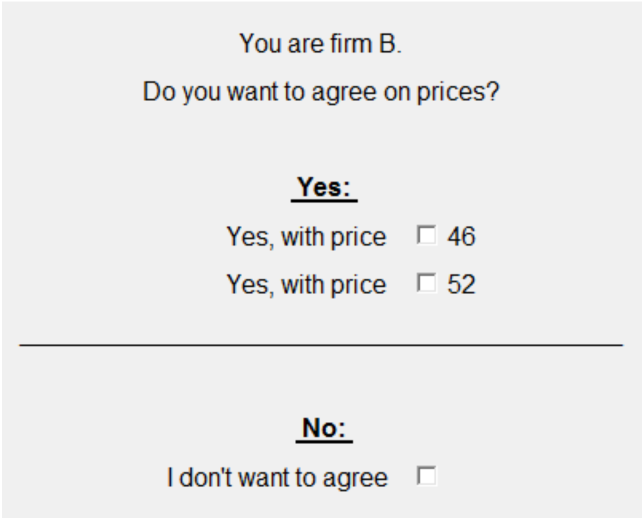
You will only sell the product if the other firms do not set a lower price than you in that round. If you sell the product, your earnings are equal to the difference between the price and the cost, which is 40:

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	

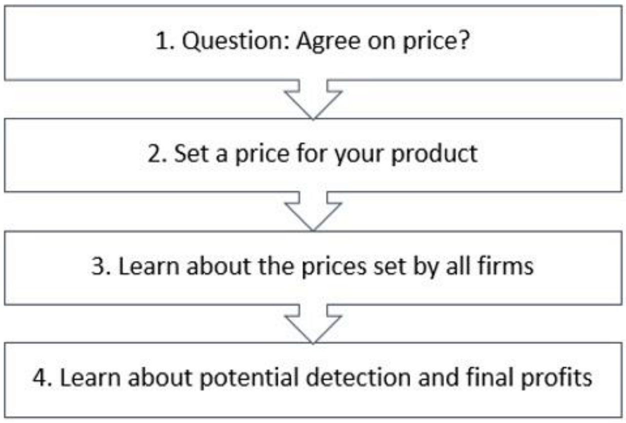
After deciding whether you would like to form a price agreement, you have to set a price by filling the "Choose a price" box shown below. If a price agreement is reached, a message will appear above the "Choose a price" box showing the price that you agreed on. If no price agreement is reached in that 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:

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.