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## Competition in Stackelberg Oligopolies:

## First Mover Advantage vs. Inequality Aversion

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# Competition in Stackelberg Oligopolies - First Mover Advantage vs. Inequality Aversion

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**Abstract**

This paper reports on experimental results from a 2-period sequential Stackelberg game where players have a one time opportunity to invest positive relative profits in order to lower marginal cost and gain competitive advantage. Theory predicts one sub-game perfect Nash equilibrium in pure strategies with both Stackelberg leaders and Stackelberg followers playing absolute profit maximizing strategies and leaders earning much larger payoffs than followers. Experimental results, however, show that Cournot play is modal. Stackelberg leaders learn to play fair through punishment. Investment to lower marginal cost was more frequent among Stackelberg followers, who used relative profit maximizing strategies to punish rather than to gain competitive advantage.

**Keywords**

Dynamic Games, Repeated Games, Laboratory Experiments, Stackelberg Equilibrium, Cournot Duopoly, Profit Maximizing, Competitive Advantage

**JEL Classifications**

C730, C910, D430, L210, L250

# 1 Introduction

In 1964 Stiegler wrote, "No one has the right, and few the ability, to lure economists into reading another article on oligopoly theory without some advance indication of its alleged contribution." A large amount of articles has emerged since then and according to Selten et al. (1997) [22], "After 150 years since Cournot (1838) [5] the duopoly problem is still open." Selten et al. (1997) [22] point out that, "An empirically well supported duopoly theory has not yet emerged." Since Cournot (1838) [5] introduced his equilibrium, research in quantity games has progressed to take on much more of a behavioral character. Assumptions about information were relaxed allowing for different approaches to develop. Especially since Alchian (1950) [1] the idea that it is only profit maximization that drives firm behavior has been disputed. Many articles sprung from Alchian's insightful conclusion that firms do not have enough information to be profit maximizers, thus making the more successful firm the more likely survivor. Schenk-Hoppe (2000) [21] points out that obtaining information about inverse demand and cost is either extremely costly or simply impossible, which may render the game theoretical toolbox useless. Harstad and Selten (2013) [9] call for closer collaboration between theoretical modeling and experiments and that too little headway has been made to move away from the optimization approach.

The experiment reported on in this paper suggests that the game theoretical toolbox is a rather poor predictor for Stackelberg duopolies and previously reported deviations from theorized outcomes can be confirmed. Theory predicts one sub-game perfect Nash equilibrium in pure strategies for the repeated dynamic Stackelberg game with large discrepancies in payoffs for Stackelberg leaders and Stackelberg followers. Players are presented with an opportunity to invest positive relative profits into cost-saving technologies to lower marginal cost for the following period gaining competitive advantage. Experimental results indicate that the Cournot quantity is the most frequently chosen quantity with only minor differences in payoffs between leaders and followers. Some Stackelberg leaders choose Cournot quantities in an effort to play fair in order to sustain long term relationships with equal market shares, while others learn to play Cournot through retribution of Stackelberg followers. Overall, investment into cost saving technologies only play a minor role and the driving force is equality in payoffs considering future relationship. Due to similar outcomes in Huck et al. (2001)[10] and

Fonseca et al. (2005)[7] there are strong indications that optimization may not be a good predictor in Stackelberg games as fairness trumps the rational optimization approach.

# 2 Literature

Alchian (1950) [1] suggested that if firms do not know how to maximize, they may either imitate or attempt trial and error. It is straight forward that, if lacking necessary optimization information, firms will try to imitate competitors with superior performance. In other words, if positive profits exist, and the market is symmetric, it is relative performance that matters as there is no other reference point against which to measure. The firm with the highest output will outperform its' lower output competitors and, thus, be imitated. Vega-Redondo (1997) [26] shows theoretically that long-run behavior is characterized by the Walrasian quantity, when all firms chose simultaneously, produce the same good, and face a downward sloping demand curve (see also Rhode and Stegeman, 2001 [17]). His model, however, only holds true if no firm maintains memory of previous profits, i.e. eliminating any reference point other than relative current performance. Vega-Redondo's model renders oligopolies more competitive compared to the perfect information scenario.

Another behavioral trait that may make oligopolies more competitive is spite. If firms are completely spiteful the market will converge at the Warasian equilibrium irrespective of the underlying information structure. A spiteful player may be willing to lower her own profits if in turn she lowers her competitors' profits even more, thus creating a advantageous market position (see Schaffer, 1989 [20] and Hamilton, 1970) [8]). Maynard Smith and Price (1973) [24] show that spiteful behavior is an evolutionary stable strategy, in that, if adopted by most members of a population there exist no mutant strategy that would result in higher reproductive fitness. Vriend (2000) [27] studies a genetic algorithm to point out the differences in learning dynamics. He shows that there are two aspects to spite: one being purely spiteful players, who receive enjoyment from beating others, thus there exist preferences for spiteful behavior and second, spiteful behavior relating to the limited perception of players (bounded rationality, learning, information etc). A different result is discussed in Milgrom and Roberts (1991) [14], who developed their take on adaptive (sophisticated) learning. According to the authors pure imitation is as far-fetched an assumption as equilibrium play, as firms will not merely base their decision on some rule about past play, i.e. they are intelligent and learn to learn by combining past experiences with whatever else that may contribute to making appropriate decisions. The authors show that over time players will converge at the Nash equilibrium, see also (Conlisk, 1980 [4] and Rassenti et al., 2000) [16])

Selten et al. (1997) [22] show that in a finite super game of asymmetric Cournot duopoly, instead of optimization, players use fairness to form co-operative goals called ideal points, which they try to achieve through reciprocation. In Selten and Ostman (2000) [23], the authors show that symmetric duopolies with common knowledge of demand and cost function, as well as communication, seem to have a tendency towards collusive behavior, while asymmetric duopolies without communication and with little information about other players' profits have the tendency to converge towards the Cournot-Nash equilibrium. Huck et al. (1999)[11] show that, in general, more information about the market yields less competitive outcomes while more information about competitors yields more competitive outcomes, see also Huck et al. (2000) [12]. Bernhardt and Bergin (2004) [2] discuss theoretically two types of learning dynamics. Their contribution lies in their analysis of how long-run equilibrium outcomes depend on the historical information received through these two learning dynamics. The two types of learning discussed are learning by imitation of others and learning by introspection, meaning individual learning, see also Riechmann (2006a) [19] and Riechmann (2006b) [18]. The results show that introspective learning leads to the Nash equilibrium and that for imitative dynamics the outcome lies in the point where no player can increase the difference between himself and other players, i.e. the Walrasian outcome.

Huck et al. (2001)[10], study a Stackelberg duopoly experimentally and compare it to the simultaneous moves model of a standard Cournot case. Theory predicts higher output and lower aggregate profits in the Stackelberg game. Experimental results show that for both fixed and random matching Stackelberg output is higher than Cournot output. The fixed pair treatment indicates that aggregate output is lower than under random matching for both Counot and Stackelberg. The authors find that there is much less collusion in Stackelberg markets than in Cournot markets. They also report considerable deviation from the theorized output in the Stackelberg market, and that when pairs are fixed, markets become less competitive, i.e. Stackelberg leaders produce, on average, less than theoretically predicted, while Stackelberg followers produce more than theoretically predicted. The authors argue that this is in line with the prediction of Fehr and Schmidt (1999) [6], and that the behavior of the Stackelberg follower can be explained through reward for cooperative behavior of the Stackelberg leader and punishment of the Stackelberg leader for choosing an exploitative approach, i.e. inequality aversion. Huck et al. (2002) [13] found that despite theoretical predictions Stackelberg leadership almost never emerges (see also Mueller, 2006 [15]). Instead they found that the Cournot-Nash was achieved in about 50% of all plays. Fonseca et al. (2005)[7] added asymmetry to the model which, theoretically, should strengthen the emergence of Stackelberg leadership of the low-cost firm. However, experimental evidence suggests that despite the introduced asymmetry no significant differences, compared to the symmetric case, can be observed and the previous results of Huck et al. (2002)[13] are robust and Cournot play is the most frequently played quantity.

# 3 Theoretical Predictions

The following experimental model is a simple parameterized oligopoly with 2-periods. There exist a one-time possibility (period one) to lower marginal cost if players successfully outperform their competitor in terms of profit, i.e. positive relative profit. The idea goes as follows, if players achieve the same level of profits, then, by assumption, all players can invest the same amount into cost-saving technologies and lower marginal cost by the same amount. If, however, one player achieves positive relative profit, then, by assumption, the player may gain a competitive advantage in the following period due to the larger investment into cost-saving technologies. Bester (1993) [3] states that the closer substitutes the good are, the larger the amount of investment into cost reduction may be. As both Stackelberg leaders and followers produce one homogeneous good, behavior in period one may center around the relative profit maximizing strategy in order to reduce cost for period two.

Inverse Demand:

$$P^t(Y^t) = 160 - Y^t, \text{ where } Y^t = \sum_{i=1}^{2} y_i^t \tag{1}$$

Firms face the following cost function:

$$C^t(y_i^t) = 40(1 - \delta_i^t)y_i^t, \text{ where} \tag{2}$$

$$\delta_i^t = \frac{I_i^{t-1}}{\pi_i^{t-1}}2, \text{ and} \tag{3}$$

$$I_i^{t-1} = \frac{\pi_i^{t-1} - \pi_{-i}^{t-1}}{2} \forall\ \pi_i^{t-1} > \pi_{-i}^{t-1} > 0, \text{ else } I_i^{t-1} = 0 \tag{4}$$

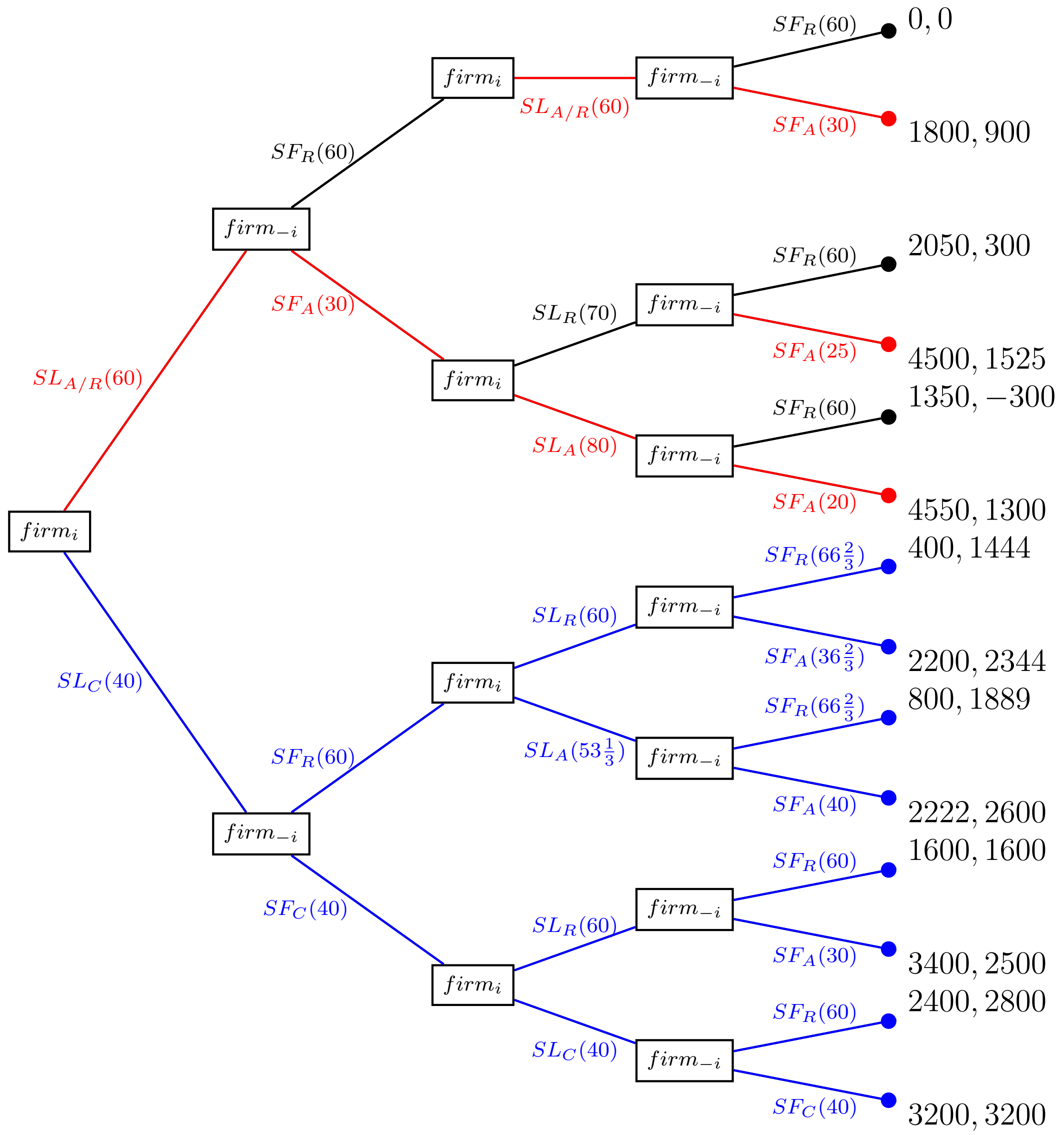
It follows that:

$$\delta_i^t = \frac{\pi_i^{t-1} - \pi_{-i}^{t-1}}{\pi_i^{t-1}} \tag{5}$$

Equation (2) deserve some clarification. It is proposed that in period $t$ cost not only depends on output $y_i^t$ but also on some delta $\delta_i^t$. The size of $\delta_i^t$ depends on an amount invested $I_i^{t-1}$ into cost-saving technologies in the previous period. The investment is double effective in cost. For simplicity it was predetermined that players would invest half their positive relative profits. Alternatively one might leave the investment up to the player. This, however, renders the experiment much more complicated as the payoff vector for period 2 becomes very large and computation of possible future scenarios would be too complicated for the present experiment (it would make for an interesting future experiment). Mathematically speaking, equation (3) and (4) are obsolete. In the experiment, however, it is important for players to understand that any decrease in marginal cost is the result of an investment into cost-saving technologies as opposed to merely a reward for positive relative profits. This also explains the difference between profit and payoff, as a player's profit may not be her payoff due to the money invested. Both firms start out in cost symmetry, as the cost function's $\delta_i^t$ does not yet exist, assuming $t$ being the first period.

Due to the dynamic character of the model it seemed appropriate to limit the number of quantity choices to four. It was essential that player were able to foresee all eventualities to make "informed" decisions, which might have been compromised using a fifth or more quantities. The available quantities consisted of the absolute profit maximizing quantity (A), the relative profit maximizing quantity (R) and two other quantities, one between A and R referred to as high quantity (H) and one being the lowest quantity (L). H and L were fitted in equal distances between and below A and R. The game tree (figure 1) summarizes the outcomes and allows for a concise way to find the existing sub-game perfect Nash equilibrium in pure strategies. The equilibrium path is highlighted in red and consists of absolute profit maximizing Stackelberg (A) play throughout. This result is perfectly in line with a simpler one-shot Stackelberg game and predicts that the Stackelberg leader (SL) will exploit the Stackelberg follower (SF) using her first mover advantage at [(60|30) and (80|20)], though, at substantially higher (lower) profits for the Stackelberg leader (Stackelberg follower) due to the arising asymmetry, i.e. the lower marginal cost for the Stackelberg leader in period two. The game tree only contains the absolute profit maximizing and relative profit maximizing quantity as the other two quantities do not play a role in the equilibrium analysis. Absolute and relative profit maximizing quantities may fall together on the same quantity for the Stackelberg leader, indicated as A/R. Given the findings by Huck et al. (2001)[10] it may be of interest to include a "fairness branch" consisting of the Cournot quantity (C) - blue branch. The Cournot branch, in fact, became the most frequently selected branch indicting that fairness considerations matter greatly, though, they may be brought on by fear of retribution as well as intrinsically fair behavior. Theory predicts SL to earn 4550 while SF only earn 1300, generating aggregate theorized payoffs in the Stackelberg game of 5850. The equal payoff scenario in the Cournot branch gives each player a payoff of 3200, which, aggregated, provides higher efficiency as $6400 > 5850$.

Figure 1: Stackelberg game with addition of Cournot branch



# 4 Experimental Procedures

The experiment was run at the laboratory for economic and business research at the University of Kaiserslautern, Germany in May 2012. Participants were recruited in class and through sign-up list on campus. All participants were either students of business administration, business administration in connection with a multitude of natural science concentration, engineering, or mathematics. Most participants had reached at least their second year of study. The experiment was pen-paper and excel spreadsheet based. All computations and available quantities had to be selected from the spreadsheets and entered into provided report cards. Subjects were randomly assigned to a specific computer in the laboratory, which ensured the initial random matching of participants. Whether players were Stackelberg leaders or followers was revealed to them at their respective computers. After the instructions were read and the spreadsheet thoroughly explained, participants were encouraged to ask questions, which were carefully answered, without providing information that went beyond the general instructions. Participants, then, were asked to fill out a short questionnaire to verify that everyone had understood the instructions and experiment. No one had to be excluded. The experiment consisted of ten games of 2 periods each, which players were informed about. Quantity options consisted of four choices, including the absolute profit maximizing quantity, the relative profit maximizing quantity, high quantity, and a low quantity but were not labeled as such.

Players were also informed that they would receive a time compensation of 7.00 EUR and additionally would receive the amount (payoff) earned in each period of the experiment. Players were informed that the payment in each period would depend on their quantity choice and the quantity choice of their opponent, who was not known to the player and was not visually accessible to them. Payoffs had a scaling factor of 1000, meaning that an actual payoff to players in the amount of, for example, 1.60 EUR corresponded to the modeled payoff of 1600. Leaders and followers were aware of the sequential nature of the experiment and were called first and second movers. In every period players would note their quantity choice on the provided report cards, which was then completed by adding the opponents quantity and both players payoff after every period. Hence, report cards also served as a history of outcomes as the experiment progressed. Excel spreadsheets served as an information tool for both leaders and followers, i.e. players would simulate all quantity combinations of first and subsequently second period and their respective outcomes. For example, leaders would test how each of their quantities would generate four different quantities for followers. They were then able to make guesses about followers' choices and payoffs in period one, as well as second period quantities and payoffs. Followers were also able simulate all possible outcomes, but had to wait until first movers made their choices before they knew what quantities were actually available for selection. This is straight forward, as different quantities chosen by Stackelberg leader would result in different quantities available to Stackelberg followers due to the sequential 4-quantity setup. This procedure was then repeated for all 10 games or 20 periods. All players were informed that they are in a market consisting of themselves and one other player. They also knew that they would play the same opponent in all 10 games. The four different quantity option in period one available to Stackelberg leaders were: 30 (L), 40 (C), 50 (H), and 60 (A/R), each resulting in four different quantities available to followers.

For Stackelberg leaders, in period one, absolute and relative profit maximizing strategies were identical, i.e. 60. The Cournot quantity, 40, was added to give first movers the option to offer a quantity to the second mover that seemed fair in terms of equal payoff. Second movers then decide whether they wanted to reciprocate or not. Both players had to consider their future relationship, in that, responding aggressively to a Cournot quantity may destroy future cooperation. Hence, options to either try to gain competitive advantage, through investment, may conflict with building long-term relationships. Payoffs in period one are computed by subtracting a player's investment from it's profit. The decision process due to the sequential nature of the game is as follows: The Stackelberg leader decides on a quantity in period one and notes it on the provided report card. The leader's choice is reported to the Stackelberg follower who enters the leaders quantity into their report card and spreadsheet. The leader's quantity then generates four quantities for the followers to choose from. After Stackelberg followers make their choices, quantities, profits, investments, period 2 costs, and payoffs become common knowledge in each duopoly. Spreadsheets then generated four choices for leaders in period two based on the results from period one and the sequential process starts over.

## 5 Experimental Results

In the following it will be examined if players quantity decisions are in line with theoretical predictions or if fairness matters more. Does experience influence decision making? In other words, do players learn from past play and the choices of the other player? Do player try to lower marginal cost through investment by playing relative profit maximizing strategies? or, is equality in payoffs preferred?

Given the 4-quantity setup of the experiment, a Cournot quantity in period two can only exist if period one strategies consist of (C|C) or (A/R|R), i.e. (40|40) or (60|60), rendering the Cournot quantity relatively fragile to minor variations. Nonetheless, Cournot play is modal at roughly 50%. Only one game is consistent with the theoretical prediction of absolute profit maximizing strategies of both leader and follower, while 39 games consisted of all Cournot play. These results confirm earlier findings by Huck et al. (2002) [13] and Fonseca et al. (2005)[7] who show that despite theoretical predictions, Stackelberg leadership almost never emerges and Cournot is the most frequently chosen quantity.

Tables 1 through 5 summarize the experimental results. The absolute profit maximizing Stackelberg quantity in period one is only selected 11% of the time. As a matter of fact, all quantities other then the Cournot quantity, are selected very little of the time, i.e. L at 9%, A at 11%, H at 13%, and R at 14%. The Cournot quantity, in period one, was selected 110 out of 200 times or 55%. This result strongly contradicts the optimization approach, suggesting that players prefer equality in payoffs over dominant strategies.

As all players faced the same opponent in all 10 games, Stackelberg leaders and followers needed to consider how current choices may influence their future relationship. If, for example, a leader could choose Cournot resulting in equal payoffs for herself and her opponent, she may be inclined to play such a quantity over her dominant strategy due to either intrinsic motives, i.e. she may be a truly fair player, or she may select Cournot quantities merely out of fear of retribution, i.e. a follower may punish unfair behavior with aggressive competitive play eroding all profits in the market. Such a Stackelberg follower may, perhaps, be called spiteful as she is willing to hurt herself only to hurt the Stackelberg leader too. However, the usual definition of spite would require the Stackelberg leader being hurt more than the spiteful follower. Due to the sequential nature of the game, this is an impossibility as followers maximum spite lies in relative profit maximizing quantities leading to zero profits for both players. The loss in potential payoff is greater for the leader than for the follower though. It is difficult to pinpoint spite as a motive here, as relative profit maximizing quantities may be used to punish leaders to change future outcomes instead of only receiving joy from beating the opponent. Similarly, and given that a Stackelberg leader chose to play Cournot, a Stackelberg follower may reciprocate with Cournot quantities to maintain a fair relationship in future periods. Such a case may suggests that players have preferences to sustain equal market share over myopic profit maximization, which may also show that markets can allocate more sustainably than suggested by theory.

Table 1: Summary of Quantities

| Games | L | C | A | H | R |
|---|---|---|---|---|---|
| Period 1 | 9% | 55% | 11% | 13% | 14% |
| Period 2 | 14% | 44% | 26% | 9% | 8% |
| Total | 11% | 49% | 18% | 11% | 11% |

Table 2: Game 1-3 (Period 1) of Stackelberg Leaders and Followers

| Period 1 | L | C | A | H | R |
|---|---|---|---|---|---|
| Leaders | 7% | 37% | 27% | 30% | 0% |
| Followers | 3% | 33% | 7% | 3% | 53% |

Table 3: Game 4-10 (Period 1) of Stackelberg Leaders and Followers

| Period 1 | L | C | A | H | R |
|---|---|---|---|---|---|
| Leader | 11% | 67% | 11% | 10% | 0% |
| Follower | 9% | 60% | 4% | 11% | 16% |

Table 1 summarizes the game. As theory predicts one sub-game perfect Nash equilibrium in pure strategies consisting of only absolute profit maximizing behavior creating a large cost advantage for Stackelberg leaders in period

Table 4: Game 1-3 (Period 2) of Stackelberg Leaders and Followers

| Period 2 | L | C | A | H | R |
|---|---|---|---|---|---|
| Leaders | 23% | 30% | 37% | 3% | 7% |
| Followers | 3% | 23% | 50% | 13% | 10% |

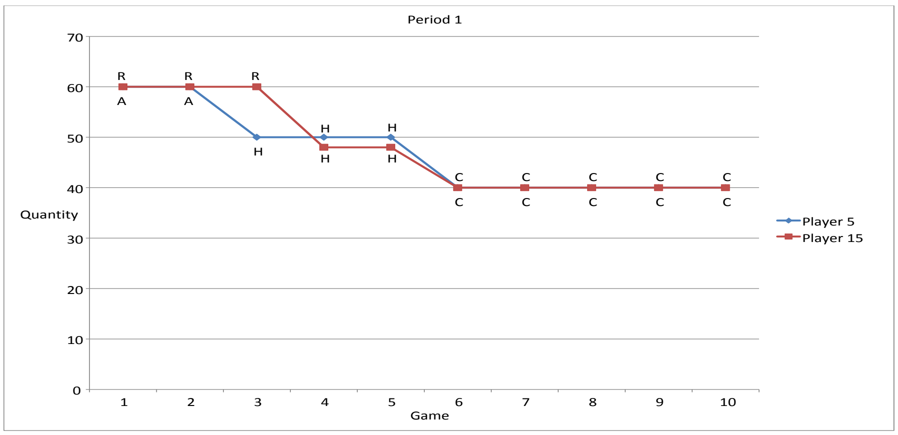
Table 5: Game 4-10 (Period 2) of Stackelberg Leaders and Followers

| Period 2 | L | C | A | H | R |
|---|---|---|---|---|---|
| Leader | 19% | 56% | 14% | 3% | 9% |
| Follower | 10% | 46% | 23% | 14% | 7% |

two, they have to decide if they wanted to play the absolute profit maximizing quantity, giving them their first mover advantage, in an attempt to earn disproportionately large payoffs, or select a quantity that may be considered fair-play in terms of equal payoffs for both players (Cournot quantity). The situation was somewhat different for the followers, as they may be able to redirect (perhaps punish) leaders for using (perhaps abusing) their first mover advantage and counter strike by selecting relative profit maximizing strategies to erode all profits to force leaders to change their strategies in the following period and games. A Wilcoxon matched-pairs signed-ranks test (one-tailed) shows that quantities in games 1-3 are significantly higher (***at the 1% level) than quantities in games 4-10. Tables 2 and 3 may explain theses differences. Stackelberg followers select R 53% of the time in games 1-3. This may be interpreted as retribution and the attempt to redirect Stackelberg leaders to play fair by chosing Cournot quantities next time around, which appears to have worked as Cournot strategies increase from 37% in games 1-3 to 67% in games 4-10 (leaders) and from 33% in games 1-3 to 60% in games 4-10 (followers) with a sharp drop in followers' R play.

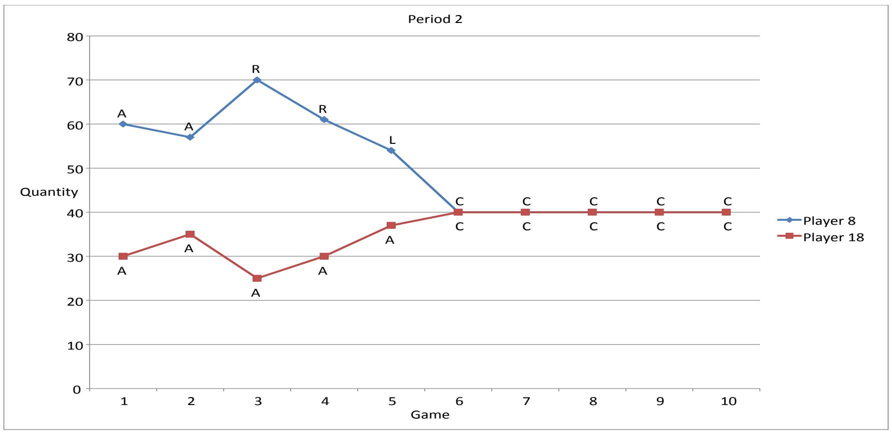
**Example:** Figure 2 depicts Player 5 (Stackelberg leader) and player 15 (Stackelberg follower) in period 1. The two players were able to established coordination of quantities over time. Player 5 notes that in the beginning her behavior was characterized by profit maximization which changed towards the middle of the game to what she referred to as stable profits (stable in the sense of equal payoff distribution at the Cournot quantity). Player 15 writes that he was interested in signaling cooperation and to "educate" (punish or suggest a better quantity) the opponent if he did not like her choice. Starting period 6 both players successfully coordinated their strategies at the Cournot quantity.

Figure 2: Strategies Player 5 and 15 in Period 1



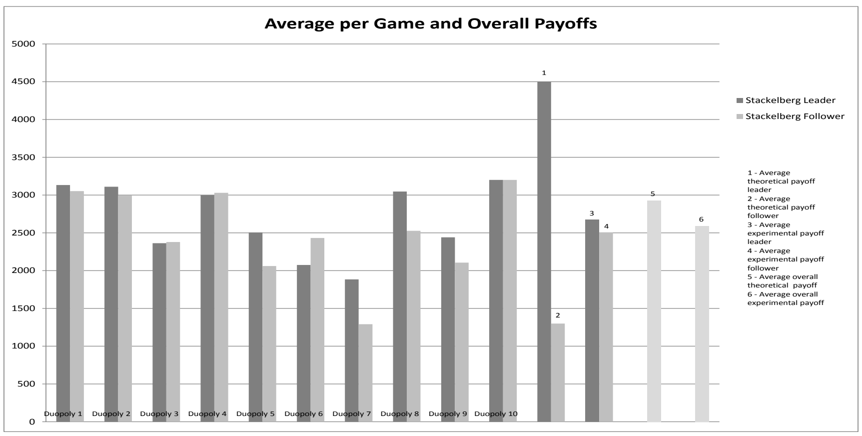

As period two is the last period in each game, punishment may be less likely. Stackelberg leaders may look for their dominant strategy in period two more so than in period one, as they do not need to fear Stackelberg followers' retribution as much as they did in period one. This effect may be weakened by the fixed pairing, i.e. punishment may happen to change the outcome in the following game. Additionally, no further investment is possible in period two, which may speak in favor of absolute profit maximizing strategies. Further analysis shows that there are no significant differences between the means of period 2 in games 1-3 and games 4-10 (Wilcoxon matched-pairs signed-ranks test, two-tailed, at the 5% level), indicating that period 2 play did not significantly become fairer or not as the experiment progressed. Nonetheless, consulting tables 4 and 5 shows that especially strategy A was largely abandoned in favor of C. Figure 3 depicts such a case. Player 8 (Stackelberg leader) and player 18 (Stackelberg follower) start playing Cournot in period 2 after game 5.

Figure 3: Strategies Player 8 and 18 in Period 2




Theory predicts that Stackelberg leaders earn an equilibrium payoff of 4550 and followers earn 1300. On average the equilibrium payoff for both first and second mover is 2955, which is below the Cournot outcome of 3200. Figure 4 depicts the actual per player average payoff, theorized individual payoffs, theorized average payoff, and experimental average payoff. Overall and combining Stackelberg leaders and followers, the average experimental payoff of 2591 is slightly lower than the averaged theorized outcome of 2955 suggesting that on average this Stackelberg game produces higher aggregate output and, therefore, a lower market price, than predicted by theory. The difference in theorized average and experimental average payoff, however, pales in light of the large differences between average theoretical and average experimental payoff of leaders and of followers, that is, when considering Stackelberg leaders and Stackelberg followers separately large differences between theory and experiment emerge. Experimental results show that Stackelberg leaders earned on average 2676 compared to 4550 (theoretical prediction) and Stackelberg followers earned 2507 compared to 1300 (theoretical prediction). This comes as no surprise as Cournot quantities are the most frequently chosen quantity (for both players) being lower than absolute profit maximizing quantities for leaders and higher than absolute profit maximizing quantities for followers. Duopoly 10 was the only market achieving perfect Cournot play for all 10 games. Consequently, players in this duopoly achieved the largest payoff of all players. Duopoly 7, on the other hand, consisted of the fewest Cournot plays and achieved the lowest payoff for both leader and follower.

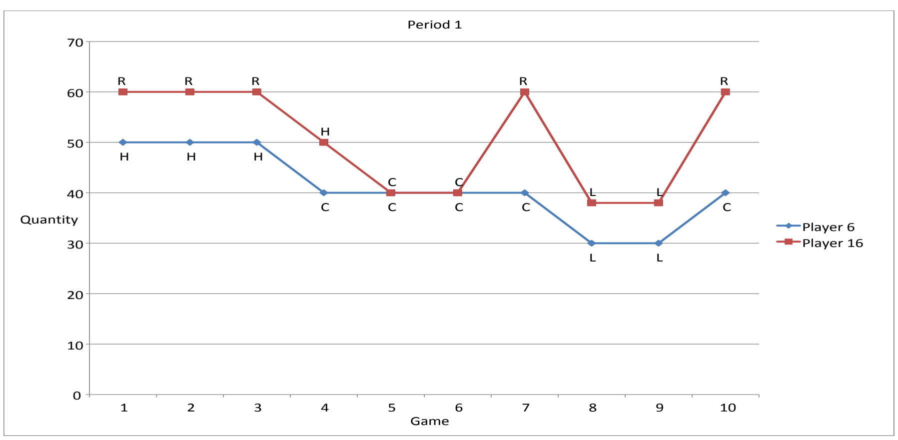
Figure 4: Average payoffs per player in the Stackelberg game.




Investment into cost-saving technologies to gain a stronger market position, i.e. lower marginal cost, which may have motivated players towards relative profit maximizing strategies, only occurred 35 out of 200 times or 17.5% and only in 8 of the 35 times was the investment achieved by Stackelberg leaders. Why did Stackelberg followers, more frequently, achieve lower marginal cost in period two than Stackelberg leaders, who had a clear first mover advantage? There are two interesting aspects to this. The first one is that in 92 first period choices Stackelberg leaders were either unable to achieve lower marginal cost, due to retribution, or they did not attempt to achieve lower marginal cost out of fairness or out of retribution fear. The second interesting aspect is that followers achieved a cost advantage 27 times indicating that they harshly punished leaders for choosing anything other than the Cournot quantity, even, for example, an H quantity (punishing H with R play happened 11 times). This is a very important point as it vehemently contradicts theoretical prediction. It also tells about fairness, in that, it may be brought about by punishment of Stackelberg followers more so than by intrinsically motivated fair Stackelberg leaders. This may explain, why in reality, we do encounter positive profits below the joint profit maximum but above Stackelberg prediction. More specifically, price fixing, in a lax meaning of the term, may happen because firms play fairer than expected, even if it is out of fear of losing profit margins.

**Example:** Figure 5 depicts Player 6 (Stackelberg leader) and player 16 (Stackelberg follower) in period 1. Although the Stackelberg leader does not fully use its first mover advantage playing absolute profit maximizing strategies, the follower replies by selecting relative profit maximizing strategies in the first 3 games and continuously selects quantities at least as high as the leader. In this particular example the follower actually outperforms the leader in term of payoff after 10 games. Overall, 3 Stackelberg followers managed to outperform the leaders in terms of payoff.

Figure 5: Strategies Player 6 and 16 in Period 1



# 6 Summary and Concluding Remarks

Choices are far from theorized predictions and Cournot play is modal. First period quantities become less competitive after the first 3 games due to successful punishment of Stackelberg followers. There are no significant differences in quantities in period 2 with respect to duration of the experiment. However, the Cournot quantity in period 2 becomes more frequent as the experiment progressed and the absolute profit maximizing quantity becomes less frequent. Inequality aversion, punishment for bad behavior, and reward for good behavior appear to play a more important role than optimization. Indeed, 12 out of 20 players noted that they were either afraid of punishment or considered punishment for bad behavior as a key motivator for choosing quantities. Investing into cost-saving technologies, and thus, lowering marginal cost for the next period appeared to not result in more competitive play indicating, once again, that fairness considerations influenced players decisions more. Experiencing retribution leads towards more Cournot play as Stackelberg leaders learn from unfairly playing their first mover advantage. Large payoff discrepancies between leaders and followers as predicted by theory can not be reported. Again, players appear to value equality over the rational optimization approach. Overall, long-term relationships with a fair market split with very little successful investment was observed and followers largely used relative profit maximizing strategies to punish and not to invest.

Due to the findings in this paper, Huck et al. (2001)[10], Huck et al. (2002)[13], and Fonseca et al. (2005)[7] there are strong indications that optimization may not be a good predictor in Stackelberg games as fairness trumps the rational optimization approach. The repeated 2-period Stackelberg duopoly experiment shows that players chose Cournot quantities about half the time. There was only one out of 100 games that was consistent with absolute profit maximizing behavior as predicted by theory. The option to invest into cost-saving technologies to lower marginal cost in the following period creating an even larger first mover advantage, which might strengthened Stackelberg leadership, which was not observed in the experiment. It remains to be tested experimentally if players' choices change with changing opponents, i.e. assigning new random opponents after every game. If no future relationship exists, especially period two quantities may be more in line with theoretical predictions. It may also be of interest to examine how investments change once they are completely optional, that is, leaving investments up to players. This, however, would make the game more complex and strategizing into future periods, given the large quantity vector, difficult. Harstad and Selten (2013) [9] call for closer collaboration between theoretical modeling and experiments. Given the very similar experimental findings in the literature and the here presented results, it may be reasonable to adjust theoretical predictions.

# References


[1] A.A. Alchian. Uncertainty, evolution, and economic theory. *The Journal of Political Economy*, 58(3):211–221, 1950.

[2] D. Bernhardt and J. Bergin. Comparative learning dynamics. 2004.

[3] H. Bester and E. Petrakis. The incentives for cost reduction in a differentiated industry. *International Journal of Industrial Organization*, 11(4):519–534, 1993.

[4] J. Conlisk. Costly optimizers versus cheap imitators. *Journal of Economic Behavior & Organization*, 1(3):275–293, 1980.

[5] A.A. Cournot. Recherches sur les principes mathematiques de la theorie des richesses. 1838.

[6] E. Fehr and K.M. Schmidt. A theory of fairness, competition, and cooperation. *The Quarterly Journal of Economics*, 114(3):817, 1999.

[7] M.A. Fonseca, S. Huck, and H.T. Normann. Playing cournot although they shouldnt. *Economic Theory*, 25(3):669–677, 2005.

[8] W.D. Hamilton. Selfish and spiteful behaviour in an evolutionary model. 1970.

[9] Ronald M Harstad and Reinhard Selten. Bounded-rationality models: Tasks to become intellectually competitive. *The Journal of Economic Literature*, 51(2):496–511, 2013.

[10] S. Huck, W. Muller, and H.T. Normann. Stackelberg beats cournoton collusion and efficiency in experimental markets. *The Economic Journal*, 111(474):749–765, 2001.

[11] S. Huck, H.T. Normann, and J. Oechssler. Learning in cournot oligopoly–an experiment. *The Economic Journal*, 109(454):80–95, 1999.

[12] S. Huck, H.T. Normann, and J. Oechssler. Does information about competitors' actions increase or decrease competition in experimental oligopoly markets? *International Journal of Industrial Organization*, 18(1):39–57, 2000.

[13] S. Huck, H.T. Normann, and J. Oechssler. Stability of the cournot process–experimental evidence. *International Journal of Game Theory*, 31(1):123–136, 2002.

[14] P. Milgrom and J. Roberts. Adaptive and sophisticated learning in normal form games. *Games and economic Behavior*, 3(1):82–100, 1991.

[15] W. Muller. Allowing for two production periods in the cournot duopoly: Experimental evidence. *Journal of Economic Behavior & Organization*, 60(1):100–111, 2006.

[16] S. Rassenti, S.S. Reynolds, V.L. Smith, and F. Szidarovszky. Adaptation and convergence of behavior in repeated experimental cournot games. *Journal of Economic Behavior & Organization*, 41(2):117–146, 2000.

[17] P. Rhode and M. Stegeman. Non-nash equilibria of darwinian dynamics with applications to duopoly. *International Journal of Industrial Organization*, 19(3-4):415–453, 2001.

[18] T. Riechmann. Cournot or walras? long-run results in oligopoly games. *Journal of Institutional and Theoretical Economics JITE*, 162(4):702–720, 2006.

[19] T. Riechmann. Mixed motives in a cournot game. *Economics Bulletin*, 4(29):1–8, 2006.

[20] M.E. Schaffer. Are profit-maximisers the best survivors?:: A darwinian model of economic natural selection. *Journal of Economic Behavior & Organization*, 12(1):29–45, 1989.

[21] K.R. Schenk-Hoppé. The evolution of walrasian behavior in oligopolies. *Journal of Mathematical Economics*, 33(1):35–55, 2000.

[22] R. Selten, M. Mitzkewitz, and G.R. Uhlich. Duopoly strategies programmed by experienced players. *Econometrica: Journal of the Econometric Society*, pages 517–555, 1997.

[23] R. Selten and A. Ostmann. *Imitation equilibrium.* Bonn Graduate School of Economics, 2000.

[24] J.M. Smith and GR Price. lhe logic of animal conflict. *Nature*, 246:15, 1973.

[25] G.J. Stigler. A theory of oligopoly. *The Journal of Political Economy*, 72(1):44–61, 1964.

[26] F. Vega-Redondo. The evolution of walrasian behavior. *Econometrica: Journal of the Econometric Society*, pages 375–384, 1997.

[27] N.J. Vriend. An illustration of the essential difference between individual and social learning, and its consequences for computational analyses. *Journal of economic dynamics and control*, 24(1):1–19, 2000.

Table 6: All data and Statistical Testing

| | Group 1 | | | | Group 2 | | | | Group 3 | | | | Group 4 | | | | Group 5 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | player 1 | | player 11 | | player 2 | | player 12 | | player 3 | | player 13 | | player 4 | | player 14 | | player 5 | | player 15 | |
| game | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 |
| 1 | 40 | 60 | 40 | 30 | 50 | 55 | 60 | 36 | 60 | 40 | 60 | 60 | 60 | 40 | 60 | 50 | 60 | 60 | 60 | 30 |
| 2 | 50 | 55 | 60 | 50 | 40 | 40 | 40 | 40 | 30 | 45 | 60 | 48 | 40 | 40 | 40 | 40 | 60 | 60 | 60 | 60 |
| 3 | 30 | 54 | 38 | 37 | 40 | 40 | 40 | 40 | 40 | 54 | 50 | 51 | 40 | 40 | 40 | 40 | 50 | 60 | 60 | 18 |
| **Group Mean in Period 1** | | **43** | | | | **45** | | | | **50** | | | | **47** | | | | **58** | | |
| **Group Mean in Period 2** | | **48** | | | | **42** | | | | **50** | | | | **42** | | | | **48** | | |
| Group Mean Total | | 45 | | | | 43 | | | | 50 | | | | 44 | | | | 53 | | |
| Mean | 40 | 56 | 46 | 39 | 43 | 45 | 47 | 39 | 43 | 46 | 57 | 53 | 47 | 40 | 47 | 43 | 57 | 60 | 60 | 36 |
| Player Mean | 48 | | 43 | | 44 | | 43 | | 45 | | 55 | | 43 | | 45 | | 58 | | 48 | |
| Mode | | 40 | | | | 40 | | | | 60 | | | | 40 | | | | 60 | | |
| 4 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 60 | 60 | 60 | 45 | 40 | 40 | 40 | 40 | 50 | 61 | 48 | 60 |
| 5 | 40 | 40 | 40 | 30 | 40 | 40 | 40 | 40 | 60 | 65 | 45 | 28 | 40 | 40 | 40 | 40 | 50 | 61 | 48 | 14 |
| 6 | 40 | 30 | 40 | 38 | 40 | 40 | 40 | 40 | 30 | 54 | 38 | 37 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 7 | 40 | 30 | 40 | 38 | 40 | 40 | 40 | 40 | 30 | 54 | 38 | 37 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 8 | 40 | 40 | 40 | 30 | 40 | 40 | 40 | 40 | 50 | 61 | 48 | 45 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 9 | 40 | 40 | 40 | 30 | 40 | 40 | 40 | 40 | 30 | 54 | 38 | 37 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 10 | 40 | 30 | 40 | 38 | 40 | 60 | 40 | 30 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 60 |
| **Group Mean in Period 1** | | **40** | | | | **40** | | | | **43** | | | | **40** | | | | **43** | | |
| **Group Mean in Period 2** | | **35** | | | | **41** | | | | **47** | | | | **40** | | | | **44** | | |
| Group Mean Total | | 38 | | | | 40 | | | | 45 | | | | 40 | | | | 43 | | |
| Mean | 40 | 36 | 40 | 35 | 40 | 43 | 40 | 39 | 43 | 55 | 44 | 38 | 40 | 40 | 40 | 40 | 43 | 46 | 42 | 42 |
| Player Mean | 38 | | 37 | | 41 | | 39 | | 49 | | 41 | | 40 | | 40 | | 44 | | 42 | |
| Mode | | 40 | | | | 40 | | | | 60 | | | | 40 | | | | 40 | | |

| | Group 6 | | | | Group 7 | | | | Group 8 | | | | Group 9 | | | | Group 10 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | player 6 | | player 16 | | player 7 | | player 17 | | player 8 | | player 18 | | player 9 | | player 19 | | player 10 | | player 20 | |
| game | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 |
| 1 | 50 | 55 | 60 | 36 | 50 | 57 | 60 | 35 | 60 | 60 | 60 | 30 | 40 | 60 | 40 | 30 | 40 | 40 | 40 | 40 |
| 2 | 50 | 57 | 60 | 63 | 60 | 60 | 60 | 30 | 50 | 57 | 60 | 35 | 40 | 60 | 40 | 30 | 40 | 40 | 40 | 40 |
| 3 | 50 | 55 | 60 | 50 | 50 | 69 | 35 | 26 | 60 | 70 | 30 | 25 | 60 | 60 | 60 | 30 | 40 | 40 | 40 | 40 |
| **Group Mean in Period 1** | | **55** | | | | **53** | | | | **53** | | | | **47** | | | | **40** | | |
| **Group Mean in Period 2** | | **53** | | | | **46** | | | | **46** | | | | **45** | | | | **40** | | |
| Group Mean Total | | 54 | | | | 49 | | | | 50 | | | | 46 | | | | 40 | | |
| Mean | 50 | 56 | 60 | 50 | 53 | 62 | 52 | 30 | 57 | 62 | 50 | 30 | 47 | 60 | 47 | 30 | 40 | 40 | 40 | 40 |
| Player Mean | 53 | | 55 | | 58 | | 41 | | 60 | | 40 | | 53 | | 38 | | 40 | | 40 | |
| Mode | | 50 | | | | 60 | | | | 60 | | | | 60 | | | | 40 | | |
| 4 | 40 | 56 | 50 | 36 | 60 | 80 | 30 | 20 | 50 | 61 | 48 | 30 | 40 | 54 | 50 | 37 | 40 | 40 | 40 | 40 |
| 5 | 40 | 40 | 40 | 50 | 60 | 60 | 60 | 60 | 30 | 54 | 38 | 37 | 50 | 55 | 60 | 36 | 40 | 40 | 40 | 40 |
| 6 | 40 | 40 | 40 | 50 | 60 | 50 | 60 | 60 | 40 | 40 | 40 | 40 | 60 | 60 | 60 | 45 | 40 | 40 | 40 | 40 |
| 7 | 40 | 53 | 60 | 53 | 50 | 55 | 60 | 50 | 40 | 40 | 40 | 40 | 30 | 50 | 45 | 42 | 40 | 40 | 40 | 40 |
| 8 | 30 | 54 | 38 | 51 | 40 | 60 | 40 | 60 | 40 | 40 | 40 | 40 | 30 | 60 | 45 | 37 | 40 | 40 | 40 | 40 |
| 9 | 30 | 56 | 38 | 50 | 50 | 55 | 60 | 50 | 40 | 40 | 40 | 40 | 40 | 58 | 50 | 35 | 40 | 40 | 40 | 40 |
| 10 | 40 | 50 | 60 | 42 | 60 | 40 | 60 | 40 | 40 | 40 | 40 | 40 | 60 | 60 | 60 | 30 | 40 | 40 | 40 | 40 |
| **Group Mean in Period 1** | | **42** | | | | **54** | | | | **40** | | | | **49** | | | | **40** | | |
| **Group Mean in Period 2** | | **49** | | | | **53** | | | | **42** | | | | **47** | | | | **40** | | |
| Group Mean Total | | 45 | | | | 53 | | | | 41 | | | | 48 | | | | 40 | | |
| Mean | 37 | 50 | 47 | 47 | 54 | 57 | 53 | 49 | 40 | 45 | 41 | 38 | 44 | 57 | 53 | 37 | 40 | 40 | 40 | 40 |
| Player Mean | 44 | | 47 | | 56 | | 51 | | 43 | | 40 | | 51 | | 45 | | 40 | | 40 | |
| Mode | | 40 | | | | 60 | | | | 40 | | | | 60 | | | | 40 | | |

| | | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | | Group 6 | Group 7 | Group 8 | Group 9 | Group 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | d | 3 | 5 | 7 | 7 | 16 | | 13 | -1 | 13 | -2 | 0 |
| Comparing period | sign | - | - | - | - | - | | - | + | - | + | |
| 1 means - games | rank | 3 | 4 | 5.5 | 5.5 | 9 | | 7.5 | 1 | 7.5 | 2 | |
| 1-3 and 4-10 using | signed rank of d | -3 | -4 | -5.5 | -5.5 | -9 | | -7.5 | 1 | -7.5 | 2 | 0 |
| Wilcoxon | sum of abs T+ | | | | | | 3 | | | | | |
| matched-pairs | sum of abs T- | | | | | | 42 | | | | | |
| signed-ranks test | T=min{T+,T-} | | | | | | 3 | | | | | |
| (one-tailed) | critical value | | | | | | 3 (for n=9 and alpha=0.01 one-tailed) | | | | | |
| | significance | | | | | | (*** significant at the 1% level) | | | | | |
| | d | 12 | 1 | 3 | 2 | 4 | | 4 | -7 | 5 | -2 | 0 |
| Comparing period | sign | - | - | - | - | - | | - | + | - | + | |
| 2 means - games | rank | 9 | 1 | 4 | 2.5 | 5.5 | | 5.5 | 8 | 7 | 2.5 | |
| 1-3 and 4-10 using | signed rank of d | -9 | -1 | -4 | -2.5 | -5.5 | | -5.5 | 8 | -7 | 2.5 | |
| Wilcoxon | sum of abs T+ | | | | | | 10.5 | | | | | |
| matched-pairs | sum of abs T- | | | | | | 34.5 | | | | | |
| signed-ranks test | T=min{T+,T-} | | | | | | 10.5 | | | | | |
| (one-tailed) | critical value | | | | | | 6 (for n=9 and alpha=0.05 two-tailed) | | | | | |
| | significance | | | | | | (no significant differences) | | | | | |