# Cournot or Stackelberg Competition? A Survey of Experimental Research

Hildenbrand, Andreas

Department of Economics, Justus Liebig University Giessen

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# A Survey of Experimental Research[*]

Andreas Hildenbrand[†]

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[†]VWL VI Behavioral and Institutional Economics, Justus Liebig University Giessen, Licher Straße 66, 35394 Gießen, Germany. Telephone: +49 641 99-22203. Telefax: +49 641 99-22209. Electronic Mail: andreas.hildenbrand@wirtschaft.uni-giessen.de. World Wide Web: wirtschaft.uni-giessen.de.

**Abstract**

In this paper, I survey experimental studies on duopolistic quantity competition with homogeneous products and duopolistic price competition with heterogeneous products. The focus is on the papers in which the sequence of competition is endogenous. Experimental studies checking Cournot competition against Stackelberg competition act as benchmarks. I find that while Stackelberg equilibrium outcomes are seldom under quantity competition, under price competition, the Stackelberg equilibrium prediction seems to be more appropriate. However, after discussing the experimental setups, I conclude that some methodological problems are present. Moreover, I make recommendations for further research.

Keywords: Cournot competition, simultaneous competition, simultaneous play, Stackelberg competition, sequential competition, sequential play, duopoly, homogeneous products, heterogeneous products, experimental economics.

*Journal of Economic Literature* Classification Codes: C720, C910, D430, L130.

# 1 Introduction

Although the *Cournot model* and the *Stackelberg model* of duopolistic quantity competition with homogeneous products and duopolistic price competition with heterogeneous products are part and parcel of every textbook on industrial organization,[1] only few experiments testing these models have been conducted yet. The same is true for models in which the sequence of competition is endogenous. In the following, these models are referred to as *ESoC models*.

An ESoC model is a model in which the sequence of competition is not exogenously given but endogenously determined by the firms' decisions. The two most often used ESoC models were built by Hamilton and Slutsky (1990): the *extended game with action commitment* and the *extended game with observable delay*. For example, van Damme and Hurkens (1999) apply Hamilton and Slutsky's extended game with action commitment to quantity competition between firms which are asymmetric with respect to marginal costs. Another ESoC model is Saloner's (1987) *extended game with two investment periods* which has been improved by Ellingsen (1995).

Experimental studies on the Cournot and the Stackelberg quantity competition models were done by Huck et al. (2001) and Fonseca et al. (2005). Saloner's model was experimentally examined by Müller (2006), and Hamilton and Slutsky's models were tested by Huck et al. (2002) and Fonseca et al. (2006). Further, Fonseca et al. (2005) also experimentally investigated van Damme and Hurkens's model. The only experimental study checking Cournot price competition against Stackelberg price competition was done by

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[1]Most often, textbook authors speak of the *Bertrand model* when they refer to simultaneous price competition. Since Bertrand has argued with homogenous products exclusively and Cournot has applied his equilibrium concept not only to quantity competition but also to price competition, following Morrison (1998), I say Cournot quantity (price) competition when I refer to simultaneous quantity (price) competition with homogeneous (heterogeneous) products. When I refer to sequential quantity (price) competition with homogeneous (heterogeneous) products, I say Stackelberg quantity (price) competition.

Kübler and Müller (2002). Moreover, none of the ESoC price competition models has been experimentally examined yet. For example, such models were published by Hamilton and Slutsky (1990), van Damme and Hurkens (2004), Pastine and Pastine (2004), and Amir and Stepanova (2006).

In Cournot quantity competition markets, Huck et al. (2001) and Fonseca et al. (2005) find evidence for the Cournot equilibrium prediction. In contrast, Stackelberg equilibrium outcomes are seldom in Stackelberg quantity competition markets. In endogenous Stackelberg quantity competition markets, the Stackelberg equilibrium prediction is even worse. In Stackelberg price competition markets, the Stackelberg equilibrium prediction seems to be more appropriate.

Consequently, I raise the following five questions: (i) Has the Cournot quantity competition model been corroborated and the Stackelberg quantity competition model been falsified by Huck et al. (2001) and Fonseca et al. (2005)? (ii) Did Müller (2006), Huck et al. (2002), Fonseca et al. (2006), and Fonseca et al. (2005) falsify the endogenous Stackelberg quantity competition models? That is, is it not possible to explain sequential quantity competition by these models? (iii) Did Kübler and Müller (2002) find evidence for the Cournot and the Stackelberg price competition model? (iv) What can be expected from further research on price competition? In particular, will it be possible to explain price leadership by the proposed endogenous Stackelberg price competition models? (v) How should further experimental research on oligopoly models be organized?

In the following section, I recapitulate the experiments on quantity competition. After that, I investigate Müller's (2006) experiment on price competition. The findings are discussed in section 4. In the last section, I conclude.

# 2 Quantity Competition

## 2.1 Experiments on Models With an Exogenous Sequence of Competition

In a series of experiments, Huck et al. (2001) examine two markets for a homogeneous good. In every market, two firms compete in quantities. Both firms face a linear inverse demand function: $p(q) = \max\{30 - q, 0\}$, $q = q_1 + q_2$. Each cost function is linear in output: $c_i(q_i) = 6q_i$, $i = 1, 2$. Hence, marginal costs are constant and identical. In the Cournot market, firms act simultaneously. In the Stackelberg market, firms move sequentially.

The Cournot and Stackelberg equilibrium predictions as well as the predicted outcomes under collusion are shown in Table 1. The focus is on the Stackelberg market treatments, the Cournot market treatments serve as control treatments. By means of their setup, Huck et al. test whether subjects behave according to an asymmetric subgame-perfect Nash equilibrium prediction.

| Prediction | Cournot | Stackelberg | Collusion |
|---|---|---|---|
| Quantities | $q_i^C = q_{3-i}^C = 8$ | $q_i^L = q_{3-i}^L = 12$, $q_i^F = q_{3-i}^F = 6$ | $q_i^J = q_{3-i}^J = 6$ |
| Total quantity | $q^C = 16$ | $q^S = 18$ | $q^J = 12$ |
| Profits | $\pi_i^C = \pi_{3-i}^C = 64$ | $\pi_i^L = \pi_{3-i}^L = 72$, $\pi_i^F = \pi_{3-i}^F = 36$ | $\pi_i^J = \pi_{3-i}^J = 72$ |
| Total welfare | $TW^C = 256$ | $TW^S = 270$ | $TW^J = 216$ |

Table 1: Cournot and Stackelberg equilibrium predictions.
Source: Huck et al. (2001, p. 751).

The experiment was run in lecture halls with pen and paper at Humboldt University Berlin. Overall, 134 students from various fields of study, mostly from economics and business administration as well as law, participated in 7 sessions. Every session consisted of 10 rounds and lasted between 60 and 75 minutes. Participants' average earnings were

€ 8.01. Each subject was told to "play the role of a firm" and had to choose its quantity from a $13 \times 13$ payoff bimatrix.

For Cournot markets, Huck et al. find that, under random matching, average quantities per round are close to the Nash equilibrium quantities; under fixed matching, average quantities per round are lower because the collusive quantity is chosen more often. Further, there is a noticeable endgame effect under fixed matching: collusion breaks down in the last rounds. That is, under random matching, the theoretical predictions are supported to a large extent. For Stackelberg markets, the picture is different: under random matching, leaders mostly supply less than predicted by the subgame-perfect Nash equilibrium, and followers typically supply more; under fixed matching, firms compete less intensively at large. Thus, the experimental results differ from the theoretical predictions. However, as predicted, because of the higher total output, the Stackelberg markets are associated with a higher welfare than the Cournot markets.

## 2.2 Experiments on Models With an Endogenous Sequence of Competition

Huck et al. (2002) use the same $13 \times 13$ payoff bimatrix as Huck et al. (2001). In addition, to endogenize the order of moves, they extend the quantity-choosing game by a time-setting game. Following Hamilton and Slutsky (1990), according to the extended game with action commitment, firms are able to choose their quantities in one of two periods. If a firm commits to a quantity in the first period (moves early), it does not know whether the other firm also moves early or commits to a quantity in the second period (moves late, waits). By waiting until the second period, a firm is able to observe the other firm's action of the first period. The market is assumed only to exist in the second period, therefore, profits from simultaneous play in the first period are the

same as profits from simultaneous play in the second period. The extensive form of the extended game with action commitment is depicted in Figure 1.
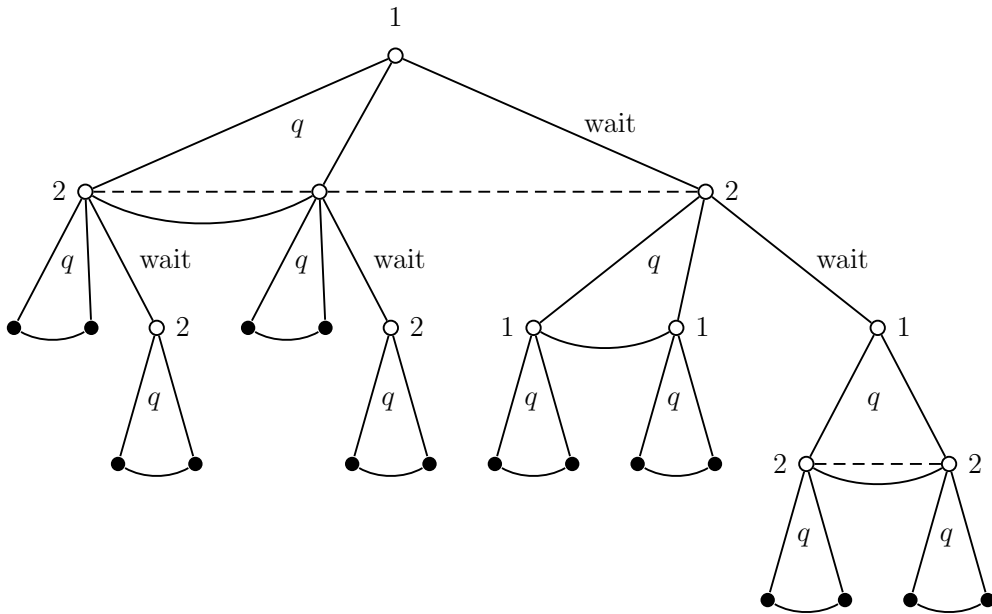


Figure 1: Extensive form of Hamilton and Slutsky's (1990, p. 35) extended game with action commitment.

After the elimination of weakly dominated strategies, the extended game exhibits two subgame-perfect Nash equilibria in pure strategies: one of the two firms moves early and the other one moves late. Besides these two equilibria, a Stackelberg equilibrium in mixed strategies exists: both firms commit themselves to $q = 10$ with a probability of 2/5 and wait with a probability of 3/5. Before the elimination, another subgame-perfect Nash equilibrium in pure strategies is present: both firms choose their Cournot equilibrium quantity in the first period. Moreover, in weakly dominated strategies, there is a variety of equilibria in mixed strategies. Huck et al. are interested in checking Hamilton and Slutsky's prediction of endogenous Stackelberg competition. By means of their setup, Huck et al. check whether subjects eliminate weakly dominated strategies.

The computerized experiment was run at Humboldt University Berlin. Overall, 70 students from various fields of study, mostly from economics and business administration

as well as law, participated in 7 sessions: 4 sessions with a small version of the payoff bimatrix and 3 sessions with a large version. Every session consisted of 10 rounds. The 3 sessions with the large bimatrix, each consisting of 30 rounds, lasted about 90 minutes; the 4 sessions with the small bimatrix, each consisting of 10 rounds, lasted about 50 minutes. Participants' average earnings were € 10.53 in the sessions with 30 rounds and € 8.80 in the sessions with 10 rounds. Each subject was told to "have the role of a firm."

For the large bimatrix, consisting of 13 rows and 13 columns, Huck et al. find that, under random matching, endogenous Stackelberg equilibria are extremely seldom, and their frequency does not increase with experience. Further, participants have problems in coordinating their actions: in about 25 percent of all rounds, coordination fails. Over time, the frequency of collusive quantities increases because endogenous Stackelberg followers reward cooperation/punish exploitation more often. Cournot equilibria are the most frequent outcomes. For the small bimatrix, consisting of 3 rows and 3 columns, the picture is the same. Hence, Huck et al. conclude that the failure of Hamilton and Slutsky's theoretical prediction of endogenous Stackelberg competition is not due to the complexity of the large bimatrix. Further, they record that subjects seem to prefer symmetric outcomes to asymmetric outcomes, but they are sceptical whether this result is the same for markets with asymmetric firms or price competition.

Hamilton and Slutsky's (1990) extended game with action commitment is also used by Fonseca et al. (2005). Adopting the idea of Huck et al. (2002), firms are asymmetric with respect to marginal costs. Both firms face a linear inverse demand function: $p(q) = \max\{30 - q, 0\}$, $q = q_1 + q_2$. Each cost function is linear in output: $c_1(q_1) = 6q_1$, $c_2(q_2) = 8q_2$. Again, the extended game exhibits three subgame-perfect Nash equilibria in pure strategies: one subgame-perfect Nash equilibrium in weakly dominated strategies in which both firms choose their Cournot equilibrium quantity in the first period and two subgame-perfect Nash equilibria in which one of the two firms moves early and the other

8

one moves late.

For this setup of the game, van Damme and Hurkens (1999) predict sequential play with a specific order of play: since committing early is risky, the firm for which committing early is less risky is expected to be the leader. Using Harsanyi and Selten's (1988) risk dominance criterion, van Damme and Hurkens show that committing early is less risky for the low-cost firm, that is, only the Stackelberg equilibrium, in which the low cost firm leads, survives the refinement. By means of their setup, Fonseca et al. test whether subjects eliminate weakly dominated strategies and select equilibria according to the risk dominance criterion.

The Cournot and Stackelberg equilibrium predictions are shown in Table 2.

| Prediction | Cournot | Stackelberg: LF | Stackelberg: FL |
|---|---|---|---|
| Quantities | $q_1^C = \frac{52}{6}, q_2^C = \frac{40}{6}$ | $q_1^L = \frac{78}{6}, q_2^F = \frac{27}{6}$ | $q_1^F = \frac{42}{6}, q_2^L = \frac{60}{6}$ |
| Total quantity | $q^C = \frac{92}{6}$ | $q_{LF}^S = \frac{105}{6}$ | $q_{FL}^S = \frac{102}{6}$ |
| Profits | $\pi_1^C = \frac{5408}{72}, \pi_2^C = \frac{3200}{72}$ | $\pi_1^L = \frac{6084}{72}, \pi_2^F = \frac{1458}{72}$ | $\pi_1^F = \frac{3528}{72}, \pi_2^L = \frac{3600}{72}$ |
| Total welfare | $TW^C = \frac{17072}{72}$ | $TW_{LF}^S = \frac{18567}{72}$ | $TW_{FL}^S = \frac{17532}{72}$ |

Table 2: Cournot and Stackelberg equilibrium predictions.
Source: Author.

The experiment was run in lecture rooms with pen and paper at the University of London. Overall, 60 students participated in 6 sessions.[2] Every session consisted of 20 rounds.[3] Participants' average earnings were €13.63.[4] Again, each subject was told to "play the role of a firm" and had to choose its quantity from a $15 \times 15$ payoff bimatrix.

Fonseca et al. find that, under random matching, endogenous Stackelberg equilibria are seldom: only in 31 percent of all rounds, the low-cost firm emerges as the endogenous leader; the high-cost firm is observed to be the leader in 18 percent of all rounds. In

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[2]Fonseca et al. do not divulge the fields of study.

[3]The duration of the sessions is not divulged either.

[4]Fonseca et al. report £8.30. Since they did not mention the date when the experiment was run, the exchange rate of December 28, 2001 was used for the calculation.

the residual rounds, simultaneous play occurred – mostly in the first period. Further, there is no trend towards the risk-dominant equilibrium over time. Compared with the experimental results of Huck et al. (2002), firms' timing decisions are nearly identical. Furthermore, firms' output decisions are not in accordance with van Damme and Hurkens' prediction: when a firm, no matter which type, commits in the first period, it produces approximately the Cournot output on average. Thus, low-cost firms are not able to exploit their efficiency advantage to become Stackelberg leaders.

The payoff bimatrix generated by Huck et al. (2001) is also used by Fonseca et al. (2006). In contrast to Huck et al. (2002), Fonseca et al. employ Hamilton and Slutsky's (1990) extended game with observable delay to endogenize the order of moves. The extensive form of the extended game with observable delay is depicted in Figure 2.
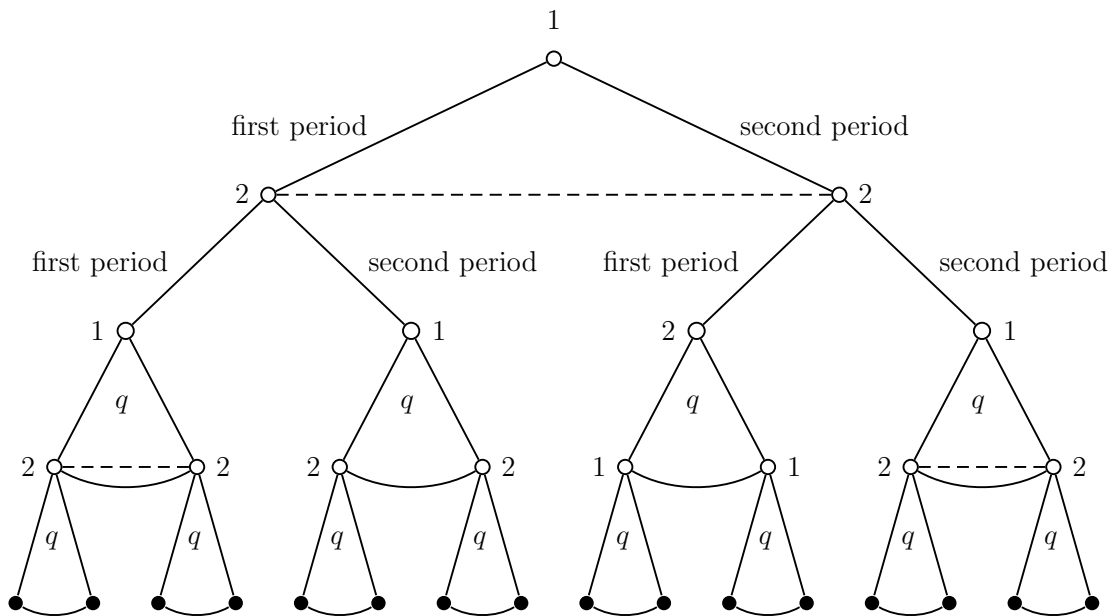


Figure 2: Extensive form of Hamilton and Slutsky's (1990, p. 33) extended game with observable delay.

Firms simultaneously announce a production period and then they produce in the announced sequence. Since duopolistic quantity competition is associated with decreasing reaction functions, each firm prefers its Cournot equilibrium payoff to its Stackelberg

equilibrium follower payoff. Thus, in equilibrium, both firms announce the first period and achieve Cournot payoffs. By means of their setup, Fonseca et al. test whether subjects behave according to a symmetric subgame-perfect Nash equilibrium prediction in a more complex game than the standard Cournot game.

The computerized experiment was run at the University of London. Overall, 70 students from various fields of study participated in 7 sessions: 5 sessions with random matching and 2 sessions with fixed matching. In order to allow for learning, the random-matching sessions consisted of 30 rounds. The fixed-matching sessions consisted of 10 rounds. Every session lasted between 60 and 90 minutes. Participants' average earnings were € 21.38. Again, each subject was told to "have the role of a firm."

Fonseca et al. find that, under random matching, there is a trend towards equilibrium timing behavior. However, the relative frequency of decisions for the first period does not exceed 72 percent. Further, the equilibrium prediction that both firms decide for the first period only occurs in 55 percent of the cases. In these simultaneous quantity choosing subgames, firms' quantity choices are almost identical and move towards the Cournot prediction. In the sequential quantity choosing subgames, first movers' outputs are smaller than the Stackelberg prediction, but larger than the Cournot prediction. That is, both leaders' and followers' payoffs are smaller than Cournot players' payoffs. Under fixed matching, the relative frequency of decisions for the first period is lower: about 50 percent. The equilibrium prediction that both firms decide for the first period only occurs in 32 percent of the cases. In all quantity choosing subgames, average outputs are lower than in the random-matching treatments, indicating a tendency to collude. That is, firms' payoffs are higher than in the random-matching treatments. Compared with the results above, Fonseca et al.'s findings are puzzling: although there is a unique symmetric subgame-perfect Nash equilibrium (coordination failures or inequality aversion are no problems) and experienced subjects mostly choose the Cournot quantity, there is a

11

tendency to wait for the second period. That is, the experimental result does not completely support the theoretical prediction.

As Huck et al. (2001), Müller (2006) experimentally investigates two markets for a homogeneous good. In every market, two firms compete in quantities. Both firms face a linear inverse demand function: $p(q) = \max\{100 - q, 0\}$, $q = q_1 + q_2$. Each cost function is linear in output: $c_i(q_i) = 1q_i$, $i = 1, 2$. Hence, marginal costs are constant and identical. In one market, the Cournot market, firms act simultaneously. In the other market, the order of moves is endogenous.

According to Saloner (1987) and Ellingsen (1995), there are two periods in which firms are able to produce their outputs. The outputs simultaneously chosen in the first period are public information in the second period. Therefore, in the second period, firms simultaneously choose their additional (nonnegative) outputs fully aware of the actions in the first period. After the second period, the market clears. As in Hamilton and Slutsky's (1990) extended game, production costs are assumed to be the same in both periods. Saloner shows that any outcome on the outer envelope of the reaction functions between and including the firms' Stackelberg points $(S_{LF}, S_{FL})$ constitutes a subgame-perfect Nash equilibrium. This set is depicted in Figure 3. Ellingsen complements Saloner's analysis by demonstrating that only Stackelberg behavior survives the iterative elimination of weakly dominated strategies. That is why he predicts that one of the two Stackelberg outcomes will occur. By means of his setup, Müller checks whether subjects iteratively eliminate weakly dominated strategies.

The computerized experiment was run at Humboldt University Berlin and the University of London. Overall, 40 students participated in 20 sessions: 10 sessions with a Saloner-Ellingsen duopoly treatment and 10 sessions with a Cournot duopoly treatment.[5] Every session consisted of 25 rounds. The 10 sessions with the Saloner-Ellingsen duopoly

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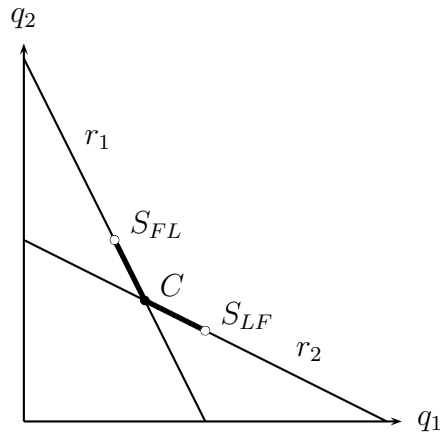[5]Müller does not divulge the fields of study.

Figure 3: Reaction curves and equilibria.

treatment lasted about 80 minutes; the 10 sessions with the Cournot duopoly treatment lasted about 45 minutes. Participants' average earnings were € 17.44. Each subject was told to "represent a firm."

Müller finds that, under fixed matching, Stackelberg equilibrium outcomes are extremely rare in the Saloner-Ellingsen duopoly treatment: only 8 out of 250 quantity combinations are classified as Stackelberg outcomes.[6] Compared with the outcomes in the standard Cournot duopoly treatment, these outcomes are not associated with higher total quantities. An endgame effect is observed in both treatments: total quantities rise in the last rounds – and are close to the Cournot equilibrium prediction. That is, the experimental result does not support Ellingsen's theoretical prediction of Stackelberg behavior.

# 3 Price Competition

Kübler and Müller (2002) experimentally examine two markets for a heterogeneous good. In every market, two firms compete in prices. Both firms face a linear demand function:

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[6]Since participants choose quantities from a finite grid, outcomes are classified as equilibrium outcomes if they do not deviate more than 10 percent from the equilibrium prediction.

$q_i(p_i, p_{3-i}) = \max\{16 - 2p_i + p_{3-i}, 0\}$, $i = 1, 2$. Production is costless. Hence, marginal costs are constant, identical, and zero. In the Cournot market, firms act simultaneously. In the Stackelberg market, firms move sequentially.

The Cournot and Stackelberg equilibrium predictions as well as the predicted outcomes under collusion are shown in Table 3. Roughly speaking, Kübler and Müller carry over Huck et al.'s (2001) experimental design to price competition. By means of their setup, Kübler and Müller test whether subjects behave according to an asymmetric subgame-perfect Nash equilibrium prediction.

| Prediction | Cournot | Stackelberg | Collusion |
|------------|---------|-------------|-----------|
| Prices | $p_i^C = p_{3-i}^C = 4$ | $p_i^L = p_{3-i}^L = 6$, $p_i^F = p_{3-i}^F = 5$ | $p_i^J = p_{3-i}^J = 8$ |
| Profits | $\pi_i^C = \pi_{3-i}^C = 53$ | $\pi_i^L = \pi_{3-i}^L = 58$, $\pi_i^F = \pi_{3-i}^F = 68$ | $\pi_i^J = \pi_{3-i}^J = 65$ |

Table 3: Cournot and Stackelberg equilibrium predictions.
Source: Kübler and Müller (2002, p. 1442).

The computerized experiment was run at Humboldt University Berlin in June 2000 and in January and May 2001. Overall, 120 students, undergraduates as well as graduates, from various fields of study, mostly from economics and business administration, participated in 10 sessions. Every session consisted of 15 rounds and lasted about 50 minutes. Participants' average earnings were € 8.69. Each subject was told to "play the role of a firm" and had to choose its price from a $10 \times 10$ payoff bimatrix.

For Cournot markets, Kübler and Müller find that, under random matching, median prices of the last 5 rounds match the Nash equilibrium prices; under fixed matching, median prices of the last 5 rounds are higher. That is, the behavior is more collusive under fixed matching than under random matching. This result also holds for the mean prices. Therefore, under random matching, the theoretical predictions are supported to a large extent. For Stackelberg markets, the picture is similar: under random matching, median prices of the last 5 rounds match the subgame-perfect Nash equilibrium prices;

under fixed matching and a sequential course of action (in contrast to the strategy method), the median prices of the last 5 rounds are identical to the median prices under random matching. Under fixed matching and Selten's (1967) strategy method, the leader's median price of the last 5 rounds equates to the follower's median price. However, for all treatments, mean leader prices (no matter whether all rounds or only the last 5 rounds are considered) exceed mean follower prices, and mean follower profits exceed mean leader profits. Thus, the experimental results widely match the theoretical predictions in the Cournot market treatments as well as in the Stackelberg market treatments.

# 4 Discussion

First of all, it is surprising that only a handful of experiments checking Cournot competition against Stackelberg competition have been published yet. It is also surprising that only one of these experiments involves price competition. Although the Cournot model and the Stackelberg model are part and parcel of every textbook on industrial organization, and there is a long history of characterizing oligopolistic industries by models of price competition, in particular by price leadership models,[7] an extensive experimental investigation has not been performed yet.

A reason for this may be that experimental methods in this field of research are seen as inappropriate. That is, echoing Friedman (1953), that the domain of the theory is seen to exclude the laboratory. To investigate whether using the laboratory is feasible, following Cubitt (2005), I start from identifying the formal objects of the theory. These are players, actions, payoffs, and information. Players act simultaneously or sequentially.

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[7]For the classical price leadership models, see Forchheimer (1908) in conjunction with Zeuthen (1930), Stigler (1947), and Markham (1951). For a survey of these models, see Scherer and Ross (1990, p. 248–261).

They are assumed to be rational and to maximize their payoffs. The domain, which is the set of real phenomena to which the theory is intended to apply, consists of firms that compete duopolistically in quantities or prices for profits. Now, the question is: Is it possible to find an experimental design within the domain of the theory? Presuming that the theory is general, the answer is yes in principle. Participants can be told that they represent firms, choose quantities or prices under a given sequence of competition, and receive profits subject to their chosen actions. However, the answer depends on the auxiliary hypothesis that firms act like subjects. In addition, Binmore (1999) insists that economic theory is only expected to predict in the laboratory if the experimental design is not only in the domain of the theory but also provides "simple" tasks, "sufficient" time for learning, and "adequate" incentives.

All published experiments fulfill these criteria to a large extent. If the auxiliary hypothesis is taken to be true, experimental designs seem to be in the domain of the theory. The judgement of simplicity of tasks, the sufficiency of time for learning, and the adequacy of incentices depends on the quantification of simple, sufficient, and adequate. In all mentioned experiments, tasks seem to be simple. Participants are told that they represent firms, choose quantities or prices under a given sequence of competition, and receive profits subject to their chosen actions. Except for Müller's (2006) experiment, participants choose quantities or prices from a bimatrix. In Müller's experiment, participants choose quantities from a finite grid.[8] Contemplating the time for learning, the picture is mixed. Some sessions consist of 30 rounds. Others only have 10 rounds. Incentives seem to be adequate: payoffs are chosen to reflect opportunity costs. Therefore, an adverse selection among potential participants is avoided. If payoffs were chosen not to reflect opportunity costs, it would have been likely that income-maximizing subjects

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[8]In a Cournot oligopoly experiment, Gürerk and Selten (2010) observe a presentation effect under fixed matching: subjects who are given payoff bimatrices choose collusive quantities more often than subjects who are given a profit calculator instead. However, under random matching, there should be no such presentation effect.

would not have participated in the experiment.

However, the slopes of the reaction curves are small in magnitude, that is, losses from playing a disequilibrium strategy, which is in the neighborhood of the equilibrium strategy, are low. This can be a problem. For instance, Goeree and Holt (2001) present an experiment on Basu's (1994) "traveler's dilemma" game. Two players simultaneously select an integer between and including 180 and 300. If they have selected different numbers, both players are paid according to the lower of the two numbers, and, in addition, a transfer $R > 1$ is added to the payoff of the player with the lower number and subtracted from the payoff of the player with the higher number. If they have selected identical numbers, both players are paid according to their numbers. In the unique Nash equilibrium, both players select the number 180. That is, the theoretical prediction is 180. Since $R$ is the cost of being undercut, Goeree and Holt speculate that the behavior might depend on the value of $R$. In particular, they conjecture: the higher the value of $R$, the better is the Nash equilibrium prediction. To investigate their conjecture, they implement two treatments: a treatment with $R = R^h = 180$ and a treatment with $R = R^l = 5$. The experiment was run at the University of Virginia. Overall, 50 students from undergraduate economics classes participated. All participants made decisions in both treatments. In both treatments, the game was only played once. These two games were presented randomly arranged and separated by a number of other games. Goeree and Holt find that about 80 percent of all participants choose the Nash equilibrium strategy in the $R^h$ treatment. However, in the $R^l$ treatment, the Nash equilibrium strategy is only chosen by about 10 percent of all participants. Moreover, about 80 percent of all participants choose 300, that is, they choose the strategy which is at the opposite end of the strategy set.

Smith and Walker (1993) report on similar findings in 31 experiments: the higher the

payoffs are, the better is the prediction and the lower is the variance.[9] They argue that this is based on decision costs. Decision costs are caused by the effort to decide. In their eyes, the decision problem is one of balancing the benefit against the costs of reducing the deviation. If decision costs are assumed to decrease with increasing simplicity and experience, then it follows that simplifying the instructions and playing more rounds will increase the predictive power of a true theory. In addition, the predictive power of a true theory is increased by increasing the payoff level: this causes an increase in effort. Regarding the experiments mentioned above, although the payoffs are chosen to reflect opportunity costs, incentives for choosing the equilibrium strategy are low due to the payoff level in connection with the "flat" reaction curves. The role of decision costs could have been analyzed by Kübler and Müller (2002) without additional treatments. Since undergraduates as well as graduates participate in their experimental study and decision costs are likely to be lower for graduates than for undergraduates, a separate evaluation of the two groups seems to be promising. However, due to the post-experimental questionnaire, these two groups cannot be identified.

Another argument for the poor results under quantity competition is mentioned by Huck et al. (2001, 2002) themselves, Lau and Leung (2007), and Santos-Pinto (2008): disadvantageous inequality aversion.[10] Since both reaction curves slope downward, none of them enters the Pareto superior set relative to the equilibrium of the Cournot game (see Figure 4, i). Hence, a firm's Stackelberg leader profit exceeds its Cournot profit and its Cournot profit exceeds its Stackelberg follower profit: Stackelberg competition disadvantages the following firm relative to Cournot competition.[11]

Since both reaction curves slope upward under price competition, that is, each of them

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[9]There are experimental studies in which higher payoffs do not cause a better performance of the participants. For a survey, see Camerer and Hogarth (1999).

[10]For a discussion of disadvantageous inequality aversion in ultimatum bargaining games, see Güth et al. (1982). For a survey on ultimatum bargaining behavior, see Güth and Tietz (1990).

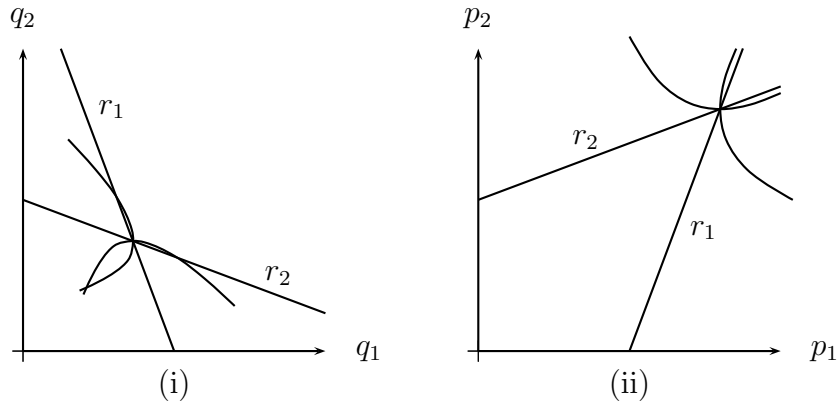[11]For a detailed presentation, see Hamilton and Slutsky (1990).

Figure 4: Reaction curves and Pareto superior sets.

enters the Pareto superior set relative to the equilibrium of the Cournot game (see Figure 4, ii), a firm's Stackelberg follower profit exceeds its Stackelberg leader profit and its Stackelberg leader profit exceeds its Cournot profit: Stackelberg competition advantages both firms relative to Cournot competition. Hence, Huck et al. (2002) conjecture that endogenous Stackelberg price competition might be more likely to be observed in the laboratory than endogenous Stackelberg quantity competition. Their conjecture is supported by a partially successful application of Fehr and Schmidt's (1999) model of inequality aversion by Huck et al. (2001): on the one hand, their data suggest that Stackelberg followers are averse to disadvantageous inequality; on the other hand, Stackelberg leaders seem to be advantageous inequality loving. Kübler and Müller's findings on exogenous Stackelberg price competition are in line with this conjecture.

# 5 Conclusion

I have summarized and analyzed experimental studies on duopolistic quantity competition with homogeneous products and duopolistic price competition with heterogeneous products. First, I find that only a handful of experiments checking Cournot competition against Stackelberg competition have been conducted yet and that only one of these

19

experiments involves price competition. Second, I assert that Stackelberg equilibrium outcomes are seldom under quantity competition and that the Stackelberg equilibrium prediction seems to be more appropriate under price competition. Third, I get that experimental designs seem to be in the domain of the theory as long as the auxiliary hypothesis that firms act like subjects is taken to be true.

Tasks seem to be "simple". Contemplating whether there has been "sufficient" time for learning, the picture is mixed. Some sessions consist of 30 rounds. Others only have 10 rounds. Incentives seem to be "adequate" because payoffs are chosen to reflect opportunity costs, but losses from playing a disequilibrium strategy can be low. Following Smith and Walker (1993), I argue that this may be an argument for the poor results. Another reason is mentioned by Huck et al. (2001, 2002) themselves: disadvantageous inequality aversion. Their reasoning is supported by a partially successful application of Fehr and Schmidt's (1999) model of inequality aversion.

Due to the methodological problems mentioned above, I reason that the quantity competition models have not been falsified so far. However, doubts seem to be appropriate. Therefore, I suggest further research on the adequacy of incentives. This is of particular importance in experiments on endogenous competition models. Concerning the high complexity of those experiments, high decision costs are likely to be expected. Increasing the number of rounds solely may not suffice.

In consideration of the results of experiments on quantity competition models, Kübler and Müller's (2002) findings are surprising. Since decision costs are likely to be the same as those under quantity competition, incentives cannot be assumed to be stronger. However, according to Fehr and Schmidt's (1999) model of inequality aversion, as in the experiments on quantity competition, subjects seem to be advantageous inequality loving. Aside, many price competition models have not been tested yet (see Table 4 in the appendix). So far, I reason that there is not enough experimental research to speak

of evidence for the price competition models.

Independently of the results of further experimental research, treating firms as economic agents with the sole objective of profit maximization seems to be problematic in the case of oligopolistic competition: if only few firms are present in a market, these firms are large and complex. Typically, they are characterized by a separation of ownership and management. This fact is not taken into account in any model. However, such institutional arrangements may be important. For example, Vickers (1985), Fershtman and Judd (1987), and Sklivas (1987) show that strategic delegation can serve as a commitment device in a Cournot oligopoly market.

# Appendix

| Variable | Model | | Experiment | |
|---|---|---|---|---|
| | Author(s) | Order of moves | Author(s) | Course of action |
| Quantity | Cournot | exogenous | Huck et al. (2001) Fonseca et al. (2005) | pen and paper |
| | Stackelberg | exogenous | Huck et al. (2001) | pen and paper |
| | Saloner (1987) and Ellingsen (1995) | endogenous | Müller (2006) | computer |
| | Hamilton and Slutsky (1990): "action commitment" | endogenous | Huck et al. (2002) | computer |
| | Hamilton and Slutsky (1990): "observable delay" | endogenous | Fonseca et al. (2006) | computer |
| | van Damme and Hurkens (1999) | endogenous | Fonseca et al. (2005) | pen and paper |
| Price | Cournot | exogenous | Kübler and Müller (2002) | computer |
| | Stackelberg | exogenous | Kübler and Müller (2002) | computer |
| | Hamilton and Slutsky (1990): "action commitment" | endogenous | no experiments yet | |
| | Hamilton and Slutsky (1990): "observable delay" | endogenous | no experiments yet | |
| | van Damme and Hurkens (2004) | endogenous | no experiments yet | |
| | Pastine and Pastine (2004) | endogenous | no experiments yet | |
| | Amir and Stepanova (2006) | endogenous | no experiments yet | |

Table 4: Models and experiments.

Source: Author.

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