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The critical discount factor as a measure for cartel stability?

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Abstract This paper considers the stability of tacit collusion in price setting duopolies with repeated interaction. The minimum discount factor above which tacit collusion can be sustained in a subgame perfect equilibrium is called the critical discount factor δ^*. In addition, δ^* is often used as an intuitive measure for the stability of a tacit cartel, assuming that a collusive equilibrium is more difficul to sustain when δ^* increases. However, according to standard theory the distance $\delta - \delta^*$ between the actual and the critical discount factor does not matter for stability as long as $\delta > \delta^*$. This paper contributes experimental evidence that supports the intuitive idea that a larger critical discount factor makes collusion a less likely outcome.

1 Introduction

We consider the pricing behavior of firm in an infinitel repeated Bertrand oligopoly. Usually explicit price agreements in such a market are prohibited by law, but often firm do nevertheless manage to coordinate their pricing strategies with less obvious methods. Consider for example the German electricity market, with firm managing to realize notable markups although their pricing is closely observed by the cartel authority. In such cases, when coordination of prices takes place in a more 'mysterious' way, we speak of tacit collusion. The discount factor, that firm apply to their future profit plays a crucial rule for the stability of such tacit agreements. Stable collusion is

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only possible if cartel members attach a sufficientl high value to their future earnings. Thus, we can derive a minimum discount factor above which collusion can be sustained in a subgame perfect equilibrium. This minimum discount factor is called δ^*. In the literature, δ^* is often additionally used as a measure for the stability of tacit agreements.[1] As δ^* increases, a collusive equilibrium is usually assumed to be more difficul to sustain. This characterization of the impact of a changing critical discount factor is specifie by Symeonidis (2002): 'a standard way to examine the impact of exogenous factors on cartel sustainability […] is to examine the comparative static properties of the critical discount factor δ^*. In particular, a change in any exogenous variable that causes δ^* to increase makes collusion less likely, since collusion is then sustainable for a smaller set of deltas.' There are several experiments on Bertrand as well as Cournot competition, considering various market design variables with respect to their influenc on stability of collusive behavior. When analyzing the impact of all those factors most of them implicitly presume that the critical discount factor comprises a measure for stability of cooperative behavior in the market. In theory, however, the critical discount factor should only matter for firms behavior in so far as collusion is a sustainable outcome when their actual discount factor δ is larger than the critical δ^*, but not when it is smaller (see Fig. 1). According to the theory, we expect collusion to be stable when δ is above δ^*. As long as this condition holds the constraint on the critical discount factor is not binding. Conversely, as soon as δ is below δ^* no collusion should be possible. Assuming perfectly rational agents, the size of the distance between the actual discount factor and its critical value should not matter at all. Either pricing agreements are stable or they are not, but theory does not defin a 'degree' of stability.[2] A change in the critical discount factor δ^*, in the literature often treated as a measure of cartel stability, does per se have no impact on the extent of tacit collusion. This holds as long as the increase in δ^* is small enough so that δ is after the change still larger than δ^* (if the change was so drastic that δ would afterwards be below δ^*, then, of course, collusion should no longer be an equilibrium at all).

This study provides experimental evidence that in fact there is a 'degree' of stability which is lower when the critical discount factor δ^* increases. It will present two treatments of a pricing duopoly experiment in which we manipulate the value of δ^* such that $\delta^* < \delta$ always holds. The modificatio we make between the two treatments can be interpreted as a varying degree of product differentiation. We will show that, in contrast to standard theory, deviations from a collusive outcome occur significantl more often if δ^* is larger. Intuitively, we can think of the difference $\delta - \delta^*$ as a measure for human agents' 'temptation' to deviate from cooperative behavior. The larger this difference the smaller is the incentive to deviate. For $\delta - \delta^* > 0$ theory predicts collusion being a self-enforcing equilibrium, no matter how large the distance is. A

1 One empirical example for this statement is the Nestle–Perrier case considered by Compte et al. (2002). Against the background of the merger of two large French suppliers of mineral water they demonstrate how varying capacities through mergers influenc the stability of collusion. Within this context an increase in the critical discount factor is considered as a measure of less stability.

2 The same could be tested for the opposite case where δ is always below δ^*. Here we would expect cooperation not to be stable in both cases. However, in the case of a higher critical discount factor (with a larger distance to the actual δ) it could be that cooperative attempts are more likely to succeed.

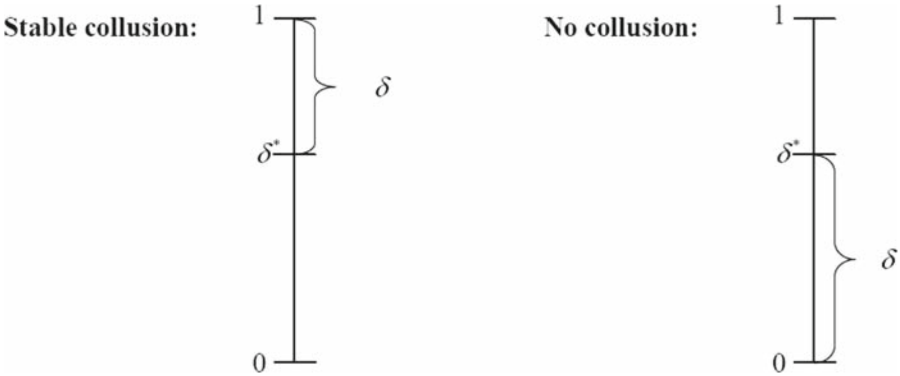

Fig. 1 Stability of tacit collusion depending on discounting

deviation from price collusion causes a high gain in the current period, because the fir can attract more customers, but it leads to losses in the future, because the other fir will decrease its price, too, and regain its market share. Continuous cooperation, on the contrary, leads to constant moderate profits A small difference between δ and δ^* means that also the difference between the profit following the decision to deviate or to continue cooperation is small. Therefore, the prospect of a large short run gain might then suffic to induce an agent to deviate, although it does not pay off in the long run. This attractiveness of the high short run profi is more tempting if the difference $\delta - \delta^*$ is small and, thus, when δ^* is large.

2 Theoretical background

The work probably closest to ours is a study of Feinberg and Husted (1993), which considered the critical delta experimentally in a Cournot environment. They show that collusive equilibria occur more often the more future profit are worth. However, their experiment differs in various aspects from what we want to show. The main difference is that they modify δ in such a way that collusion is only an equilibrium in one of their treatments but not in the other. In our experiment, in contrast, we focus on the comparison of two settings that theoretically should both be stable, because δ is always above δ^*. Second, Feinberg and Husted keep the critical discount factor constant whereas actual discounting is manipulated. In our study actual discounting will stay the same while δ^* varies. Finally, their experiment considers a simple repeated prisoners' dilemma. This is a strong simplificatio of the Cournot model since participants can only chose between two different actions, cooperation and non-cooperation. We will extend the choice set and include more options. Similar comments hold for a paper of Chincarini (2003) who concentrates on trigger strategies, varying the continuation probability p instead of the discount rate δ. He find that trigger strategies are only applied (in about 30% of the cases) when p is larger than a critical value p^c.

In order to consider the role of the critical discount factor in more detail, we select a different experimental design. To keep interaction as simple as possible, we maintain the duopoly framework. The new idea is to compare two similar treatments of a price-setting game that should theoretically both yield the same cooperative outcome. Behavior of perfectly rational agents should not differ between treatments as long as δ^* is sufficientl low (lower than the actual 'patience'-parameter δ) because the game they are playing is independent of the distance between δ and δ^*. If, in contrast, the critical discount factor indeed has the intuitive impact on the behavior of human agents, the treatments should yield different outcomes in a way that a higher δ^*, although still below δ, leads to less cooperation.

Looking for a theoretical frame for the experiment, the standard Bertrand supergame is not the most appropriate model because it exhibits a problem with multiplicity of equilibria. Depending on the strategy formation, each equilibrium profi between the Walrasian outcome (Bertrand–Nash-equilibrium with prices equal to marginal costs) and joint profi maximization is a possible equilibrium in the repeated game. Since participants are free to choose any price they want and since they are playing for several rounds, the possible set of equilibria is overwhelming (Shapiro 1989). Without a clearly define strategy assumption, however, discount factors cannot even be calculated. Theory often simplifie the oligopoly situation to the two-choice prisoners' dilemma game and considers only trigger strategies. Cooperation then means joint profi maximization and a deviation yields the strongest punishment possible, the pure Bertrand–Nash equilibrium with zero profits If the game is repeated infinitel , of course, all outcomes between those extremes are also possible equilibria. Thus, strategies and resulting equilibria in the repeated game are again not clearly define and the problem remains that we cannot calculate a unique δ^*. As can be seen from the Chincarini (2003) paper, trigger strategies are only adopted in about 30% of the cases in such an experiment. Thus, there remain 70% of the observations which cannot be classifie into this simple category.

To reduce multiplicity of equilibria, Maskin and Tirole (1988) offer an interesting approach. They present a sequential move framework, which has some useful properties the Bertrand supergame lacks. In sequential games, the key results concerning the critical discount factor in infinitel repeated games are the same as in simultaneous Bertrand competition (Tirole 1988). However, sequential play allows restricting participants' behavior to Markov strategies and therefore reduces possible equilibria to a smaller set. Intuitively, a fir does not have to build beliefs about the other firm s price decision in the following period to optimize its behavior because it is in this period the only one deciding about its price.[3] According to the Markov restriction Maskin and Tirole impose, players' strategies depend only on profit-rel vant state variables. In a sequential game the state can simply be define as the opponent's price in the previous period as this is the only profi relevant information determining a firm s pricing decision. Consequently, firms reaction to a certain price has always to be the same. The Markov assumption in a sequential game makes equilibrium analysis much easier. It is neither necessary to care about firms beliefs about their opponent's behavior nor does history more than one period ago matter. Moreover, multiplicity of

[3] This is similar to the inertia introduced in the game by Huck et al. (1999). The idea of sequential moves in a Bertrand model is in fact not very revolutionary since there are already experiments that introduced inertia into pricing oligopolies. From inertia, it is only one step further to actual sequential moves.

equilibria decreases drastically since the set of possible profit can be restricted to a tighter interval (see Propositions 3 and 7 in the Maskin and Tirole paper). Of course, Markov is a somewhat restrictive assumption. In the real world—and similarly in an experimental environment—trust and path-dependence are likely to play a major role. The experimental test of the model will show, however, that this simplificatio is reasonable.

The basic idea of the Maskin and Tirole model is as follows: in an infinit horizon sequential duopoly game, two firm $(i = 1, 2)$ compete in prices. In odd-numbered periods, fir 1 chooses its price, whereas in even-numbered periods fir 2 sets prices. Thus, each fir is limited to change its price in every second period and to leave it unchanged for the subsequent period. The total industry profi in each period depends on price p, costs c, and demand $D(p)$:

$$\Pi(p) \equiv (p - c) \cdot D(p).$$

Consumers buy from the cheapest supplier, thus individual profit are determined as a function of prices:

$$\Pi^i(p_t^1, p_t^2) = \begin{cases} \Pi(p_t^i) & \text{if } p_t^i < p_t^j \\ \Pi(p_t^i)/2 & \text{if } p_t^i = p_t^j \\ 0 & \text{if } p_t^i > p_t^j. \end{cases}$$

Future profit are discounted with factor δ. Intertemporal profi is therefore

$$\sum_{s=0}^{\infty} \delta^s \cdot \pi^i \left(p_{t+s}^1, p_{t+s}^2 \right).$$

Markov perfect equilibria within this framework are derived as pairs of dynamic reaction functions (R^1, R^2) for all prices $\hat{p}$. R^1 gives the best reply if fir 1 is about to move, whereas R^2 is (from fir 1's point of view) the distribution of best reply strategies of fir 2. Both reaction functions are based on valuation functions for all possible price decisions. These valuations are for fir 1

$$V^1(\hat{p}) = \max_p \left[\pi^1(p, \hat{p}) + \delta \cdot W^1(p) \right],$$

if it is fir 1's turn to move and fir 2's current price is $\hat{p}$ and

$$W^1(\hat{p}) = E_p \left[\pi^1(\hat{p}, p) + \delta \cdot V^1(p) \right],$$

if last period fir 1 played $\hat{p}$ and fir 2 is about to move.

$V^1(\hat{p})$ gives fir 1's present discounted profi of choosing p and $W^1(\hat{p})$ is fir 1's valuation of the current situation if fir 2 is about to move while fir 1 is still bound to the price it set in the period before. For fir 2 symmetric conditions hold.

As long as the discount factor is sufficientl high two different types of equilibria are possible within the model, focal price equilibria and Edgeworth cycles: in a focal price equilibrium, the pair of strategies (R^1, R^2) results in pricing behavior, where it is optimal for both firm to collude at the focal price (for example, the monopoly price). At any price above, the focal price is a best reply, whereas at any price below, firm sooner or later revert to collusion, probably after some 'punishment' phase. Edgeworth cycles are cyclical price patterns where firms starting from a very high price level, successively undercut each other until the price war becomes too costly and then return to a price above the monopoly level.

Additionally to the Markov restriction to firms behavior Maskin and Tirole require a stable equilibrium to be renegotiation-proof and, thus, to suffic stronger conditions than pure subgame-perfection. A Markov perfect equilibrium is therein called renegotiation-proof, if there exists no other equilibrium that Pareto-dominates it.[4] In our tacit collusion framework, this idea refers to situations in which firm might have an incentive to reconsider the strategies they committed to, for example after a defection from cooperation. If we require renegotiation-proofness we do not allow strategies implying firm being tempted to change their mind at any point of time. The requirement of renegotiation-proofness disqualifie most equilibria in the sequential price game. Neither focal price equilibria asides monopoly pricing nor Edgeworth cycles are robust against the temptation to renegotiate because they are Pareto-dominated by strategies that lead to the monopoly price as focal price. Thus, Maskin and Tirole show that the simple monopoly price equilibrium is the only one that is renegotiation-proof[5] so that neither fir would prefer to establish any other level of collusion (see Proposition 6 of their paper). Of course, the unique renegotiation-proof equilibrium strategy for completeness also has to contain a reaction to prices that never occur. In detail, it comprises the following pair of symmetric strategies:

- Set the monopoly price p^m if the other fir did so in the previous period.
- If the other fir deviates, set a price of $\underline{p}$.
- If the other fir set $\underline{p}$, return to p^m.

The minimum price $\underline{p}$ is determined in a way that it satisfie $4 \cdot \Pi(\underline{p}) \geq \Pi(p^m) > 4 \cdot \Pi(\underline{p} - k)$ with k being the (sufficientl fine price grid.

The renegotiation-proof focal price equilibrium concept of Maskin and Tirole is appropriate to illustrate tacit collusion. First, it contains a unique renegotiation-proof

[4] Van Damme (1989) already introduced renegotiation-proofness into a repeated prisoners' dilemma game. He applies a similar concept of renegotiation-proofness and shows that the multiplicity of equilibria can be reduced to a smaller set. However, his approach is a different one than that of Maskin and Tirole. Both have in common that they name a pair of strategies renegotiation-proof if it automatically leads to a payoff path where at no stage the payoff is dominated by another reaction than prescribed by the strategy. In the simultaneous-move framework of Van Damme this requires that all intermediate equilibria on the payoff path have to be renegotiation-proof, too. There are many different possible equilibria, all of which are renegotiation-proof.

[5] Van Damme's definitio is a weaker one, because it requires only internal consistency. That is, in his model a renegotiation-proof equilibrium can be dominated by another equilibrium and nevertheless be renegotiation-proof. The dominance-criterion of Maskin and Tirole includes also external dominance so that for a renegotiation-proof equilibrium any other equilibrium that Pareto-dominates the renegotiation-proof one does not even exists.

Table 1 Industry profit depending on the minimum price

Price	0	1	2	3	4	5	6	7	8	9	10
Industry profi	0	18	32	42	48	50	48	42	32	18	0

equilibrium outcome, namely collusion at the monopoly price. Thus, it precisely predicts equilibrium behavior in a way that upcoming deviations, which are in the original center of interest, can be clearly observed. Second, it nevertheless contains a detailed prediction of the reaction in case of a deviation. The collusive equilibrium can be reached again when one fir for whatever reason started a price war. Even in this situation, both firm profi from relenting themselves. However, none of the firm has an incentive to deviate from the focal price since for a sufficientl high discount factor the best reply to the monopoly price is also the monopoly price.[6] Edgeworth cycles will be ignored in our study since the concept has been shown not to generate renegotiation-proof equilibria. Thus, the model by Maskin and Tirole fit very well for an experiment testing whether a change in the critical discount factor influence the stability of tacit collusion.

3 A numerical example

For the experimental implementation, we derive a numerical example from the Maskin and Tirole model. We conduct a sequential pricing duopoly according to their model with a special parametrization that fit our discount factor requirements. In order to enable participants in the experiment to get an overview of their choice set in reasonable time, the price set is restricted to the integers [0; 10].[7] From Maskin and Tirole's assumptions industry profit have to be strictly concave. The profi function of the experiment is based on linear demand $D(p) = 2 \cdot (10 - p)$. Costs are assumed to be zero. Thus, industry profit depending on prices are as in Table 1.

Products are homogeneous so that consumers always buy from the cheaper firm If both firm charge the same price, demand (and therefore aggregate profit is shared equally. Although only one fir at a time is allowed to adjust its price, profit in each round are calculated according to a Bertrand situation. For the 'waiting' firm its price decision from the previous round still holds. In our example, the unique renegotiation-proof equilibrium mentioned above consists in strategies of the two firm that lead to

[6] From a behavioral point of view, the idea of renegotiation-proofness is a reasonable assumption because the outcome it predicts is supported by other experimental research concerning efficien y. As long as only the supplier side of the market is modeled and no consumers suffer from higher prices in our experiment, collusion at the monopoly price is in our framework the most efficien outcome. As earlier experiments have shown (Engelmann and Strobel 2004; Charness and Rabin 2002), participants in experiments attach high value to maximization of total payoff. Thus, if people are concerned about efficien y in general, their optimal strategy will lead them to monopoly pricing, too.

[7] This price grid is not fin enough to support all properties of the underlying theoretical model. In particular, it undermines the proof of existence of a lower bound for equilibrium focal prices for pure strategies. The restriction of the price set is nevertheless justifiabl since the unique renegotiation-proof equilibrium, this work will concentrate on, does not need this particular proof.

Table 2 Markov reaction functions depending on prices in the repeated game

Price	0	1	2	3	4	5	6	7	8	9	10
Best reply	5	$\begin{cases} 1 \text{ with prob } \alpha \\ 5 \text{ with prob } 1-\alpha \end{cases}$	1	1	1	5	5	5	5	5	5

coordination at $p = 5$. Equilibrium strategies are illustrated by the symmetric reaction functions $R(p)$ in Table 2.

Suppose the firs moving fir 1 chooses a price of 5. In the second period, fir 2 can decide whether it wants to cooperate or to start a price war. In the case of tacit collusion, both firm set a price of 5 and share the monopoly profi of 50 equally. Doing this forever and discounting their profit with δ, their intertemporal profi is equal to $25 \cdot \frac{1}{1-\delta}$. If fir 2 for whatever reason decides to start a price war in period 2, it underbids fir 1 by choosing a price of 4 and, thus, faces a profi of 48. In the next period, fir 1's best reaction is to undercut its opponent drastically by setting a price of 1 (see Appendix A for a proof of this reaction being optimal) so that fir 1 receives 18, whereas fir 2 receives zero profit Intuitively, this drastic reaction is reasonable because it shortens the time without cooperation. Otherwise, firm would spend some rounds with relatively low prices while sequentially undercutting each other, which results in lower profit than the immediate reversal to cooperation. This idea is similar to the 'punishment' threat in Bertrand supergames that deters a firm s opponent from undercutting. Suppose now the firm arrive at $p = 1$. Further undercutting is no profitabl option,[8] since in this case the undercutting fir would face a profi of zero instead of 9 when continuing with a price of 1. It can better returns to the monopoly price, receiving zero profi in the next round, but afterwards gaining from collusion again. For a smaller δ the return to monopoly pricing becomes less attractive. In this case, both firm would still like to collude again, but each fir would prefer the other one to return first Therefore, it may happen that firm do not revert immediately but after a short price war. Maskin and Tirole illustrate the war of attrition that is played in such a situation. If one fir could credibly commit itself never to revert to monopoly pricing, this would make the other fir concede. However, this announcement would not be credible since—if the other fir was actually not impressed by the threat—the firs fir would be tempted to reconsider its commitment one period later. Therefore, the only renegotiation-proof strategy in this situation is playing mixed strategies. Each fir relents (sets the monopoly price) with probability $1-\alpha$ and continues the price war with probability α. α is selected in such a way that the *other* fir is just indifferent between relenting and not relenting itself. Thus, expected payoffs to a fir from relenting and further low-pricing have to be equal. Continuing the price war yields a fir a profi of $9 + \delta \cdot W_1$, whereas returning to the monopoly price leads to a profi of $25 \cdot \frac{\delta}{1-\delta}$. For indifference, profit resulting from each decision have to be equal:

$$25 \cdot \frac{\delta}{1-\delta} = 9 + \delta \cdot W_1,$$

[8] This can be derived from the condition that $\underline{p}$ has to satisfy $4 \cdot \Pi(\underline{p}) \geq \Pi(p^m) > 4 \cdot \Pi(\underline{p} - k)$, which here turns out as $4 \cdot 18 > 50 > 4 \cdot 0$. For this condition to hold the used price grid is fin enough.

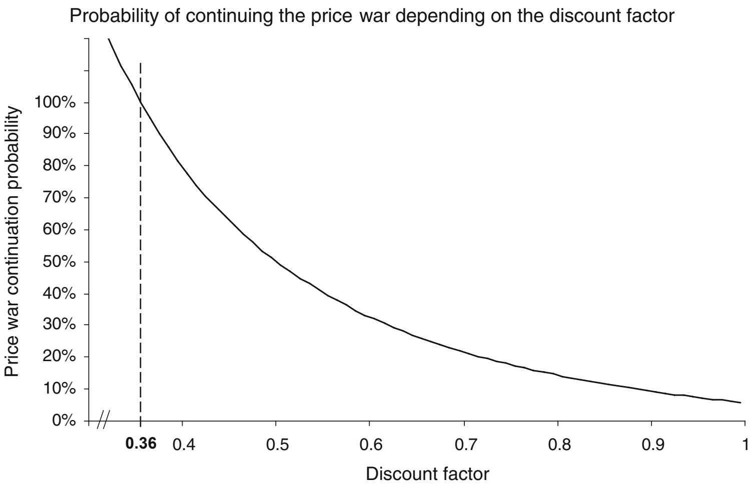

Fig. 2 Probability of continuing the price war depending on δ

where W_1 is the expected payoff of a fir if the opponent plays mixed strategies,

$$W_1 = \alpha \cdot \left[9 + 0 \cdot \delta + 25 \cdot \frac{\delta^2}{1-\delta}\right] + (1-\alpha) \cdot \left[18 + 25 \cdot \frac{\delta}{1-\delta}\right].$$

With probability α the opponent continues the price war in the next period. In this case, the firs fir is again indifferent between relenting and further low-pricing and we can assume that the firs fir will relent itself in the next but one period. Thus,

$$25 \cdot \frac{\delta}{1-\delta} = 9 + \delta \cdot \left\{\alpha \cdot \left[9 + 25 \cdot \frac{\delta^2}{1-\delta}\right] + (1-\alpha) \cdot \left[18 + 25 \cdot \frac{\delta}{1-\delta}\right]\right\}$$

From this equation α can be derived as a function of delta with

$$\alpha(\delta) = \frac{9 - 7\delta}{9\delta + 25\delta^2}.$$

For high values of δ (when future profit are highly valued) α is low because the incentive to re-cooperate is large, whereas for a decreasing discount factor the probability to continue low-pricing is higher. For δ below 0.36 firm would never revert to p^m. Figure 2 shows the continuation probability of a price war for different values of δ.

We now come back to the initial decision problem of a colluding fir whether to deviate from collusive monopoly pricing or not. Suppose, fir 2 has to choose between undercutting to $p = 4$ and continuing collusion with $p = 5$.

Collusion in our model yields half the monopoly profi forever and therefore

$$\pi_c^i = 25 \cdot \frac{1}{1-\delta},$$

Table 3 Modifie payoff table for prices between 0 and 5

The fir with the lower price faces payoffs according to the standard profi function as in the baseline treatment. The fir with the higher price, in contrast, receives a positive payment instead of zero

Price B	Price A						
	0	1	2	3	4	5	…
0	0	1	4	7	10	13	
	0	0	0	0	0	0	
1	0	9	1	4	7	10	
	1	9	18	18	18	18	
2	0	18	16	1	4	7	
	4	1	16	32	32	32	
3	0	18	32	21	1	4	
	7	4	1	21	42	42	
4	0	18	32	42	24	1	
	10	7	4	1	24	48	
5	0	18	32	42	48	25	
	13	10	7	4	1	25	
⋮							

whereas undercutting results in a profi of

$$\pi_u^i = 48 + 0 \cdot \delta + 0 \cdot \delta^2 + 25 \cdot \frac{\delta^3}{1-\delta}.$$

Thus, cooperation is profitabl if

$$25 \cdot \frac{1}{1-\delta} \geq 48 + 25 \cdot \frac{\delta^3}{1-\delta}$$

which holds approximately for $\delta > 0.58$.

To investigate the effect of a higher δ^*, firm s payoffs are modifie such that the δ^* of the game increases. This is basically done by introducing another treatment where the fir with a higher price than the other receives a positive payment instead of zero. Table 3 summarizes the payoff modificatio in the relevant area of prices between 0 and 5. A rough intuition for such a payoff modificatio is a situation with product differentiation. In the light of Deneckere (1983) our choice of parameters in the modifie case represents the following situation: the fir with the lower price continues to sell the original product, whereas the other fir now sells a relatively close complement to the original product at a higher price.[9] In line with Deneckere's results, the critical discount factor that is necessary for self-enforcing tacit collusion increases with differentiation. Intuitively, this modificatio increases the temptation of human decision makers to deviate, because the costs of the price war after a deviation decrease.

[9] Profit of the high-price fir in our modifie payoff table do not strictly follow a product differentiation model but are rather simply linear in the difference between the two prices.

In theory such a modificatio should nevertheless not influenc rational agents' behavior as long as the actual discount factor is sufficientl high, because the option to deviate is rather hypothetical. Cooperation remains the optimal payoff-dominant renegotiation-proof strategy and deviations should theoretically not occur in both treatments. The best reply strategies for the new situation remain the same as before.

Gains from colluding and undercutting, respectively, can be calculated as before. Individual collusive profi π_c^i in each period remains the same whereas the profi from undercutting is now given by

$$\pi_u^i = 48 + \delta \cdot 7 + \delta^2 \cdot 10 + 25 \cdot \frac{\delta^3}{1-\delta}.$$

This has two implications. First, it makes the war of attrition disappear because α , the probability of continuing a price war, is below zero for all possible values of δ. Thus, $\alpha(\delta) = \bar{\alpha} = 0$ and firm return to monopoly pricing immediately from a price level of $p = 1$. Second, deviating becomes more attractive. Cooperation is now profitabl if

$$25 \cdot \frac{1}{1-\delta} \geq 48 + \delta \cdot 7 + \delta^2 \cdot 10 + 25 \cdot \frac{\delta^3}{1-\delta},$$

which only holds approximately for $\delta > 0.78$. Thus, the critical discount factor that is necessary for stable collusion is higher than in the basic treatment. We will call the basic situation with $\delta^* = 0.58$, where the fir with the higher price faces zero profit treatment LOW. The second treatment, where payoffs are modifie according to Table 3, is called HIGH. The actual discount factor in both treatments is assumed to be 1. This is reasonable since participants in our experiment receive their total payment at the end of the experiment. Thus, the actual discount factor δ is higher than δ^* in both treatments. We expect, however, that the temptation to deviate from cooperative monopoly pricing increases in the modifie treatment and, thus, that more deviations occur in this treatment. The intuition for the higher temptation to deviate becomes clear when we compare the costs of a deviation in both treatments taking the profit from collusion in each round as a reference point. In LOW, the expected costs of a deviation for the deviating fir depend on the duration of the war of attrition. The expected value of the costs of a deviation, $\pi(\text{dev}) - \pi(\text{col})$, is equal to

$$\begin{aligned}
&\underbrace{48-25}_{p_1=4;p_2=5} + \underbrace{0-25}_{p_1=4;p_2=1} + (1-\alpha)(\underbrace{10-25}_{p_1=5;p_2=1}) + \alpha(\underbrace{9-25}_{p_1=1;p_2=1}\\
&\quad + (1-\alpha)(\underbrace{18-25}_{p_1=1;p_2=5}) + \alpha(\underbrace{9-25}_{p_1=1;p_2=1}) + \cdots \\
&= 23 - 25 - 25(1-\alpha)(1+\alpha^2-\alpha^4+\cdots) - 16(\alpha+\alpha^2+\alpha^3+\cdots) \\
&\quad -7(1-\alpha)(\alpha+\alpha^3+\alpha^5+\cdots) \\
&= 23 - 25 - 25\frac{1}{1+\alpha} - 16\frac{\alpha}{1-\alpha} - 7\frac{\alpha}{1+\alpha}
\end{aligned}$$

For $\delta = 1$ the probability to continue a price war is equal to $\alpha(\delta = 1) = \frac{1}{17}$ so that the expected costs of a deviation are equal to $\pi(\text{dev}) - \pi(\text{col}) = -27$ in LOW. In HIGH, there is no war of attrition ($\alpha = 0$) and the costs of a deviation are straightforward: compared to the profit of collusive monopoly pricing a deviation yields costs of

$$\pi(\text{dev}) - \pi(\text{col}) = \underbrace{48 - 25}_{p_1 = 4;\, p_2 = 5} + \underbrace{7 - 25}_{p_1 = 4;\, p_2 = 1} + \underbrace{10 - 25}_{p_1 = 5;\, p_2 = 1} = -10$$

We see that the costs of a deviation are smaller in HIGH than LOW and therefore the temptation to deviate is harder to resist in HIGH with $\delta^* = 0.78$.

4 Experimental design

We compare two treatments of the sequential price game with different δ^*'s. In both treatments the actual δ is above δ^* so that collusion should be stable both times. The difference between δ and δ^*, however, is larger in the firs treatment than in the second one. It will be analyzed whether this difference in the critical discount factor leads to a change in stability of collusion.

In the theoretical model the time horizon was infinite For practical reasons, it is very convenient to approximate this by a long finit horizon of the experiment, because it is definitel impossible to have a forever-lasting experiment.[10] Theoretically a finit horizon implies inability to collude due to a backward induction argument: the incentive to coordinate disappears in the fina round and, anticipating this, firm fail to coordinate from the very beginning. However, experience has shown that people do not behave as predicted by the backward induction argumentation (and they also do not expect their fellow subjects to do so), but do actually cooperate in finit games almost as in infinit ones (Rosenthal 1981). Normann and Wallace (2005) show that the choice of the termination rule has no significan impact on cooperation in repeated prisoners' dilemma experiments except for an endgame effect given the known finit horizon. Transferring their conclusion our experiment is conducted with a long finit horizon of 50 rounds assuming that behavior is the same as in an infinitel repeated game until some rounds before the announced end of the game. In this paper, we proceed as follows: we divide our data for the analysis into two parts. In the (larger) firs part of the experiment we expect participants to behave as if they face a quasi-infinit horizon. The fina rounds during the second part of the experiment are treated separately because we expect endgame effects to determine the results.

In LOW, duopoly participants face the original payoff table which implies $\delta^* = 0.58$. In HIGH, a shift in the critical discount factor to 0.78 takes place whereas the actual delta of 1 remains the same. Remember that in our model—assuming perfectly rational agents—this variation in the critical discount factor should not cause

[10] Alternatively, we could have introduced a market continuation probability. We decided against this option because our intention was to observe behavior over a relatively long time horizon (implying a high continuation probability) which can hardly be implemented without losing participants' belief in the continuation probability being the same after each period. For are deeper analysis of this problem see Bruttel and Kamecke (2007).

a difference in participants' behavior. Coordination at the focal price is the only renegotiation-proof equilibrium and should be fully stable since the actual discount factor is larger than the critical discount factor. In an uncertain world with participants' motives being rather complex and not following perfect rationality, however, the difference between the two δ^*'s might be of importance. Referring to the product differentiation interpretation of treatment HIGH, the possibility to sell the differentiated product while being punished during a price war makes the consequences of a deviation less severe. Thus, behaviorally it seems not unlikely that a higher δ^* in HIGH actually leads to more deviations from the collusive outcome than in LOW. In fact, less collusion in HIGH than in LOW would confir the initial hypothesis of an observable impact of the critical discount factor's value.

The experiment is programmed and conducted with the software z-Tree (Fischbacher 2007). Participants are called type 'A' and 'B' to distinguish which of them is allowed to adjust his price in odd and even periods, respectively. Type A and B are determined randomly. The experiment is conducted with 82 participants. All of them are business and economics students but inexperienced with oligopoly experiments. 38 out of 82 participate in treatment LOW, 44 in treatment HIGH. Each session lasted less than one hour. On average, participants earned 9.62 Euros in the experiment which corresponds to an usual student hourly wage.[11] The group size varies between 8 and 12. Participants can only take part in one session. In each session, subjects are randomly matched with one of their fellow participants in a partner design. Of course, they only know that it is someone sitting in the same room as they do, but they do not know which one it is. The initial price of B is predetermined to zero so that both firm start with zero profit to avoid that fir A, given that it is allowed to set its price in the very firs round, has an advantage.

5 Results

We will now test the hypothesis that a larger critical discount factor makes collusion less stable. After a general overview of the price patterns in the experiment we will successively consider different measures for stability of collusion to test the hypothesis. We will fin that the length of cooperative sequences provides a suitable but insignifican measure. Average prices and the number of deviations during the game descriptively illustrate the result although they are not reliable indicators for the stability of collusion. We will close this section with a check whether we captured all behavioral patterns in the analysis.

5.1 General overview

The unique renegotiation-proof equilibrium strategy describes behavior quite well. Table 4 shows the frequency of reactions to each certain price. In principle, participants

[11] Several experimental studies show that high or low stakes rarely have an impact on participants' behavior. Cameron (1999) and Slonim and Roth (1998) fin that behavior of inexperienced participants in the ultimatum game is slightly closer to rational decision making when stakes increase drastically. For a general overview over varying stakes in the experimental literature see Camerer and Hogarth (1999).

Table 4 Frequency distribution of price reactions

Price in $t-1$	# cases	Reaction (in %)										
		0	1	2	3	4	5	6	7	8	9	10
0	33	48.5	3.0	0.0	0.0	0.0	42.4	0.0	0.0	0.0	0.0	6.1
1	222	3.2	65.3	0.9	0.9	4.1	12.2	6.3	1.4	2.3	1.4	2.3
2	163	1.2	46.0	33.7	1.2	0.6	3.1	9.2	1.2	0.6	1.2	1.8
3	177	2.3	1.1	60.5	26.6	0.0	2.8	5.1	0.0	0.6	1.1	0.0
4	158	1.3	0.0	3.2	69.0	21.5	3.2	0.0	1.9	0.0	0.0	0.0
5	439	0.0	0.0	0.0	0.7	23.0	76.3	0.0	0.0	0.0	0.0	0.0
6	36	0.0	0.0	0.0	5.6	11.1	83.3	0.0	0.0	0.0	0.0	0.0
7	8	0.0	0.0	0.0	0.0	25.0	75.0	0.0	0.0	0.0	0.0	0.0
8	6	0.0	16.7	0.0	0.0	33.3	50.0	0.0	0.0	0.0	0.0	0.0
9	5	0.0	0.0	0.0	0.0	0.0	60.0	40.0	0.0	0.0	0.0	0.0
10	8	0.0	0.0	0.0	0.0	25.0	75.0	0.0	0.0	0.0	0.0	0.0

cooperate at the monopoly price of 5 and they rarely set a price of zero. Reversal to monopoly pricing after a deviation occurs, as predicted by the model, with an immediate price increase from $p = 1$ to $p = 5$. Sporadically we observe prices above the monopoly price. This may be due to initial difficultie of the participants to understand the structure of the game. The questionnaires fille in by the participants after each session furthermore indicate that some participants considered a price above 5 as an appropriate measure to induce the opponent to cooperate. For most participants, the assumption of Markov strategies seems reasonable, since the pricing structure definitel follows an almost predictable pattern and participants usually react in the same way to a certain price.

The finit horizon does—as in Normann and Wallace (2005)—not seem to hinder cooperative behavior in general. Many participants seem pretty well to be able to establish cooperation except for a few fina periods of the game, in which endgame effects occur. Definin the last deviation from cooperative pricing within a duopoly as the starting point of the respective endgame, we fin the surprising result that the endgame starts earlier in LOW than in HIGH. In LOW, the last deviation occurs 4.92 periods before the end whereas in HIGH cooperation collapses not until 2.27 rounds before the end of the game. This is surprising because it seemingly contradicts our hypothesis that collusion should be more stable in LOW, since we might have expected that more stable collusion also implies a later occurrence of endgame effects.[12] However, we have to be very careful when analyzing the fina rounds of the experiment. The

[12] In particular, we could have expected that participants reach cooperation only because each pretends to be willing to cooperate, similar to the argumentation in Kreps et al. (1982). If both firm send such signals to make the other fir trust them and cooperate, we should also observe collusive behavior until shortly before the end of the game. For this explanation to hold, however, we would expect that collusion breaks down earlier in HIGH than in LOW. The opposite is the case. Thus, our data does not support the hypothesis that such a signaling story is an explanation for cooperation in the finit horizon game.

long time horizon of 50 periods also leads to other forms of puzzling behavior due to boredom because of the simple and highly repetitive task in the experiment:[13] in the questionnaire after the experiment a question was included whether and if that was the case, when participants became bored during the experiment. Many participants indicated that they indeed were bored from a certain point of time onward, which was located between rounds 25 and 40. Round 33 seems a good guess about the average beginning of boredom. Consequently, participants' intention to 'make something happen' induced them to deviate from established cooperation even in LOW, where cooperation was predicted to be more stable. In our experimental data the frequency of deviations in both treatments converged by the end of the 50-period-game and makes the differences between them less significant When evaluating the data in the statistical tests, we therefore concentrate on round 1-33. The restriction to 33 rounds will show clearer results, but we can replicate all results for the whole 50-period time horizon,[14] although sometimes on a lower significanc level.

5.2 Duration of cooperation

Whenever a participant set the monopoly price, our model predicts that the opponent sets the monopoly price, too, so that we should expect long series' of cooperative monopoly pricing in the experiment. However, our actual participants are human agents and therefore likely to act emotionally rather than strictly according to a theoretical prediction. They might feel a temptation to deviate from cooperation in order to realize a high short run profi even if it does not pay of in the long run. Thus, a phase of mutual cooperation is always at risk to stop abruptly with a deviation of one participant no longer resisting the temptation of the short run profit The stronger this temptation the shorter is the expected duration of mutual cooperation. As shown in the numerical example, the temptation to deviate is larger in HIGH than in LOW. Therefore, a shorter average duration of cooperation in HIGH would confir the hypothesis that collusion is less stable in HIGH.

Before comparing the duration of cooperation in both treatments let us firs briefl argue why we have to distinguish two different types of cooperation in the experiment. Their distinction will become relevant later when comparing the number of deviations in both treatments. Both types of cooperation have in common that they start with a cooperative price choice of one of the two participants. There are many initial cooperative price choices that do not result in mutual cooperation but rather in an immediate defection of the respective opponent. In such a case, we speak of a *cooperative attempt*. If the initial cooperative price choice is followed by a longer

[13] This is a general problem of a repeated-game setting with unchanged market conditions over time. If we wanted to avoid boredom we would have to make the game more demanding, for example by modifying its conditions from time to time. Such a design, however, would make it much harder to assign differences in participants' behavior to differences between the treatments.

[14] One session of treatment LOW stopped unexpectedly after 33 rounds due to a computer crash. Where possible, we nevertheless included the data from this session also into the 50-rounds-analysis because the computer crash was naturally not anticipated by the participants.

Table 5 Average duration of cooperative sequences

33 rounds		50 rounds	
LOW	HIGH	LOW	HIGH
11.54	8.68	12.92	11.09
(11.05)	(9.04)	(13.25)	(9.33)
p value = 0.3439		p value = 0.5448	

Standard errors in brackets

mutually cooperative price sequences close to the monopoly price, we speak of a *cooperative sequence*. Such sequences are define as follows:

Definitio A *cooperative sequence* has at least one of the following characteristics:

1. $p = 5$ at least twice in a row.
2. $p = 5$ at least twice in a row and $p > 5$ during the sequence.
3. $p = 4$ at least twice in a row and the price in the period before was not equal to 5.

The duration of cooperative sequences provides the most valid test for the hypothesis that a larger δ^* makes collusion less stable. More stability of collusion is indicated by longer duration of cooperative monopoly pricing (see Table 5). A higher stability of tacit collusion in LOW is reflecte by a longer average duration of cooperative sequences $DC_{LOW} = 11.54$ than in HIGH ($DC_{HIGH} = 8.68$). In the repetition of the test for the overall 50 rounds these values increase to 12.92 in LOW and 11.09 in HIGH respectively. This difference, however, is statistically not significan [15] due to high variances in the length of the sequences.

5.3 Average prices

Figure 3 shows the average prices over time. They are relatively close to each other in both treatments. In the last third of treatment LOW they sightly decrease which confirm the argument that boredom determined behavior in later rounds of this treatment. At firs sight, average prices seem to be a natural measure for the stability of collusion because they combine two measures, frequency of deviations and duration of cooperation. Considering their implications more carefully, however, we conclude that average prices are not an appropriate measure for stability. The duration of periods of defection, which is also implicitly comprised in average prices, diminishes their explanatory power as we will see in the following paragraphs.

We have seen that the model predicts at $p = 1$ a war of attrition in LOW but not in HIGH. Thus, we expect that the duration of mutual defection is longer in LOW than in HIGH (see Table 6), implying a slower return from low-level-pricing to monopoly pricing. Indeed, mutual defection in LOW lasts on average 2.38 rounds and in HIGH 1.67 rounds. This difference is significan at the 5% level (p value = 0.0101). Analysis of all 50 rounds confirm the results, with a mean duration of mutual defection of

[15] In the following, if nothing else is stated statistical significanc is tested using a one-sided Wilcoxon–Mann–Whitney test.

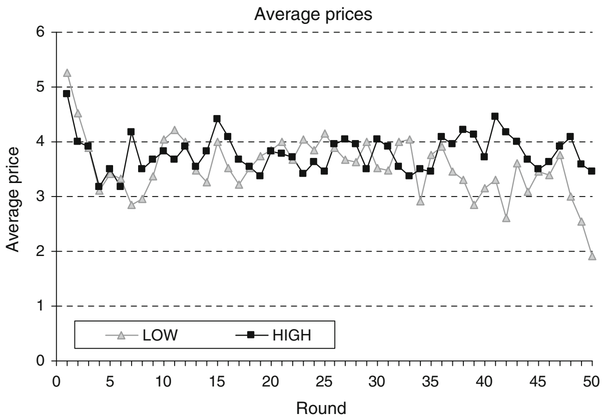

Fig. 3 Average prices in both treatments over time

Table 6 Average duration of mutual defection

33 rounds		50 rounds	
LOW	HIGH	LOW	HIGH
2.38	1.67	2.55	1.60
(0.94)	(0.78)	(1.43)	(0.77)
p value = 0.0101		p value = 0.0026	

Standard errors in brackets

2.55 in LOW and 1.60 in HIGH (p value = 0.0026). Thus, the war of attrition is definitel shorter in HIGH than in LOW. It is, however, also longer than theory would predict.

The longer defection lasts, the lower average prices are over time. We have seen in the numerical example that the average duration of mutual defection is by the nature of the model longer in LOW than HIGH. In the experiment, duration of defection is even longer than in the model. Thus, low average prices in the previous paragraph can likewise be caused by frequent deviations in HIGH and by long duration of defection in LOW, which indicates low stability of collusion in the firs case and high stability in the second case. Therefore, average prices are not a suitable measure of stability of collusion.

5.4 Number of deviations

The next test for the hypothesis of less stability of collusion in HIGH is the number of deviations from the collusive outcome $p = 5$. If the hypothesis was true, deviations should occur more often if δ^* increases. A deviation is in the experiment define such that it considers not only deviations from $p = 5$ to $p = 4$ as predicted by the model, but it does also include similar deviations from cooperative play occurring during the experiment.

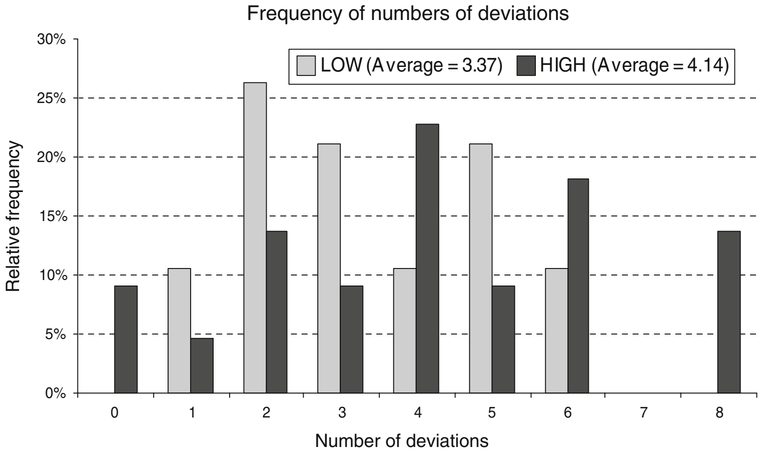

Fig. 4 Frequency distribution of the total number of deviations per pair within 33 rounds

Definitio A price decision of player i in period t is called *deviation* if the following conditions are satisfied

1. In period $t-1$ (at least) player j set the monopoly price (or above).
2. In period t player i chooses a price below 5.

To test the main hypothesis that a higher critical discount factor in HIGH leads to less cooperation than in LOW, we now compare the frequency of deviations in both treatments. The null hypothesis 'no difference in the average number of deviations' is tested against the alternative 'more deviations in HIGH'. Let us firs conduct the tests only with "true" deviations that occur after cooperative sequences as define in Sect. 5.2. Within 33 rounds, we fin an average number of 0.68 deviations in LOW and 1.50 in HIGH. This difference is significan at the 1% level (p value = 0.0080). The same holds for the analysis within all 50 rounds (1.23 devations in LOW, 2.32 deviations in HIGH, p value = 0.0065). After short cooperative attempts, in contrast, there are nearly as many deviations in both treatments (2.68 (4.08) in LOW and 2.64 (3.50) in HIGH within 33 (50) rounds). Considering deviations after cooperative attempts and cooperative sequences jointly (see Fig. 4 for an illustration of deviations within 33 rounds), we therefore get less clear results than in the case of cooperative sequences. In LOW, on average 3.37 deviations occur within 33 rounds. In HIGH this number increases to 4.14 deviations. The null hypothesis can be rejected at the 10% level (p value = 0.0991). Repeating the test for all 50 periods results shows no significan difference (LOW 5.31 deviations, HIGH 5.82 deviations, p value = 0.3653). Thus, statistical evidence for more deviations in HIGH than in LOW exists mainly in comparison of deviations from cooperative sequences in the firs 33 rounds but not in comparison of deviations from cooperative attempts in all 50 rounds.

The higher number of deviations in HIGH is partially explained by the shorter duration of defection. In contrast to the model, which predicts continuous cooperation and, in case of a deviation, an immediate return to cooperation, we additionally

Table 7 Duration (in rounds) of phases in between mutual cooperation and defection

	LOW	HIGH
Duration cooperation[a]	4.39	3.88
Duration undercutting	2.69	2.24
Duration defection	2.38	1.67
Duration of a 'circle'	9.46	7.79

[a] For simplicity, here we use a weighted average of the duration of (long) cooperative sequences and (short) cooperative attempts

fin another phase of play in the experiment. If subjects deviated to $p = 4$, the opponent's reaction does several times not follow the strategy that Maskin and Tirole predict. Instead of reacting with a price decrease to 1, they underbid each other sequentially in steps of 1.[16] This sequential undercutting is the firs phase after a deviation from monopoly pricing. We see that the duration of this phase after a deviation, comprising on average 2.69 rounds in LOW and 2.24 rounds in HIGH until $\underline{p} = 1$ is reached (see Table 7), should—in contrast to the model's prediction—not be neglected in the analysis. Together with the duration of the war of attrition, these non-cooperative phases of play determine a remarkable share of a pricing sequence. This impacts behavioral patterns much stronger than predicted by theory. As long as firm set their prices competitively none of them can deviate from cooperation because they just do not cooperate at that time. Thus, if firm return faster to monopoly pricing, it takes less time until there is another opportunity to deviate. A longer war of attrition in LOW (that could have been neglected according to the theory), combined with a longer duration of the undercutting phase, naturally lengthens the circle after one deviation so that there is less time for more deviations within a certain period of time. The number of deviations within a certain time interval is therefore also not the best measure for stability of collusion in the experiment.

5.5 Check: inclusion of all price decisions in the analysis?

Let us finall consider whether the above analysis includes all decisions of participants during their play. The typical pattern of play in the experiment comprises three different stages: first some periods of cooperation (either a cooperative sequence or a cooperative attempt), second, a undercutting phase, and, third, some periods of defection. After that, one of the two participants usually initiates cooperation again so that a new period of cooperation starts. If we sum up the average duration of such phases of cooperation, undercutting and defection, we obtain the duration of a 'circle' of pricing. Multiplying the average duration of such a circle by the number of deviations (being equal to the number of circles), we should end up with the total duration of 33

[16] This does partially question the applicability of renegotiation-proof strategies. For the experiment, however, this has no significan impact because under this strategy pair all former considerations regarding discounting still hold although the difference in critical discount factors between the two treatments becomes smaller.

Table 8 Duration of phases in between mutual cooperation and defection

	LOW	HIGH
Duration of a ‘circle’	9.46	7.79
# deviations	3.37	4.14
Residual choices	1.12	0.73

periods.[17] The missing difference to the total of 33 periods are residual price choices that cannot be explained with the above pattern of play. The number of “residual choices” is therefore calculated as follows:

$$\text{Residual choices} = 33 - \#\,\text{Deviations} \cdot (\text{Cooperation} + \text{Undercutting} + \text{Defection})$$

Table 8 summarizes the calculations. We see that data is well captured by the division into different stages, since only 1.12 rounds in LOW and 0.73 rounds in HIGH out of 33 rounds remain unexplained.

6 Discussion

At the beginning, we highlighted the fact that many papers implicitly make the intuitive assumption that the critical discount factor δ^* provides a measure to analyze the stability of a tacit cartel. This practice, however, contradicts standard economic theory, which does not defin a varying degree of stability. The experiment in this study indicates that intuition is right. For both the LOW and the HIGH treatment in our experiment, the actual discount factor lies above its critical value which means in theory—assuming rationality and no uncertainty—that we should exclusively observe mutual cooperation. However, in both treatments we see cooperation to be unstable which contradicts the theoretical prediction in the sense that deviations from tacit collusion occur. Most interestingly, instability is higher in treatment HIGH, in which the critical discount factor is higher than in treatment LOW. Thus, δ^*’s distance to the actual discount factor δ in fact seems to provide a measure for the relative degree of stability of tacit cartel agreements. There are more deviations from the collusive outcome and the average duration of cooperative sequences is shorter when δ^* is higher. Our results therefore support the hypothesis that an increase in δ^* indeed leads to less tacit collusion. They have, however, less statistical significanc than we had hoped for. The difference in the duration of cooperation is statistically not significan and the significanc of the difference in the number of deviations depends on the definitio of a deviation.

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[17] We restrict this analysis to the data for the firs 33 periods because for 50 periods we can hardly consider full cycles due to the endgame effect.

Appendix A: Optimality of $p = 1$ as a reaction to a deviation

To see whether it is optimal to react to a deviation with an immediate price cut to $\underline{p} = 1$, we have to compare expected future profit from all different possible reactions. We present the proof only for treatment LOW, since all results become even clearer in HIGH. First, we show that $p = 1$ yields a higher payoff than $p = 2$ and next that $p = 1$ also yields a higher profi than $p = 3$ and $p = 4$. For the calculation of the profit we can assume that each fir reverts to monopoly pricing $p = 5$ immediately as soon as price $p = 1$ is reached. This holds because the respective other fir mixes its strategy in such a way that the deciding fir is just indifferent between relenting and continuing the price war. Thus, once $p = 1$ is reached, profit from further price war continuation have to be equal to profit from an immediate return to monopoly pricing:

$$\pi(1) = 18 + \alpha\left(\delta \cdot 9 + \delta^2 \cdot 0 + \frac{\delta^3}{1-\delta} \cdot 25\right) + (1-\alpha)\left(\delta \cdot 18 + \frac{\delta^2}{1-\delta} \cdot 25\right).$$

If we insert $\alpha(\delta) = \frac{9-7\delta}{9\delta+25\delta^2}$ this can be simplifie to

$$\pi(1) = 9 + \delta \cdot 25 + \frac{\delta^2}{1-\delta} \cdot 25.$$

Profit from $p = 2$ are given by

$$\pi(2) = 32 + \delta \cdot 0 + \delta^2 \cdot 0 + \frac{\delta^3}{1-\delta} \cdot 25.$$

Thus, $\pi(1) > \pi(2)$, if

$$9 + \delta \cdot 25 + \frac{\delta^2}{1-\delta} \cdot 25 > 32 + \frac{\delta^3}{1-\delta} \cdot 25,$$

which holds for $\delta > 0.6$.

Profit from $p = 3$ are given by

$$\pi(3) = 42 + \delta \cdot 0 + \delta^2 \cdot 0 + \frac{\delta^3}{1-\delta} \cdot 25.$$

Thus, $\pi(1) > \pi(3)$, if

$$9 + \delta \cdot 25 + \frac{\delta^2}{1-\delta} \cdot 25 > 42 + \frac{\delta^3}{1-\delta} \cdot 25,$$

which holds for $\delta > 0.75$.

Staying at $p = 4$ is not a stable option, because the other's best reply would be $p = 1$:

$$\pi(4) = 24 + \delta \cdot 0 + \delta^2 \cdot 0 + \frac{\delta^3}{1-\delta} \cdot 25.$$

Thus, $\pi(1) > \pi(4)$, if

$$9 + \delta \cdot 25 + \frac{\delta^2}{1-\delta} \cdot 25 > 24 + \frac{\delta^3}{1-\delta} \cdot 25,$$

which holds for $\delta > 0.35$.

Appendix B: Instructions

(Translated from German)
Thank you for participating in this experiment.

These instructions are identical for all participants. Please read them carefully. Please raise your hand if you have any questions regarding the experiment. We will then come directly to your place. Please be quiet during the experiment and do not talk to other participants.

Your gains and losses during the experiment are counted in points. The exchange rate is 200 points for 1 Euro. You will receive your payment directly after the end of the experiment.

Each participant in this experiment plays the role of fir A or B. The product A and B are selling is only produced by those two firms You will keep your role throughout the whole experiment. You will learn on your firs computer screen whether you are fir A of fir B. The other fir is one of the other present participants in this experiment. The product A and B are selling is perfectly identical. That means the purchase decision of a certain consumer depends only on which of you sells the good at a lower prices. If both of you sell the product at exactly the same price each of you will sell the good to half of the consumers. Your payment in each round depends on your decision and on the decision of the other participant. The decisions of all other participants are irrelevant for your profits

Pricing of A and B takes place sequentially. This experiment will last for 50 periods, i.e. each fir is allowed to adjust its price 25 times. In the very firs period, fir A chooses its price. Profit in this period are calculated as if fir B had set a price of 0. At the beginning of the second period, B is informed about A's previous decision and makes B's firs decision. Consequently, in period 3, A is informed about B's decision and the resulting profit for both firm and can adjust its price. This proceeding continues sequentially while you are interacting with the same other participant throughout the whole experiment. Thus, A can adjust its price in all odd periods and B in all even periods. Apart from that, there is no difference between the firm as you can see from the payoff table below.

[Table in LOW]

		Price of A										
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Price of B	**0**	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	1	0 0	9 9	0 18	0 18	0 18	0 18	0 18	0 18	0 18	0 18	0 18
	2	0 0	18 0	16 16	0 32	0 32	0 32	0 32	0 32	0 32	0 32	0 32
	3	0 0	18 0	32 0	21 21	0 42	0 42	0 42	0 42	0 42	0 42	0 42
	4	0 0	18 0	32 0	42 0	24 24	0 48	0 48	0 48	0 48	0 48	0 48
	5	0 0	18 0	32 0	42 0	48 0	25 25	0 50	0 50	0 50	0 50	0 50
	6	0 0	18 0	32 0	42 0	48 0	50 0	24 24	0 48	0 48	0 48	0 48
	7	0 0	18 0	32 8	42 0	48 0	50 0	48 0	21 21	0 42	0 42	0 42
	8	0 0	18 0	32 0	42 0	48 0	50 0	48 0	42 0	16 16	0 32	0 32
	9	0 0	18 0	32 0	42 0	48 0	50 0	48 0	42 0	32 0	9 9	0 18
	10	0 0	18 0	32 0	42 0	48 0	50 0	48 0	42 0	32 0	18 0	0 0

[Table in HIGH]

		Price of A										
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Price of B	**0**	0 0	1 0	4 0	7 0	10 0	13 0	0 0	0 0	0 0	0 0	0 0
	1	0 1	9 9	1 18	4 18	7 18	10 18	0 18	0 18	0 18	0 18	0 18
	2	0 4	18 1	16 16	1 32	4 32	7 32	0 32	0 32	0 32	0 32	0 32
	3	0 7	18 4	32 1	21 21	1 42	4 42	0 42	0 42	0 42	0 42	0 42
	4	0 10	18 7	32 4	42 1	24 24	1 48	0 48	0 48	0 48	0 48	0 48
	5	0 13	18 10	32 7	42 4	48 1	25 25	0 50	0 50	0 50	0 50	0 50
	6	0 0	18 0	32 0	42 0	48 0	50 0	24 24	0 48	0 48	0 48	0 48
	7	0 0	18 0	32 8	42 0	48 0	50 0	48 0	21 21	0 42	0 42	0 42
	8	0 0	18 0	32 0	42 0	48 0	50 0	48 0	42 0	16 16	0 32	0 32
	9	0 0	18 0	32 0	42 0	48 0	50 0	48 0	42 0	32 0	9 9	0 18
	10	0 0	18 0	32 0	42 0	48 0	50 0	48 0	42 0	32 0	18 0	0 0

Before reaching a decision you will always be informed about the current prices of both firm in your market. In odd periods A sets a price and B has to wait whereas in even periods B sets a price and A has to wait, respectively. Thus, after each decision you made you will have to wait for a decision of your opponent before you can react again. You can nevertheless receive a payment in periods were you cannot move. In the end of each period you learn both prices and you own profi in this period.

The prices you are allowed to choose range from 0 to 10. The following table includes all payments of A and B depending on their respective prices. In the items within the table you fin the profi of fir A in the upper right corner of each item and the profi of fir B in the lower left corner of each item.

You will receive your payment directly after the end of the experiment. Please remain seated until your profit have been converted from points into Euros. You will receive the money at your place.

If you have any further questions regarding the conduction of the experiment, please give a short notice to the supervisors of the experiment. We will then come directly to your place.

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