Competitiveness and Spiteful Behavior in Simultaneous and Sequential Oligopoly Quantity Games - A Two Period Model with the Possibility to Lower Marginal Cost After Period One

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1 Introduction

There has been a vast amount of literature on oligopolies over the past 60 years. Since Cournot (1838) [12] introduced his equilibrium, which was later generalized by Nash (1951)[27], research in quantity games has progressed from pure theory 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, and thus, it is the more successful firm that is more likely to survive in the market and not the one that maximizes absolute profits, as it does not know how to maximize. I introduce some of that literature in section 2 of this dissertation.

Oligopolies are not only the most frequent market form encountered in reality, which in itself makes them very interesting to study, but also, their interactive character makes them an ideal candidate for laboratory experiments[1]. Oligopolistic firms, unlike perfectly competitive ones, have power over the market price, though, unlike with monopolies, it is limited, depending not only on one firm but on all firms acting in the oligopolistic market. It follows that the market price is influences some by all acting firms. Theoretical equilibrium outcomes in oligopolistic quantity games are somewhere in between perfect competition and monopolies, i.e. according to the Cournot-Nash equilibrium firms earn positive economic profits with a resulting loss in overall welfare compared to the efficient outcome of perfect competition but smaller loss of welfare compared to the monopolistic outcome. Quantity games in oligopolies (or Cournot games), in equilibrium, produce less output than perfect competition resulting in a market price that lies above marginal cost, which is why oligopolistic firms earn positive economic profits. Assuming that firms have enough information to achieve an absolute profit maximum is a rather strong assumption, which requires firms to have a deep understanding of the market, and in particular, information about inverse demand function and cost function. Obtaining information about inverse demand and cost is either extremely costly or simply impossible due to the complexity of the market. In order to understand how firms in oligopolistic

[1]see Riechmann (2008) [33] for a game theoretical workup of oligopolies.

settings make choices, the game theoretical toolbox may be rendered useless, as Schenk-Hoppe (2000) [38] points out, and new behavioral rules need to be established.

Two important ideas that go back to Alchian (1950) [1], which have been dominating the literature over the past 60 years, are imitation of successful behavior and trial and error. Alchian's notion is straight forward, if firms do not know how to maximize, on account of limited information on inverse demand and cost functions, thus not knowing how to achieve maximal profits, they either learn from their competition by imitating behavior that is more successful than their own, meaning if a firm earns larger profits than another, the firms with the larger profit will be imitate, or firms may choose to simply try new strategies and observe how successful they are. Vega-Redondo (1997) [48] introduced a theoretical model based on imitation that showed that if firms imitate the best, in terms of profit, and whenever firms have no memory of previously achieved profits, thus not being able to compare their profits to previous performance, the market will bring about a stable equilibrium at the Walrasian outcome, where the market price equals marginal cost and no economic profits can be earned. This is a large contradiction to the Cournot-Nash outcome, where firms earn positive profits, and is based on exactly the relaxation of the assumption that firms have information about the inverse demand function. Vega-Redondo's article, thus, implies that, if aggregate output is below the perfectly competitive level, a firm that increases output beyond the, here unknown optimal level of output, will outperform its competition if it produces more than its competition. This will generate the largest profit for the firm with the highest level of output. This also means that the increased level of output will lower the market price and shrink profits for everyone, however, will give the firm with the highest output the largest profit in the market. As there is no memory, firms only look at other firms to compare and the one with the largest profit will be copied in the next period. This process will converge at the competitive market equilibrium were all profits cease. It follows that a firm hurts itself in absolute terms, by increasing output, however, it will earn more than its competition creating a better chance to survive in the market. Hamilton (1970) [18] called this spiteful behavior, when a firm is willing to hurt itself only to hurt others more (in Vega-Redondo (1997) [48] this process is endogenous and firms may not realize that they act spitefully). Vega-Redondo's model is closely related to the works of Maynard Smith and Price (1973) [43], who first introduced the concept of evolutionary stable strategies (ESS) using Hamilton's notion of spite. A strategy is said to be evolutionary stable, if adopted by most members of society, there exist no mutant strategy that yield higher reproductive fitness, i.e. market survival. Given that it is firm survival in the market that dictates behavior, visa vie being better than ones competition, spiteful behavior may be an important behavioral trait research needs to consider. Hamilton's spite and Vega-Redondo's model of imitation of successful behavior spawned a large amount of laboratory experiments that aimed to test experimentally how firms (players) behave when information about inverse demand is absent. Quite a few experiment emerged to test how different types of information changed firm behavior and, specifically, what is the directional development, that is, can Cournot play be observed or does behavior in certain setting does converge at the Walrasian equilibrium, as predicted by Vega-Redondo? Generally speaking, experimental results suggest that more information about ones opponent renders the market more competitive while more aggregate information will result in a movement closer to the Cournot prediction, see for example Huck et al. (2000) [21].

The research focus and contribution of this dissertation lies in gaining a clearer picture and better understanding of if, how, and why firms behave spitefully when both relative profit maximizing strategies and absolute profit maximizing strategies are available. In other words, is there a deeper reason for spiteful behavior, other than the pure joy of beating ones competition, and if yes, what is it? This implies that firms must be aware of being spiteful, though they may not call it that, or on the contrary, playing absolute maximizing strategies. I, therefore, created a 2-period model in which firms, when outperforming their competition, in terms of profit in period 1, would invest into cost-saving technologies, resulting in cheaper ways to produce output, decreasing marginal cost for the second (last) period. This finite dynamic model is then applied to both a simultaneous moves (Cournot) duopoly model and a sequential moves (Stackelberg) model. Derived theoretical solutions show that the Cournot model results in a mixed strategy equilibrium with the prediction of firms choosing Cournot quantites 71% of the time while playing Walrasian quantities 29% of the time. Theory predicts that the Stackelberg model results in one sub-game perfect Nash equilibrium in pure strategies with both Stackelberg leader and Stackelberg follower choosing absolute profit maximizing quantities in both periods and no spiteful behavior. These theoretical outcomes are then applied to two laboratory experiments examining players behavior in the 2-period model.

The results show that in the simultaneous moves model behavior is much more competitive in period one than in period two. This suggest that players behave spitefully, i.e. choosing Walrasian strategies, if they can gain competitive advantage by lowering marginal cost and, thus, earning larger profits than otherwise possible. One explanation may be that firms behave more competitive whenever there is a chance to gain market share, in their ultimate quest to gain monopoly status resulting in the largest possible profit. Behavior in period two is close to theoretical prediction of Cournot play, thus, if no more investment into cost-saving technologies takes place firms maximize absolute profits, i.e. the Cournot outcome. Average payoffs in the Cournot game were below theorized predictions and significantly lower than in the sequential moves game.

In the Stackelberg game, results show that Cournot play is modal throughout both periods. This is far from the theoretical prediction of absolute profit maximizing Stackelberg play for both first and second mover. The reason for this kind of behavior may be found in other-regarding preferences, and in particular inequality aversion and cooperation. Theory predicts a large discrepancy between Stackelberg leader and Stackelberg follower, in terms of quantity and in terms of payoff, which may create friction between the players, as the Stackelberg follower may feel that she is being exploited in favor of the Stackelberg leader. The experimental results suggest, though there still is a significant difference in the average quantity of first and second move between the two periods, it falls far short of the large differences predicted by theory. In fact, there is only one case were players played a perfect Stackelberg outcome, while 39% of all games consisted of perfect Cournot play. It follows that spiteful behavior serves a different purpose in the sequential moves game, that is, it is used to punish Stackelberg leaders for trying to gain an unequal payoff split. In fact, Equality in payoff appears to be the driving force in the Stackelberg game, triggered by possible punishment of Stackelberg followers and punishment fears of Stackelberg leaders. This results in output centering around the Cournot quantity.

The remainder of this dissertation is organized in the following way: in section 2, I introduce some of the more prominent literature, from which a learned great deal and which helped me structure and base ideas upon.

Section 3 introduces the general model incorporating the research idea and on which the two experiment in section 4 are based. Section 4 introduces said experiments, which are parameterized versions of the general model. Section 5 explains the experimental procedures and section 6 is dedicated to report on the results obtained from both simultaneous and sequential moves games. I conclude this dissertation in section 7 with a summary of the findings and some remarks.

2 Literature Review

In 1964 Stiegler [46] 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) [40], "After 150 years since Cournot (1838) [12] the duopoly problem is still open." Selten et al. (1997) [40] point out that, "An empirically well supported duopoly theory has not yet emerged." The latter statement makes me confident that scientific contribution may be inferred from this present dissertation.

Indeed, a vast number of papers have focused their attention on developing such a theory, and headway has been made due to the insightful contributions of many authors. Since Cournot (1838) [12] developed his equilibrium in oligopolies, which was later generalized by Nash (1951) [27] to become the Cournot-Nash equilibrium at the point of best mutual responses, research has set out to explain behavior beyond the traditional game theoretical methodology. Although the Cournot-Nash equilibrium represent a theoretically sound outcome, it is the assumptions of this model that have been widely criticized. If all firms know exactly what the downward-sloping demand function, cost function, and actions of all other firms look like, and one assumes that absolute profit maximization is indeed what all rational-decision making firms are after, then, a stable outcome is reached at the Cournot-Nash equilibrium. However, this is not a scenario that seems overly realistic, and, as many authors show, different outcomes emerge as the underlying assumption change.

Alchian (1950) [1] points out that if firms have uncertain foresight, profit maximization may be rendered meaningless as a guide towards successful decision-making, though, it is profits by which successful and surviving firms are selected. It must therefore hold that the more successful firm and not the profit-maximizing firm, as firms do not know how to maximize, will survive in the market irrespective through what means. It is the firm that outperforms its competition that will generate positive profits, and that the crucial point is its relative position in the market compared to its actual competitor and not some hypothetical perfect profit maximizer. He continues to emphasize the following important aspect, "... models of behavior replace optimum equilibrium conditions as guiding rules of action." Alchian had, thus, successfully "opened the door" for behavioral economics to further analyze the duopoly model and suggested himself two mechanisms by which one could achieve positive profits in the absence of perfect information.

1. Individual Adaptation Through Imitation
If firms do not know how to maximize, than firms will observe and copy more successful competitors.
2. Trial and Error
Firms, through trial and error, may find more profitable ways to produce and continue to develop towards more profitable production, which may be seen as convergence towards a profit maximizing equilibrium.

Later research is based on exactly these two (and others) mechanisms [e.g. see Vega-Redondo (1997) [48], Huck et a. 2000 [21], Apesteguia et al. (2010) [5], Alós-Ferrer and Ania (2005) [3]].

Another important question concerns firm behavior even if perfect information is assumed. In his 1953 book "Essays in positive economics," Milton Friedman [16] argues that absolute profit maximization appropriately summarizes the best strategy for a firm, and whenever a firm does not behave in this manner it is likely to lose resources. Baumol (1958) [6] however, argued that firms are partially willing to forgo current profits in favor of future sales. He observed that the typical larger corporation in the United States maximizes revenues rather than profits, subject to a certain profit constraint. This profit constraint appears to be in place to generate large enough current profits to ensure growth with respect to expansion plans, dividends, and future sales. To the best of this author's knowledge, and next to Alchian (1950) [1], Baumol's 1958 paper is the first study that introduces a departure from pure short-run absolute profit maximizing objectives in exchange of a relative performance objective, though, he did not call it that. Both Alchian (1950) [1] and Baumol (1958) [6] triggered the further progress away from a pure absolute performance driven Cournot-Nash outcome[2].

Relative performance, rather than absolute performance, can be explained by the following reasoning. Let us assume a symmetric two firm market,

[2]It is worth noting that an optimal outcome in relative profit maximization does represent a Nash equilibrium if the given objective is the maximization of relative performance rather than absolute performance.

where firms face downward-sloping demand and sell all produced commodities in the market. Both firms can achieve the same absolute profit maximum at the Cournot-Nash equilibrium. Now, if one chooses to deviate from the Cournot-Nash outcome, by, say, increasing output beyond the Cournot-suggested quantity, while the other firm strictly produces Cournot quantities, then the deviating firm will raise total market output and lower the respective market price. The resulting outcomes in terms of profit are smaller for both firms compared to the absolute profit maximum, however, the firm that increased production will now outperform its competitor. Such behavior of the output-increasing firm may be referred to as spiteful.

Hamilton (1970) [18] was the first to use the term spite in the following sense, if an animal is ready to harm itself only to harm other even more, then such behavior maybe called spiteful. Hamilton also explains that with finite populations spiteful behavior may have its selective advantage and that it should be looked for in dwindling panmictic species. Hamilton uses the example of polygamous and promiscuous bower birds who wreck the bowers of their neighbors to increase their own breeding chances, as an impressive bower may be beneficial when finding a mate, i.e. relative attractiveness. He also notes that the reason why one cannot find more convincing examples of spite, is that actions are costly and that it may be hard to identify which member of a species are less than average related, and thus "fair game" to practice spiteful behavior. Although Hamilton did not relate his article to economics it became an essential building block for others to form new ideas about economic behavior.

Maynard Smith and Price (1973) [43] developed the idea of an evolutionary stable strategy (ESS) by using game theoretical methodology in connection with Hamilton's 1970 [18] notion of spite. In their important and influential paper, which was later generalized and brought into economic context by Schaffer (1988) [36] and (1989) [37], they show that an ESS is a strategy such that, if adopted by most members of a population there exist no mutant strategy that would result in higher reproductive fitness. As already mentioned, it was Schaffer (1988) [36] and (1989) [37] who brought the idea of evolutionary stable strategies into economic context by extending on Maynard Smith and Price (1973) [43] to generalize the model to hold for finite populations (N) and variable contest size (C). Schaffer (1988) [36] assumes a population of size N, entirely consisting of ESS strategies (s^{ESS}). Now, one ESS strategy is replaced by a mutant strategy (s^M). It follows that the probability of an ESS player facing a mutant player is: $\frac{C-1}{N-1}$ and that the profit function for the ESS player is:

$$\begin{aligned}\max_{s^M} \pi^{ESS} = \left(1 - \frac{C-1}{N-1}\right) \pi \left(s^{ESS}|s^{ESS}, s^{ESS}, s^{ESS}, ...\right) \\ + \frac{C-1}{N-1} \pi \left(s^{ESS}|s^{M}, s^{ESS}, s^{ESS}, ...\right)\end{aligned} \tag{1}$$

For the single mutant player the profit function is

$$\pi^M = \pi \left(s^M|s^{ESS}, s^{ESS}, s^{ESS}, ...\right) \tag{2}$$

as she will play only ESS players. According to Maynard Smith and Price (1973) [43] the equilibrium condition then becomes:

$$\pi^M \leq \pi^{ESS} \tag{3}$$

Equivalently, one may say that $\pi^M - \pi^{ESS}$ as a function of s^M reaches its maximum value of zero at $s^M = s^{ESS}$. Thus, s^{ESS} is a solution to the following maximization problem: $\max_{s^M} \pi^M - \pi^{ESS}$ and substitution of (1) and (2) leads to

$$\max_{s^m} \pi \left(s^M|s^{ESS}, s^{ESS}, s^{ESS}, ...\right) - \frac{C-1}{N-1} \pi \left(s^{ESS}|s^{m}, s^{ESS}, s^{ESS}, ...\right) \tag{4}$$

From this, one can infer an important fact, namely, an ESS player is not generally maximizing her own payoff but rather the difference between her payoff and the population's mean payoff. This is in line with the point that Hamilton (1970) [18] made and referred to as spiteful behavior, as one is willing to hurt oneself in order to hurt others even more.

In Schaffer (1989) [37], he extends on his 1988 paper of ESS and points out that absolute profit maximizing behavior may not be an ESS and that such profit maximizers may not be the best survivors. He argues that Friedman's 1953 [16] conjecture of absolute profit maximization may only be evolutionary stable if the market is one of perfect competition, "Only in the case of perfect competition, when firms have no market power ... is absolute-profit maximization always an 'appropriate summary'. This result is a consequence of the Darwinian definition of economic natural selection, whereby it is the 'fittest' firms which survive." Schaffer (1989) [37] as well as Hamilton (1970) [18] demonstrates that spiteful behavior could exist if the size of the population was not very large (oligopolies). In fact, spite may disappear in sufficiently large populations (perfect competition). Thus, whenever firms have market power, there exist potential for spiteful behavior. This was already pointed out by Alchin 1950 [1], where it was the relative position that mattered as firms are unable to maximize due to their limited knowledge. Schaffer's 1989 model does not suggest that relative profit maximization is the best strategy for survival, however, it represents the strategy that is more likely to survive.

Another influential article by Vega-Redondo (1997) [48] describes that Walrasian behavior[3] evolves in the long-run within any quantity-setting oligopolistic market, when all firms produce the same good and face a downward sloping demand curve. The analysis in this paper can be summarized as follows: Firms in a Cournot game select their strategies simultaneously in every period. As time continues the most successful behavior will be adopted by most players, e.g. through imitation. Occasionally, with some small probability ($e \to 0$) firms deviate, a.k.a. experiment or mutate [see also Alchian (1950) [1] Schaffer (1988) [36]]. Without the occasionally experimenter behavior would remain in some monomorphic state and, unless the Walrasian outcome has already been reached, not converge. The approach is straight forwards, if the experimenting firm changes its output towards more lucrative options, i.e. into the direction in which higher payoff lie, it will be copied and the market adopts to this new better position in the next period, due to the imitative behavior of other firms.

Vega-Redondo (1997) [48] describes an explicitly dynamic model related to Alchin (1950) [1] ideas but in contrast to Friedman (1953) [16] who suggested that market forces will be in line with rational behavior, i.e. absolute performance (Cournot-Nash). His model encompasses the usual monotonicity of preferences (more is better) considerations of evolutionary theory, i.e. adjusting strategies may be influenced by differences in payoffs between players.

[3]named after French economist Leon Walras (1834-1910) for his contribution to general equilibrium theory. The Walrasian quantity refers to perfectly competitive behavior, i.e. a quantity that will equate marginal cost and market price driving economic profits to the zero margin.

This learning dynamics may thus be viewed as a form of bounded rationality, i.e. an objective of performing better, or not worse, than competition, while surrendering absolute performance. In other words, in the real world, firms face complex decisions and imitation of successful strategies may be a reasonable rule of thumb. As population increases in size the usual consideration is that the market outcome moves from Cournot-Nash to the Walrasian outcome (perfect competition) at higher output, lower market price, and zero economic profits for all symmetric market participants. Vega-Redondo's important lesson is that in his finite firms setting, the Walrasian outcome is reached where classical game theory suggests Cournot-Nash. He argues that if a firm's objective function includes survival consideration as its primary focus, then even with classical consideration (perfectly rational behavior and common knowledge) Walrasian behavior would be established. This would make firms, even in oligopolistic setting, relative rather than absolute profit maximizers, resulting in zero economic profits as marginal cost equal the market price. A similar result was presented in Rhode and Stegeman (2001) [30], where the authors show that, under general circumstances, the mean Darwinian strategy pair presents a Nash equilibrium (NE) of relative profit maximizing agents.

The above mentioned articles gave rise to a rather large number of publications reporting on controlled laboratory experiments that focused on behavior in oligopolistic quantity games. I will continue to discuss some of the finding in the following. Rosenthal et al. (1984) [34] studied infinitely repeated 2 player games with ruin. Their focus lies within the impatience in preferences, which is brought about by the possibility of ruin and, thus, may result in permanent short-run effects such as elimination of competition. For players, these short-run effects may take priority over, for example, profit maximization. Thus, only after these short-run considerations have been considered, may the firm focus on long-run payoffs. The authors give the example of a monopolist who can expect larger profits than a duopolist and that the duopolist may decide to forgo short-run profits as the firms may try to compete it's way to a monopolistic position, which would more than offsets the foregone short-run duopoly profits. They observe that when one player can ruin her opponent, she does; and that players must protect themselves against such strategies, which could force them into ruin. Thus, it may be advisable for players to focus on maximal spite to either gain competitive advantage in the future or to insulate against being outperformed and, thus, possible market exit. In Cournot quantity games, for example, this would mean maximizing relative rather than absolute profits, until a monopoly position is reached.

Vriend (2000) [49] studies a genetic algorithm to point out the differences in learning dynamics. He very appropriately points out that there are two aspects to spite: one being purely spiteful players that 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). The author focuses on the second aspect. The genetic algorithm with individual learning converges towards the Cournot-Nash equilibrium while the genetic algorithm with social learning converges towards the Walrasian outcome, due to the spite effect. Individual learning refers to the fact that agents learn exclusively on the basis of their own experiences, while with social learning agents learn from the experiences of other players. This article is of particular interest to the present dissertation, as spiteful behavior may in fact be separated into different categories, i.e. there may be reasons, other than the joy of being better, as to why players choose spiteful strategies. The two period experimental setup of this dissertation makes exactly this point, firms may behave spitefully in period one only to gain competitive advantage in period two. Bester (1993) [9] states that the closer substitutes the good are, the larger the amount of investment into cost reduction may be. Thus, in this dissertation's experimental two period model, spiteful behavior in period one maybe extreme in order to reduce cost in period two.

Fershtman (1987) [14] studies a duopolistic market where giving managers incentives that combine revenue and profit maximization (instead of just profit maximization) may be a dominant strategy for owners. It is argued that traditional price theory is based on the simplified concept that firms' sole objective is profit maximization [see also Baumol (1958) [6]] and that managerial compensation is most often based on sales, which provides self-interested managers with an incentive to sacrifice profit opportunities whenever there is conflict with pure sales quantities. On the other hand providing managers with the incentive to focus on profits may result in short-run profit maximization without ensuring the firms long-run growth and fitness. Fershtman argues that maximization of a single objective cannot capture the interaction of all decision makers within the firm.

Tanaka (1999) [47] bases his paper largely on the articles by Vega-Redondo (1997) [48], Schaffer (1988) [36] and Schaffer (1989) [37] and introduces an oligopoly model with 2 groups: one group are the high cost firms and the other group the low cost firms. All firms produce the same homogeneous good and compete in quantities. He shows that the finite population evolutionary stable strategy (ESS) is equal to the Walrasian output quantity in each group.

A different result is discussed in Milgrom and Roberts (1991) [25], who developed their take on adaptive (sophisticated) learning, see Alchian (1950) [1]. They argue that most strategy games are dominated by equilibrium analysis. Yet, this implies the assumption that players are immediately and unerringly find and play a particular vector of equilibrium strategies, i.e. by assumption the equilibrium is common knowledge[4]. This, however, seems like a far-fetched assumption as in reality firms do not posses common knowledge and are unable to immediately, if ever, identify an optimal strategy. The alternative to analyzing behavior lies in learning dynamics, i.e. this implies a certain set of rules that apply during repetition of a certain game according to which players form expectations of other players' current choices as a function of past play. According to the authors this is as far-fetched an assumption as equilibrium play, as firms will not merely base their decision based 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 with a very broad model encompassing all previously discussed information and learning that over time players will converge to the Nash equilibrium.

Conlisk (1980) [11] argues along the same lines as Milgrom and Roberts (1991) [25] and that optimal outcomes are extremely hard and costly to discover. The normal assumption of rational players where behavior will eventually lead players to a steady state equilibrium may be far fetched. In his article, he creates two groups of players, optimizers and imitators, and finds that if optimizing is very costly, imitators will have as great a survival rate in the long run as costly optimizing behavior does.

[4]in economic laboratory experiments this would be a payoff table handed to subjects that would allow them to identify equilibrium play

Similar to Milgrom and Roberts (1991) [25], Rassenti et al.'s (2000) [29] goal is to shed some light on whether or not there exists convergence towards equilibrium behavior. They report on 3 different experiments of 75 periods (allowing for sufficient time for convergence). In one experiment subjects were informed about all choices of each subject in the market (SHOW). In another (NOSHOW) subjects were informed only about total output of all subjects. The third experiment consisted of 15 rounds of a certain set of parameters followed by a different set of parameters of 60 rounds, all subjects were able to observe past play of all opponents (15/60SHOW). The authors report on 2 contradicting theories, (1) Vega-Redondo (1997) [48] would predict that with more information subject behavior would become more competitive, while (2) Stigler (1964) [46] argues that with more information of individual output firms would facilitate collusion as more information about individual behavior would make it easier to detect defective behavior. In all experiments individuals were informed about the demand function, how the market price is generated and about their own constant level of marginal cost, and the fact that other firms may not have the same cost structure (asymmetric payoffs), which was the case in the experiment, creating no symmetric equilibria. The results suggest that total output, over all time periods and all 3 experiments, is greater than but still close to the NE. An interesting fact observed was that though total output is somewhat close to the Cournot prediction, individual output fluctuated far from that prediction.

Selten et al. (1997) [40] report on a finite super game of asymmetric Cournot duopoly. The authors chose a finite set, on account of infinitely many strategies, which may be attempted through fixed stopping point probabilities, are unsatisfactory due to the limited time horizon in experimental settings. Additionally, experimental evidence suggest that, except for a possible end effect, finite and infinite time horizons show no significant behavioral difference [see also Selten and Stoecken (1986) [42]]. The experiments, which I report on in the following sections, and its finite time horizon is based on exactly this reasoning. The results indicate that for experienced players, behavior is very different than predicted by theory, in that, cooperative goals are chosen by fairness consideration and pursued by a certain set of strategies. The authors explain that a cooperative goal is chosen individually by means of an ideal point, at which individuals try to accomplish cooperation. If the opponent moves towards this ideal point, players' responses tend to move output towards the ideal point. If the opponent moves away from the ideal point then players react by moving away from the ideal point of cooperation. The choice of an ideal point by fairness consideration along with a measure-for-measure policy constitutes a very simple approach that avoids optimization problems altogether. It is also a simple strategy towards profit maximization.

In Selten and Ostman (2000) [41], the Nobel Laureate shows that symmetric duopolies with with common knowledge of demand and cost function, as well as communication seems 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, though recent experimental literature indicate differently, e.g. Huck et al. (1999) [20], in that output is in fact larger than that predicted by Cournot. The authors found that in a symmetric Cournot model with constant marginal cost with a universal reference structure, meaning a set of players assigned to each player, which are sufficiently similar in structure, has a unique local imitation equilibrium at the Walrasian outcome (local equilibrium refers to the fact that it is stable with respect to small exploratory deviations whereas a global imitation equilibrium requires stability against any exploratory deviation). The authors were also able to show that in Cournot duopolies with asymmetric cost and and with the same reference structure, again, referring to similarity in structure, converges to the shared monopoly outcome.

Bernhardt and Bergin (2004) [8] 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 those 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) [32] and Riechmann (2006b) [31]. With introspection players learn from their own current and past actions and select the output level that generated the greatest payoff. With imitation players learn by comparing their payoff from current and past periods to those of all similarly situated player and selects the most successful action, i.e. players believe that other players' experiences are relevant to them. An important point is that it is not only the fact the the two types are separated by own versus other information, but also that players in the imitation framework know that their own action will affect the outcome of others (externality).

Thus, with introspective learning a choice is good if payoff in this period is larger than payoff in the previous period. With imitation on the other hand a choice may be considered good if it merely lowered the payoff of other players compared to one self. This also means that introspective learning and imitative learning correspond to one another if there is no externality effect present. 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. It follows that the payoffs of imitative behavior are lower than those of retrospective learning, thus mimicking the best leads to lower absolute profits.
Bernhardt and Bergin (2004) [8] base their analysis on the work of Vega-Redondo (1997) [48] and Schlag (1998) [39]. Schlag creates two groups of players. Two players are then randomly matched from the two groups. The players observe their own payoff and additionally the payoff of some other player from their own group matched up with a player from the other group. Players never observe the payoff of their opponents, however, they do observe the payoff of the player in their own group playing an opponent from the other group. Thus, a player learns from herself and another player playing against the same population, thus creating a scenario without an externality effect.

Similarly, in Apesteguia et al. (2007) [4] the authors set out to experimentally test how information, and more specifically information about one's direct competitor or information about a player that is just like them but plays in a different group against different players, effects play. In particular two theories are tested, which are the one by Vega-Redondo (1997) [48] and Schlag (1998)[39]. Vega-Redondo (1997) [48] predicts the Walrasian outcome in games where players can observe their immediate opponent, while Schlag (1998) [39] predicts the Cournot-Nash equilibrium when agents imitate others who are like them but play in different markets. The authors show that the difference between the two models lies mainly in the different informational assumptions rather than the specific adjustment rules, meaning that it is more important whom to imitate than how. It is found that the treatment in which opponents can be observed each other directly is the most competitive one and the treatment where players of other groups are observed coincided roughly with Cournot-Nash. Intermediate results are obtained if players can observe both. They also found that imitation is an increasing function in the size of relative profits, i.e. the larger the difference in payoffs between players the more likely is imitation. Also, and in line with Schlag (1998) [39], the probability with which a player changes her action decreases in her own payoff and increases in the maximal observed payoff. Thus, it can be concluded that the probability to imitate the best strategy is mainly driven by the difference in the maximal observed and own payoff. A questionnaire result suggested that most imitators know that they were imitating [5].

Another component is added by Alós-Ferrer (2004) [2], who introduces memory to the quantity choice setting. He argues that in Vega-Redondo (1997) [48] Walrasian outcomes are achieved as players do not have memory and thus cannot compare deviations to previous results and only compare themselves to their opponent in any particular period. He finds that when memory of at least one period is introduced that the outcome lies somewhere between Cournot and Walras. He presents memory as some kind of conditional experiment as players, if they chose a quantity that results in lower then previous period profits, may go back to the previous period's profit, realizing their mistake and correcting it. He argues that from an industrial organization point of view his paper highlights the instability of quantities above the Walrasian quantity and below the Cournot quantity but neither of them being a unique solution.

Bergin and Bernhardt (2009) [7] study long-run outcomes of imitation in symmetric games when players base their decision on average historical performance. Thus, just like Alós-Ferrer (2004) [2], the Vega-Redondo (1997) [48] assumption that firms do not obtain memory, is relaxed. They find that with sufficiently long memory imitation leads to the joint profit maximum, i.e. collusion, and the longer the time horizon the stronger the collusive effect. Cooperation on a period-to-period basis is rooted in the fact that firms understand the need to maintain relationships. The authors shows that cooperation arises naturally from imitation of successful behavior when agents have limited information and limited ability to optimize. If memory only last one period, payoffs can decline without players taking notice, if past performance will go unnoticed leading to the competitive outcome, thus imitation

[5] I always find it very interesting what players report on how they came to make a certain decision, which is why I included some of the statements made in the following experiment.

of successful strategies will lead to overall decrease profit and thus, welfare. This is the point that Vega-Redondo (1997) [48] made. If players have sufficiently long memory and the corresponding historical weighted average in those particular periods are recalled, then, and provided that sufficient weight is placed on this memory, the unique stochastically stable outcome is the monopoly outcome.

The next few studies I would like to mention here report on experimental findings in oligopoly quantity games and are mostly based on the work of three authors, (1) Steffen Huck of university College London, (2) Hans-Theo Normann of Royal Holloway College, University of London, and (3) Joerg Oechssler of Heidelberg University.[6] Over the past 13 years these authors have presented experimental results, among others, in quantity games contributing to a much better understanding of how information influences decision making in this particular market setting. In Huck et al. (1999)[20] the authors set up an oligopoly to test the competitiveness of firms when varying information. Largely based on Vega-Reondos (1997) [48] imitation model, they test their model with inertia, which does theoretically converge at Cournot-Nash. The authors create five treatments varying the information given to players in each treatment. The following results are obtained. In all treatments behavior was more competitive than predicted by the Cournot-Nash equilibrium. When given sufficient information about price, players' behavior matched that predicted by Vega-Redondo (1997) [48] where firms converge at the Walrasian equilibrium. In general, more information about the market yields less competitive outcomes while more information about ones' competition yields more competitive outcomes. If players have sufficient information to play best-replies, most will do so, though, not perfectly converging towards the theoretically predicted outcome. If players have the necessary information to imitate some players, some will become pure imitators of most successful strategies.
Offerman et al. (2002) [28], for example, show similar results with the difference being that in Huck et al. (1999) [20] information mattered at the beginning of the experiment while in their experiment information is varied throughout. They find that when information is available only on aggregate quantities then the frequency distribution is centered around Cournot-Nash.

[6] The reported Universities are current at the time this dissertation was worked on and may have changed.

When information about individual quantities are available there exist two peaks, one at the Cournot-Nash equilibrium and the other at the collusive outcome. When adding information about individual profit to individual output quantities outcomes are centered around the Walrasian outcome and also around the collusive outcome with Cournot-Nash losing its appeal.

In Huck et al. (2000) [21] two treatments are introduced, one where participants only have information about aggregate information about opponents' actions and one where players have received information about individual action (quantity or price and profits) in both treatments all participants received all necessary information about the market structure. The market consisted of four symmetric firms with differentiated products. For Cournot competition it is found that more information makes the market more competitive, again, supporting Vega-Redondo's (1997) [48] imitation model. If subjects only have aggregate information players' behavior converges towards the Nash equilibrium. In neither the Cournot nor the Bertrand case does more information about the rivals' actions lead to collusive behavior, as for example suggested by Stiegler (1964)[46]. It was also found that if the goods are strategic substitutes more information about opponents' actions and profits increase competition while in case of strategic complement additional information does not seem to influence decision making.

One of the most influential studies for this present dissertation is the paper by Huck et al. (2001)[19], who study a Stackelberg duopoly experimentally and compare to the simultaneous moves model of a standard Cournot case. Two treatments were run, where in the first treatment players remained matched to the same opponent throughout the entire game, in the second treatment opponents were randomly assigned after every period without allowing for meeting the same opponent twice. To the best of the authors knowledge, their sequential Stackelberg model has never been tested experimentally[7]. Huck et al.'s 2001 [19] results show that the simultaneous decision making process under a standard Cournot case is well predicted by theory. For the Stackelberg sequential moves game theory predicts higher output, lower aggregate profits, and higher efficiency due to the increase in consumer surplus,

[7]One of the experiments introduced in a later section of this dissertation also analyzes a sequential moves model. However, the model is considerably different from the one introduced by Huck et al. (2001)[19], in that, it shows a two period model with the possibility of asymmetry.

which offsets the decrease in producer surplus resulting in an increase in overall welfare. Experimental results show that for both treatments (fixed and random matching) Stackelberg output is higher than output under Cournot.

Under the fixed pair treatment (similar to the sequential moves model introduced in the experimental section of this dissertation) aggregate output is lower than under the 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) [13], 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, thus, indicating inequality aversion. This is an important point, as the experimental results in section 6 (sequential moves model) show how competitive first and second movers' choices become when second movers are able to punish first movers. As I will show in section 6, Stackelberg followers, indeed, punish Stackelberg leaders for exploiting their first mover's advantage.

Related to Huck et al. (2001) [19] is the article by Fonseca et al. (2005) [15], in which the authors study an oligopoly game with endogenous timing. The model is based on Hamilton and Slutsky (1990) [17] who set up a duopoly model in which firms can choose to produce their quantity in one of two periods before the market clears, with the prediction of a Stackelberg leadership emergence. Huck et al. (2002) [22] found that despite theoretical predictions Stackelberg leadership almost never emerges. Instead they found that the Cournot-Nash was achieved in about 50% of all plays. Fonseca et al. (2005)[15] added asymmetry to the model which, theoretically, should strengthen the emergence of Stackelberg leadership of the low-cost firm. However, experimental data in this paper suggest that despite the introduced asymmetry in cost no significant differences compared to the symmetric case can be observed and the previous results of Huck et al. (2002)[22] are robust and Cournot play is the most frequently played quantity.

A different approach is reported on in Huck et al. (2004) [23], wherein the authors study a simple learning process, which they call trial-and-error. Players receive no information about their rival at all. The only thing happening in their experiment is that players can decided to increase or decrease output each period. They observe whether their decision either increases or decreases output and payoff. If their quantity choice increased payoff then they will continue to increase output. If their decision decreased payoff then they will lower output in the next period. The setup is a standard symmetric Cournot oligopoly and the interesting results show that this trial-and-error process leads towards the joint profit maximum (collusion). The remarkable results show that players end up in the joint profit maximum without the ability to observe their opponent and, thus, there is no basis for coordination and punishment. The argument is as follows, if players move closer towards the collusive outcome, thus increasing their profits, they will continue to move into that direction. Once they reach the joint profit maximum further movement will lower profits. Hence, there exists a locally stable "collusive cycle." This is surprising as players know nothing about their own payoff function and have no information about their opponents[8].

A closer look into cost asymmetry and imitation was offered by Apesteguia et al. (2010) [5]. They find, based on Vega-Redondo's 1997 [48] model, that imitation, when players can observe successful strategies, will emerge and the Walrasian outcome can be observed. This result, however, is theoretically fragile to the slightest cost asymmetry. Their experiment, on the other hand, shows that in both symmetric and asymmetric setting firms converge to the competitive solution. Theory predicts that when firms have the same cost function and are located in some state other than the perfectly competitive state, any mutation towards the Walrasian state will be imitated. This is straight forward, whenever price exceeds marginal cost, a move towards the Walrasian quantity will leave the firm with the highest quantity and the largest profit, and, thus, it's strategy will be copied by others in the following period. If the price is below marginal cost, then the firm with the lowest quantity will make the smallest loss and will be copied, thus if firms face identical cost functions (symmetric market) the Walrasian state is stochastically stable. If, however, a firm has a cost advantage over its competitors

[8]This is what Reinhard Selten refered to as directional learning, see Selten and Stoecker (1986) [42]

(asymmetric setting), it may move away from the Walrasian quantity and still earn larger profits, and thus, will be imitated without other firms realizing the mutants cost advantage, which would render the Walrasian outcome not stable, i.e. once a firms imitated unsuccessfully it may revert to its previous quantity. Nonetheless, their experimental evidence suggest no significant differences between the symmetric and asymmetric treatment. Brander and Spences (1983) [45] show that in Cournot duopoly a cost reduction by one firm lowers the output of its competitor if the setting is asymmetric. As the market price in negatively related with aggregate market output, cost reduction (e.g. in this dissertation's experimental section, firms may invest into cost-saving technologies to lower cost in the following period) may be a strong point on the Cournot firm's preference list, see also Spence (1984) [44].

It is worth mentioning that there are a few studies that report on a two period model, however, the market in these models only clears once after period two. Though this setup does not match this dissertation's two period model, some interesting point have been made. Mueller (2006) [26] investigates a duopoly experimentally. The model employed is taken from Saloner (1987) [35]. Theory predicts the emergence of a Stackeberg outcome although there is some experimental evidence that suggests differently. Due large payoff differences for the first and second mover and, i.e. inequality in payoffs, some authors, see Fehr and Schmidt (1999) [13] and Bolton and Ockenfels (2000)[10], show that subjects display an aversion to disadvantageous inequality, suggesting that Stackelberg outcomes are unlikely to evolve and often times Cournot outcomes or collusive play may be observed, see Huck et al. (2002) [22]. Only eight percent of the time did the author observe Stackelberg outcomes, thus players did not seriously attempt to establish a Stackelberg play. The two period set up also did not yield higher total output at a lower market price as suggest by theory. In fact average output was the same as in the one period Cournot markets that were set up as a control group. This suggests that the Stackelberg outcome seems very unlikely to evolve in this particular setup and may just be explained by inequality aversion. This can also be confirmed in this dissertation's experimental findings where only one duopoly in only one out of 20 periods successfully established Stackelberg play.

3 General Model

Consider the following duopoly model, where the superscript t indicates time. The model consists of two time periods in total, allowing firms, if successfully outperforming its competition in period one, to lower marginal cost for period two. Thus, the model, though starting in symmetry, may turn asymmetric after period one.

$$P^t(Y^t) = a - Y^t, \text{ where } a > 0 \text{ and } Y^t = \sum_{i=1}^{2} y_i^t \tag{5}$$

$$C^t(y_i^t) = b(1 - \delta_i^t)y_i^t, \text{ where} \tag{6}$$

$$\delta_i^t = \frac{\pi_i^{t-1} - \pi_{-i}^{t-1}}{\pi_i^{t-1}}, \forall\ \pi_i^{t-1} > \pi_{-i}^{t-1} > 0, \text{ else } \delta_i^t = 0 \text{ and } b > 0 \tag{7}$$

Both firms start out in symmetry. Inverse demand is given by $P^t(Y^t)$ and downward sloping. All output is sold in the market immediately and there is no stock-building. The cost function's δ_i^t does not exist in period one, as it depends on the previous period's outcome and no such period yet exists, i.e. assuming t is the first ever period. Thus, in period one, firms' cost functions are:

$$C^t(y_i^t) = by_i^t \tag{8}$$

The above model will be analyzed theoretically and, thereafter, a parametrized version of the model will be tested experimentally as part of a controlled laboratory experiment. In the following I will break down the model into a game of simultaneous moves and one of sequential moves. In the simultaneous moves model I will break down the analysis into 4 cases in period one, upon which period two analysis will depend, i.e. maximizing absolute profits in period one, where firms forgo the possibility to lower marginal cost in period two for larger immediate profits in period one, maximizing relative profits in period one for a chance to achieve the largest possible δ_i for period two, and the mixed case where one firm chooses to maximize absolute profits while the other firm chooses to maximize relative profits, in which case the relative profit maximizer achieves the largest possible δ_i and, thus, lowering cost for period two by the maximal amount, however at the expense of lower immediate absolute profits. Thus, there are 2 cases where firms choose identical strategies, that is, both firms choose to maximize absolute profits in period one or both firms choose to maximize relative profits in period one. Both of these scenarios result in the same marginal cost in period two as in period one and consequently $\delta_i = 0$. The other 2 cases, which, due to symmetry, are really only 1 case, namely, one firm chooses to maximize relative profits in period one (the Walrasian player) while the other firm maximizes absolute profits (the Cournot player) to achieve a competitive advantage over its competition in period two, due to the decrease in cost at an expense of lower immediate profits, though, still outperforming the Cournot player in period one in terms of profit.

In the sequential moves game, the situation is somewhat different, as even if firms choose absolute profit maximizing strategies, the Stackelberg leader will gain competitive advantage in period two due to a positive relative profit in period one. I will also show that, for the first mover, it makes no difference whether she is an absolute or relative profit maximizer as the optimal output decision is the same for absolute and relative profit maximizers. However, the model's outcome does change as the second mover alters his strategy from absolute to relative profit maximization. Therefore, period one outcomes will depend on the second mover's preference to either maximize absolute profits or relative profits in period one. In neither case will the second mover achieve positive relative profits and has no chance to lower marginal cost in period two. The 2 cases under the sequential moves game for period one are: i. The first mover plays an absolute (identical to relative) profit maximizing strategy while the second mover plays an absolute profit maximizing strategy and ii. The first mover plays an absolute (identical to relative) profit maximizing strategy while the second mover plays a relative profit maximizing strategy.

I start the analysis with the simultaneous moves game with a straight forward computation of these first period strategies (in terms of absolute and relative profit maximization). Period two choices will depend on the outcomes of period one, i.e. for the simultaneous moves model there exist 4 cases, 2 of which are merely the reversal of firms (firm i is an absolute profit maximizer while firm -i is a relative profit maximizer and vice versa) and it is sufficient to to compute only one of these two scenarios.

Due to the two period bound of the model, and the fact that the possibility to lower marginal cost only exists once, after period one, period two choices may only consist of absolute profit maximizing decisions, as there is not further period to consider. Thus one might ask why relative profit maximizing strategies are at all part of the choice vector. The answer may lie in other-regarding preferences. Firms may have preferences towards simply being better than their competition, while sacrificing absolute performance. On the other hand, firms may have preferences not to be outperformed and, thus, relative profit maximizing strategies present a somewhat save strategy. Spiteful motives of players need to be considered and are included in period two. Nonetheless, in light of theorized selfish preferences, it can be expected that period two choices are in line with absolute profit maximizing behavior.

3.1 Standard Cournot

This is a straight forward computation of a Cournot model of simultaneous choices with quantity being the choice variable. Maximization with respect to quantity will show best replies as a function of the opponent's quantity and substitution will yield optimal output quantities for each firm. In this case both firms start out in symmetry, i.e. they have identical cost functions. Both firms act in the same duopoly market and both firms sell all output in the market instantaneously.

$$\max_{y_i^t} \pi_i^t = P^t(Y^t)y_i^t - C^t(y_i^t) \tag{9}$$

$$\max_{y_i^t} \pi_i^t = \left(a - y_i^t - y_{-i}^t\right) y_i^t - by_i^t \tag{10}$$

$$\frac{\partial \pi_i^t}{\partial y_i^t} = a - 2y_i^t - y_{-i}^t - b = 0 \tag{11}$$

Reaction Functions: Due to symmetry, both firms have the same reaction function as a function of the other firm's output.

$$R_i^t : y_i^t(y_{y-i}^t) = \frac{1}{2}(a-b) - \frac{1}{2}y_{-i}^t \tag{12}$$

$$R_{-i}^t : y_{-i}^t(y_i^t) = \frac{1}{2}(a-b) - \frac{1}{2}y_i^t \tag{13}$$

Optimal Quantities: Substituting one firm's reaction function into the reaction function of the other firm, and vice versa, give firms' optimal output quantities in terms of absolute profit maxima.

$$y_i^t = \frac{1}{2}(a-b) - \frac{1}{2}\left[\frac{1}{2}(a-b) - \frac{1}{2}y_i^t\right] \tag{14}$$

$$y_i^t = \frac{1}{2}(a-b) - \frac{1}{4}(a-b) + \frac{1}{4}y_i^t \tag{15}$$

Absolute profit maximizing strategies in period one are:

$$y_i^{*t} = y_{-i}^{*t} = \frac{1}{3}(a-b) \tag{16}$$

3.2 Walrasian Strategies

Here, instead of absolute profits, as computer above, maximization of relative performance is the objective. For the duopoly model this means maximizing the difference in absolute profits between the two firms. Again, output quantity is the choice variable used in the maximization problem. There are a number of reasons why a firm would want to maximize relative profits instead of absolute profits. In this particular model firms' incentives to maximize relative profits may come from a firm's goal to produce at lower-than-competitor's cost in the following period or to avoid being "left behind" in terms of competitiveness, along the lines of: *If I don't outperform my competition than they may outperform me, and I am not willing to take that risk.* Another important point here is spiteful motives. A firm may lower its own absolute profit by increasing production if, in turn, it manages to lower the other firm's absolute profit even further. Maximum spite is achieved at the point of maximal relative distance in profits between the firms, i.e. the relative profit maximum. The analysis is somewhat shorter than under absolute profit maximizing strategies. This is due to the lack of a reaction function as a function of the other firm's output. Here, the maximization problem shows that optimal output is independent of the other firms output decision.

This result can also be confirmed intuitively. If it is a firm's goal to achieve the largest possible difference in profits between itself and its competition, then it would be at the point where marginal cost equal the price, as no firm would be able to go lower and not induce negative profits. This, of course, is also the outcome of perfect competition of zero economic profits or the Bertrand price competition. Since both firms face the same cost function in period one both firms have equal share in the market at the relative profit maximum. Thus, in optimum a firm produces half the aggregate market output that would equate price and marginal cost. This quantity does not depend on the output of the other firm.

The objective function of the relative profit maximizing firm looks as follows:

$$\max_{y_i^t} \pi_i^{R,t} = \left(a - y_i^t - y_{-i}^t\right) y_i^t - by_i^t - \left[\left(a - y_i^t - y_{-i}^t\right) y_{-i}^t - by_{-i}^t\right] \tag{17}$$

The superscript R denotes relative profits and will be used in this regard henceforth.

$$\frac{\partial \pi_i^{R,t}}{\partial y_i^t} = a - 2y_i^t - y_{-i}^t - b + y_{-i}^t = 0 \tag{18}$$

The relative profit maximizing strategies in period one are:

$$y_i^{*R,t} = y_{-i}^{*R,t} = \frac{1}{2}(a - b) \tag{19}$$

Proving the intuition:

$$P^t(Y^t) = a - Y^t \tag{20}$$

$$MC_i^t = \frac{\partial C^t\left(y_i^t\right)}{\partial y_i^t} = b \tag{21}$$

Equating marginal cost and price:

$$P^t(Y^t) = a - Y^t = b = MC_i^t \tag{22}$$

Total market output:

$$Y^t = a - b \tag{23}$$

Individual output is half the aggregate output:

$$\frac{1}{2}Y^t = y_i = \frac{1}{2}\left(a - b\right) \tag{24}$$

This results is equal to that computed under relative profit maximization and confirms the intuition about the optimal Walrasian output quantity being independent of that of the other firm's output in this symmetric model. As soon as things become asymmetric, the market will no longer be split into equal shares and thus simply halving the aggregate output will no longer suffice, as will be seen further on in the analysis.

3.3 Profit Computations Simultaneous Moves

Now that optimal first period strategies have been determined, one can easily compute the resulting profits of the different strategy compilations. For simultaneous moves, four different cases are possible when combining the above computed strategies, namely:

i. Cournot plays Cournot. This is the most basic form of quantity competition and maximization of absolute profits (Cournot-Nash equilibrium). The strategy combination yields maximal absolute profits for each firm in period one, however, it will not give either firm a competitive advantage to produce at lower than competitor's cost in the following period. The model stays symmetric in the second (last) period.

ii. Walras plays Walras. Maximizing relative profits will result in zero economic profits for both firms. The outcome is identical to that of perfect competition or Bertrand price competition. Both firms try to get ahead and build competitive advantage for period 2, however, if both firms follow this strategy both will earn zero profit and fail in their attempt to build such a competitive advantage. The model stays symmetric in the second (last) period.

iii. (iv.) Cournot plays Walras (Walras plays Cournot). Firms enter the game with different strategies. The relative profit maximizing firm (Walrasian player) will produce more output than the absolute profit maximizing firm (Cournot player). This leads to lower absolute profits for both firms, however, the Walrasian player achieves higher absolute profits compared to the Cournot player. Thus, not only does the Walrasian player outperform its competition in period one, it also achieves a competitive advantage in period two, by successfully lowering marginal cost below that of the Cournot player. In period two the model becomes asymmetric due to the different cost functions.

i. Cournot plays Cournot $\left[\frac{1}{3}(a-b), \frac{1}{3}(a-b)\right]$

$$\pi_i^t = \pi_{-i}^t = \left(a - y_i^{*t} - y_{-i}^{*t}\right) y_i^{*t} - b y_i^{*t} \tag{25}$$

$$\pi_i^t = \pi_{-i}^t = \left(a - \frac{1}{3}(a-b) - \frac{1}{3}(a-b)\right) \frac{1}{3}(a-b) - b\left(\frac{1}{3}(a-b)\right) \tag{26}$$

$$\pi_i^t = \pi_{-i}^t = \frac{1}{9}(a-b)^2 \tag{27}$$

Both firms achieve the same positive absolute profit. This results in the same decision situation in period two as no firm establishes a cost advantage over the other.

ii. Walras plays Walras $\left[\frac{1}{2}(a-b), \frac{1}{2}(a-b)\right]$

$$\pi_i^t = \pi_{-i}^t = \left(a - y_i^{*R,t} - y_{-i}^{*R,t}\right) y_i^{*R,t} - b y_i^{*R,t} \tag{28}$$

$$\pi_i^t = \pi_{-i}^t = \left(a - \frac{1}{2}(a-b) - \frac{1}{2}(a-b)\right)\frac{1}{2}(a-b) - b\frac{1}{2}(a-b) \tag{29}$$

Both firms play the same relative profit maximizing strategy. This results in an absolute profit equal to 0 for both players. Neither firm gains a cost advantage in period two, the model is still symmetric.

$$\pi_i^t = \pi_{-i}^t = 0 \tag{30}$$

iii. (iv.) Cournot plays Walras (Walras plays Cournot) $\left[\frac{1}{3}(a-b), \frac{1}{2}(a-b)\right]$

The Cournot player generates the following profit:

$$\pi_i^t = \pi_{-i}^t = \left(a - y_i^{*t} - y_{-i}^{*R,t}\right) y_i^{*t} - b y_i^{*t} \tag{31}$$

$$\pi_i^t = \left(a - \frac{1}{3}(a-b) - \frac{1}{2}(a-b)\right)\frac{1}{3}(a-b) - \frac{1}{3}(a-b)\,b \tag{32}$$

$$\pi_i^t = \frac{1}{18}(a-b)^2 \tag{33}$$

The Walrasian player's profits are:

$$\pi_i^t = \pi_{-i}^t = \left(a - y_i^{*t} - y_{-i}^{*R,t}\right) y_i^{*R,t} - b y_i^{*R,t} \tag{34}$$

$$\pi_{-i}^t = \left(a - \frac{1}{3}(a-b) - \frac{1}{2}(a-b)\right)\frac{1}{2}(a-b) - \frac{1}{2}(a-b)\,b \tag{35}$$

$$\pi_{-i}^t = \frac{1}{12}(a-b)^2 \tag{36}$$

Clearly, the Walrasian player outperforms the Cournot player, albeit, at a cost to its absolute profits (when compared to the absolute profit maximizing strategy computed under Cournot plays Cournot).

$$\pi_i^t = \frac{1}{18}(a-b)^2 < \frac{1}{12}(a-b)^2 = \pi_{-i}^t \tag{37}$$

The Walrasian player achieves a cost advantage in the next period. The model changes from a symmetric to an asymmetric one. It makes sense to assume that the lower marginal cost in period two are brought about by an investment into, for example, new technologies. This investment on the other hand lowers the Walrasian player's period one profit. In order to avoid changes in the model, I assume that an investment takes place of the following kind:

$$I_i^t = \frac{\pi_i^t - \pi_{-i}^t}{2} \; \forall \; \pi_i^t > \pi_{-i}^t > 0, \text{ else } I_i^t = 0 \tag{38}$$

The outperforming firm (here the Walrasian player) makes an investment into cost-saving technologies equal to half the size of the difference between the 2 firms absolute profits, or half the relative profit. This, still, leaves the Walrasian player with larger profits than its competitor in the current period. I further assume that the investment is double effective in cost, meaning that a one dollar investment will trigger a two dollar decrease in marginal cost. This assumption will leave the model unchanged and adds some realism (causality) as to why marginal cost are lower in period two:

$$\text{If: } I_i^t = \frac{\pi_i^t - \pi_{-i}^t}{2} \text{ and } \delta_i^{t+1} = \frac{I_i^t}{\pi_i^t}2 \tag{39}$$

$$\text{Then: } \delta_i^{t+1} = \frac{\pi_i^t - \pi_{-i}^t}{\pi_i^t} \tag{40}$$

Here the only investment possible is made by the Walrasian player and equals:

$$I_i^t = \frac{\frac{1}{12}(a-b)^2 - \frac{1}{18}(a-b)^2}{2} \tag{41}$$

$$I_i^t = \frac{1}{72}(a-b)^2 \tag{42}$$

It follows that the Walrasian player's true profit ($\hat{\pi}_i^t$) in period one is equal to its absolute profit minus the investment. This amount is still larger than the

Cournot player's profit in period one. The notation $\hat{\pi}$ is used to indicate that this firm's first period profit has been reduced by an investment. Indirectly it also indicates that this firm achieved a cost advantage in period two.

$$\hat{\pi}_i^t = \pi_i^t - I_i^t = \frac{1}{12}(a-b)^2 - \frac{1}{72}(a-b)^2 \tag{43}$$

$$\hat{\pi}_i^t = \frac{5}{72}(a-b)^2 \tag{44}$$

The investment will result in the following cost reduction (δ). As there exist only one opportunity to invest into cost saving technologies (after period one), δ does not require a superscript t. However, for reasons of conformity I decided to keep the superscript. It also helps identify the respective period.

$$\delta_i^{t+1} = \frac{I_i^t}{\pi_i^t}2 \tag{45}$$

$$\delta_i^{t+1} = \frac{\frac{1}{72}(a-b)^2}{\frac{1}{12}(a-b)^2}2 \tag{46}$$

$$\delta_i^{t+1} = \frac{1}{3} \tag{47}$$

The (period one) Walrasian player's new cost function in period two is:

$$C^{t+1}(y_i^{t+1}) = b(1-\delta_i^{t+1})y_i^{t+1} \tag{48}$$

$$C^{t+1}(y_i^{t+1}) = \frac{2}{3}by_i^{t+1} \tag{49}$$

The (period one) Cournot player is left with the same cost function it already faced in period one, as it was unable to generate a cost advantage on account of its lower absolute profits.

$$C^{t+1}(y_i^{t+1}) = by_i^{t+1} \tag{50}$$

3.4 Simultaneous Moves Strategies in Period Two

Optimal quantity choices in period two depend on the outcomes in period one. For the simultaneous moves model, in case both firms choose the same strategy in period one, both will face the same symmetric market in period two. These outcomes have already been calculated under the symmetric setting of period one, i.e. Cournot plays Cournot, Walras plays Walras, and Cournot plays Walras (Walras plays Cournot), which is why I include profits as well. If **both firms choose the same strategies in period one**, period two strategies and profits are:

i. Cournot plays Cournot in period two

$$y_i^{*t+1} = y_{-i}^{*t+1} = \frac{1}{3}(a-b) \tag{51}$$

$$\pi_i^{t+1} = \pi_{-i}^{t+1} = \frac{1}{9}(a-b)^2 \tag{52}$$

ii. Walras plays Walras in period two

$$y_i^{*t+1} = y_{-i}^{*t+1} = \frac{1}{2}(a-b) \tag{53}$$

$$\pi_i^{t+1} = \pi_{-i}^{t+1} = 0 \tag{54}$$

iii. (iv.) Cournot plays Walras (Walras plays Walras) in period two

The Cournot player will play the following strategy and generate the following profit:

$$y_i^{*t+1} = \frac{1}{3}(a-b) \tag{55}$$

$$\pi_i^{t+1} = \frac{1}{18}(a-b)^2 \tag{56}$$

The Walrasian player will play the following strategy and generates a higher profit on account of its output being higher:

$$y_i^{*t+1} = \frac{1}{2}(a-b) \tag{57}$$

$$\pi_i^{t+1} = \frac{1}{12}(a-b)^2 \tag{58}$$

If, however, firms play different strategies in period one, i.e. the Walrasian player builds a cost advantage in period two than optimal quantities need to be computed for period two. The asymmetric model to be considered for period two strategy computation is build upon **Cournot plays Walras or Walras plays Cournot** in period one.

$$P^{t+1}(Y^{t+1}) = a - Y^{t+1}, \text{ where } a > 0 \text{ and } Y^{t+1} = \sum_{i=1}^{2} y_i^{t+1} \tag{59}$$

$$C^{t+1}(y_i^{t+1}) = b(1 - \delta_i^{t+1})y_i^{t+1}, \text{ where} \tag{60}$$

Second period's cost function for the period one Cournot player is identical to it's cost function from period one as the firm was unable to build a cost advantage:

$$C^{t+1}(y_i^{t+1}) = by_i^{t+1} \tag{61}$$

Second period's cost Function for the period one Walrasian player, who achieves a cost advantage in period two due to a positive relative profit in period one:

$$C^{t+1}(y_i^{t+1}) = \frac{2}{3}by_i^{t+1} \tag{62}$$

Consequently, the maximization problem in period two needs to take into account 2 different cost functions. **The period two Cournot model for the period one Cournot player** looks as follows:

$$\max_{y_i^{t+1}} \pi_i^{t+1} = \left(a - y_i^{t+1} - y_{-i}^{t+1}\right) y_i^{t+1} - by_i^{t+1} \tag{63}$$

$$\frac{\partial \pi_i^{t+1}}{\partial y_i^{t+1}} = a - 2y_i^{t+1} - y_{-i}^{t+1} - b = 0 \tag{64}$$

Period two Reaction Function for the period one Cournot player:

$$R_i^{t+1} : y_i^{t+1}(y_{y-i}^{t+1}) = \frac{1}{2}(a-b) - \frac{1}{2}y_{-i}^{t+1} \tag{65}$$

The reaction function is identical to that of period one. However, optimal output quantity will be different due to the other firms cost advantage.

The period two Cournot model for the period one Walrasian player looks as follows:

$$\max_{y_{-i}^{t+1}} \pi_{-i}^{t+1} = \left(a - y_i^{t+1} - y_{-i}^{t+1}\right) y_{-i}^{t+1} - \frac{2}{3}by_{-i}^{t+1} \tag{66}$$

$$\frac{\partial \pi_{-i}^{t+1}}{\partial y_{-i}^{t+1}} = a - y_i^{t+1} - 2y_{-i}^{t+1} - \frac{2}{3}b = 0 \tag{67}$$

Period two Reaction Function for the period one Walrasian player:

$$R_{-i}^{t+1} : y_{-i}^{t+1}(y_i^{t+1}) = \frac{1}{2}\left(a - \frac{2}{3}b\right) - \frac{1}{2}y_i^{t+1} \tag{68}$$

Optimal Quantities: Substituting R_{-i}^{t+1} into R_i^{t+1} results in Firm i's optimal absolute output in period two:

$$y_i^{t+1}(y_{-i}^{t+1}) = \frac{1}{2}(a - b) - \frac{1}{2}\left[\frac{1}{2}\left(a - \frac{2}{3}b\right) - \frac{1}{2}y_i^{t+1}\right] \tag{69}$$

If the period one Cournot player wants to produce an absolute profit maximizing quantity in period two, she would optimally choose:

$$y_i^{*t+1} = \frac{1}{3}\left(a - \frac{4}{3}b\right) \tag{70}$$

If the period one Walrasian player wants to produce an absolute profit maximizing quantity in period two, she would optimally choose:

$$y_i^{*t+1} = \frac{1}{3}\left(a - \frac{1}{3}b\right) \tag{71}$$

The incentive to maximize relative profits (Walrasian strategies) in period two can no longer stem from the objective to further lower marginal cost as no successive period exist. Nonetheless, relative performance cannot simply be discarded and may play an important role as firms may have spiteful motives, in that they receive utility purely from the fact that they outperform their competition. This comes at an expense of lower absolute profits. As in period one, spiteful behavior reaches its optimum at the relative profit maximizing quantity. Period one Cournot player's relative profit maximizing strategy in period two is equal to that of period one as it is independent of the other firm's output and it's cost function has not changed.

$$\begin{aligned} \max_{y_i^{t+1}} \pi_i^{R,t+1} = {} & \left(a - y_i^{t+1} - y_{-i}^{t+1}\right) y_i^{t+1} - by_i^{t+1} - \\ & \left[\left(a - y_i^{t+1} - y_{-i}^{t+1}\right) y_{-i}^{t+1} - \frac{2}{3}by_{-i}^{t+1}\right] \end{aligned} \tag{72}$$

$$\frac{\partial \pi_i^{t+1}}{\partial y_i^{t+1}} = a - 2y_i^{t+1} - y_{-i}^{t+1} - b + y_{-i}^{t+1} = 0 \tag{73}$$

$$y_i^{*R,t+1} = \frac{1}{2}(a-b) \tag{74}$$

Period one Walrasian player, however, produces a relative profit maximizing quantity in period two larger than that of period one due to its lower marginal cost in period two:

$$\begin{aligned} \max_{y_i^{t+1}} \pi_i^{R,t+1} = \left(a - y_i^{t+1} - y_{-i}^{t+1}\right) y_i^{t+1} - \frac{2}{3} b y_i^{t+1} - \\ \left[\left(a - y_i^{t+1} - y_{-i}^{t+1}\right) y_{-i}^{t+1} - b y_{-i}^{t+1}\right] \end{aligned} \tag{75}$$

$$\frac{\partial \pi_i^{t+1}}{\partial y_i^{t+1}} = a - y_{-i}^{t+1} - 2y_i^{t+1} - \frac{2}{3}b + y_{-i}^{t+1} = 0 \tag{76}$$

$$y_i^{*R,t+1} = \frac{1}{2}\left(a - \frac{2}{3}b\right) \tag{77}$$

3.5 Period Two Profit Computations Simultaneous Moves

All possible strategies for absolute and relative profit maximization for both periods have been computed. This following part is designed to show all possible outcomes of first and second period strategies, i.e. aggregate profits. As mentioned before, there are four possible cases in period one [(Cournot plays Cournot) , (Walras plays Walras) , (Cournot plays Walras) , (Walras plays Cournot)]. Each one of these four cases from period one has four possible outcomes in period two, for a grand total of 16 aggregate profits after period two. Once these have been established, I use backward induction to solve the game. There are two cases from period one, which do not require new computation as they did not result in a model change from symmetry to asymmetry as no positive relative profits were achieved. For these two cases from period one, period two outcomes are merely the entire profit vector from period one (I already included period two outcomes for these cases when I indicated the respective strategies). Therefore, only 8 outcomes need to be computed in this section. However, for reasons of completeness, I will also show the 8 outcomes computed in period one and aggregate over two time periods. Once all 16 outcomes have been shown I will present them in game tree form, which allows for a much more concise representation and makes backward induction relatively easy.

3.5.1 Case i: Cournot Plays Cournot in Period One

This leaves the model unchanged for period two, which means both firms are faced with the same maximization problem and results are period one outcomes, which have already been computed. I use Π_i to indicate aggregate profits.

1. **Cournot plays Cournot in period two**

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = 2\left(\frac{1}{9}(a-b)^2\right) = \frac{2}{9}(a-b)^2 \tag{78}$$

2. **Walras plays Walras in period two**

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = \frac{1}{9}(a-b)^2 + 0 = \frac{1}{9}(a-b)^2 \tag{79}$$

3. **Cournot plays Walras in period two**

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = \frac{1}{9}(a-b)^2 + \frac{1}{18}(a-b)^2 = \frac{3}{18}(a-b)^2 \tag{80}$$

4. **Walras plays Cournot in period two**

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = \frac{1}{9}(a-b)^2 + \frac{1}{12}(a-b)^2 = \frac{7}{36}(a-b)^2 \tag{81}$$

3.5.2 Case ii: Walras Plays Walras in Period One

This also leaves the model unchanged for period two and both firms face the same maximization problem and results are period one outcomes, these have also been computed before.

5. **Cournot plays Cournot in period two**

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = 0 + \frac{1}{9}(a-b)^2 = \frac{1}{9}(a-b)^2 \tag{82}$$

6. **Walras plays Walras in period two**

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = 0 \tag{83}$$

7. Cournot plays Walras in period two

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = 0 + \frac{1}{18}(a-b)^2 = \frac{1}{18}(a-b)^2 \tag{84}$$

8. Walras plays Cournot in period two

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = 0 + \frac{1}{12}(a-b)^2 = \frac{1}{12}(a-b)^2 \tag{85}$$

3.5.3 Case iii: Cournot plays Walras in Period One

This case requires computation of period two outcomes, using the strategies calculated in the asymmetric period two game.

9. Cournot Plays Cournot in Period Two

One might have an intuition about the importance of 'Cournot plays Cournot' in period two as there is no following period. Any behavior deviating from a strict absolute profit maximizing behavior must lie within other-regarding preferences. If there is no next period and, thus, no opportunity to further lower cost and further build competitive advantage, and this is known to all players, then playing Cournot strategies seem to be the only rational thing to do. However, in light of spiteful motive, one must not underestimate the power of relative profit maximizing strategies.

Period one Cournot player achieves the following period two and aggregate profit:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*t+1}\right) - \left(y_{-i}^{*t+1}\right)\right]\left(y_i^{*t+1}\right) - b\left(y_i^{*t+1}\right) \tag{86}$$

$$\begin{aligned}\pi_i^{t+1} = \left[a - \frac{1}{3}\left(a - \frac{4}{3}b\right) - \frac{1}{3}\left(a - \frac{1}{3}b\right)\right]\frac{1}{3}\left(a - \frac{4}{3}b\right) - \\ \frac{1}{3}\left(a - \frac{4}{3}b\right)b\end{aligned} \tag{87}$$

$$\pi_i^{t+1} = \frac{1}{9}\left(a - \frac{4}{3}b\right)^2 \tag{88}$$

This says, that the period one Cournot playing firm, while it's opponent plays Walras in period one, will have an absolute profit maximum in period two, when both firms choose absolute maximizing strategies in period two, of $\frac{1}{9}\left(a-\frac{4}{3}b\right)^2$. Thus, aggregation over 2 periods yields:

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = \frac{1}{18}(a-b)^2 + \frac{1}{9}\left(a-\frac{4}{3}b\right)^2 = \frac{1}{6}a^2 - \frac{11}{27}ab + \frac{41}{162}b^2 \quad (89)$$

10. Walras plays Walras in period two

Period one Cournot player achieves the following period two profit:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*R,t+1}\right) - \left(y_{-i}^{*R,t+1}\right)\right]\left(y_i^{*R,t+1}\right) - b\left(y_i^{*R,t+1}\right) \quad (90)$$

$$\pi_i^{t+1} = \left[a - \frac{1}{2}(a-b) - \frac{1}{2}\left(a-\frac{2}{3}b\right)\right]\frac{1}{2}(a-b) - \frac{1}{2}(a-b)\,b \quad (91)$$

$$\pi_i^{t+1} = \frac{1}{12}\left(b^2 - ab\right) \quad (92)$$

Period one Cournot playing firm, while it's opponent plays Walras in period one, will have a relative profit maximum in period two, when both firms play their relative profit maximizing strategy in period two, of $\frac{1}{12}(b^2-ab)$. Aggregation over 2 periods yields:

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = \frac{1}{18}(a-b)^2 + \frac{1}{12}\left(b^2-ab\right) = \frac{1}{18}a^2 - \frac{7}{36}ab + \frac{5}{36}b^2 \quad (93)$$

11. Cournot plays Walras in period two

Period one Cournot player achieves the following period two profit:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*t+1}\right) - \left(y_{-i}^{*R,t+1}\right)\right]\left(y_i^{*t+1}\right) - b\left(y_i^{*t+1}\right) \quad (94)$$

$$\pi_i^{t+1} = \left[a - \frac{1}{3}\left(a-\frac{4}{3}b\right) - \frac{1}{2}\left(a-\frac{2}{3}b\right)\right]\frac{1}{3}\left(a-\frac{4}{3}b\right) - \frac{1}{3}\left(a-\frac{4}{3}b\right)b \quad (95)$$

$$\pi_i^{t+1} = \frac{1}{18}a^2 - \frac{4}{27}ab + \frac{8}{81}b^2 \tag{96}$$

Period one Cournot playing firm, while it's opponent plays Walras in period one, will make a profit in period two, given it plays Cournot while it's opponent plays Walras in period two, of $\frac{1}{18}a^2 - \frac{4}{27}ab + \frac{8}{81}b^2$. Aggregation over 2 periods yields:

$$\begin{aligned}\Pi_i = \pi_i^t + \pi_i^{t+1} = \frac{1}{18}(a-b)^2 + \frac{1}{18}a^2 - \frac{4}{27}ab + \frac{8}{81}b^2 = \\ \frac{1}{9}a^2 - \frac{7}{27}ab + \frac{25}{162}b^2\end{aligned} \tag{97}$$

12. Walras plays Cournot in period two

Period one Cournot player achieves the following period two profit:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*R,t+1}\right) - \left(y_{-i}^{*t+1}\right)\right]\left(y_i^{*R,t+1}\right) - b\left(y_i^{*R,t+1}\right) \tag{98}$$

$$\begin{aligned}\pi_i^{t+1} = \left[a - \frac{1}{2}(a-b) - \frac{1}{3}\left(a - \frac{1}{3}b\right)\right]\frac{1}{2}(a-b) - \\ \frac{1}{2}(a-b)\,b\end{aligned} \tag{99}$$

$$\pi_i^{t+1} = \frac{1}{12}a^2 - \frac{5}{18}ab + \frac{7}{36}b^2 \tag{100}$$

Period one Cournot playing firm, while it's opponent plays Walras in period one, will make a profit in period two, given its strategy is relative profit maximization in period two while it's opponent's strategy is characterized by absolute profit maximization in period two, of $\frac{1}{12}a^2 - \frac{5}{18}ab + \frac{7}{36}b^2$. Aggregation over 2 periods yields:

$$\begin{aligned}\Pi_i = \pi_i^t + \pi_i^{t+1} = \frac{1}{18}(a-b)^2 + \frac{1}{12}a^2 - \frac{5}{18}ab + \frac{7}{36}b^2 = \\ \frac{5}{36}a^2 - \frac{7}{18}ab + \frac{1}{4}b^2\end{aligned} \tag{101}$$

3.5.4 Case iv: Walras plays Cournot in Period One

This case is case iii. in reversed order, i.e. in case iv., case iii. outcomes are the opponent's outcomes, which in turn means that case iv. outcomes are the outcomes of the opponent in case iii. The following are the computations for a period one Walrasian player while its competitor chose to be a Cournot player in period one. There are, again, 4 possible outcomes:

13. Cournot plays Cournot in period two

Period one Walrasian player achieves the following period two profit:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*t+1}\right) - \left(y_{-i}^{*t+1}\right)\right]\left(y_i^{*t+1}\right) - \frac{2}{3}b\left(y_i^{*t+1}\right) \tag{102}$$

$$\begin{aligned}\pi_i^{t+1} = \left[a - \frac{1}{3}\left(a - \frac{1}{3}b\right) - \frac{1}{3}\left(a - \frac{4}{3}b\right)\right]\frac{1}{3}\left(a - \frac{1}{3}b\right) - \\ \frac{1}{3}\left(a - \frac{1}{3}b\right)\frac{2}{3}b\end{aligned} \tag{103}$$

$$\pi_i^{t+1} = \left(\frac{1}{3}a - \frac{1}{9}b\right)^2 \tag{104}$$

This says, that the period one Walras playing firm, while it's opponent plays Cournot in period one, will have an absolute profit maximum in period two, when both firms play absolute profit maximizing strategies in period two, of $\left(\frac{1}{3}a - \frac{1}{9}b\right)^2$. Thus, aggregation over 2 periods yields:

$$\begin{aligned}\Pi_i = \hat{\pi}_{-i}^t + \pi_i^{t+1} = \frac{5}{72}(a-b)^2 + \left(\frac{1}{3}a - \frac{1}{9}b\right)^2 = \\ \frac{13}{72}a^2 - \frac{23}{108}ab + \frac{53}{648}b^2\end{aligned} \tag{105}$$

14. Walras plays Walras in period two

Period one Walrasian player achieves the following period two profit:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*R,t+1}\right) - \left(y_{-i}^{*R,t+1}\right)\right]\left(y_i^{*R,t+1}\right) - \frac{2}{3}b\left(y_i^{*R,t+1}\right) \tag{106}$$

$$\begin{aligned}\pi_i^{t+1} = \left[a - \frac{1}{2}\left(a - \frac{2}{3}b\right) - \frac{1}{2}(a-b)\right]\frac{1}{2}\left(a - \frac{2}{3}b\right) - \\ \frac{1}{2}\left(a - \frac{2}{3}b\right)\frac{2}{3}b\end{aligned} \tag{107}$$

$$\pi_i^{t+1} = \frac{1}{12}ab - \frac{1}{18}b^2 \tag{108}$$

The period one Walras playing firm, while it's opponent plays Cournot in period one, will achieve profits in period two, when both firms maximize relative profits in period two, of $\frac{1}{12}ab - \frac{1}{18}b^2$. Aggregation over 2 periods yields:

$$\begin{aligned} \Pi_i = \hat{\pi}_{-i}^t + \pi_i^{t+1} = \frac{5}{72}(a-b)^2 + \frac{1}{12}ab - \frac{1}{18}b^2 = \\ \frac{5}{72}a^2 - \frac{1}{18}ab + \frac{1}{72}b^2 \end{aligned} \tag{109}$$

15. Cournot plays Walras in period two

Period one Walrasian player achieves the following period two profit:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*t+1}\right) - \left(y_{-i}^{*R,t+1}\right)\right]\left(y_i^{*t+1}\right) - \frac{2}{3}b\left(y_i^{*t+1}\right) \tag{110}$$

$$\begin{aligned} \pi_i^{t+1} = \left[a - \frac{1}{3}\left(a - \frac{1}{3}b\right) - \frac{1}{2}(a-b)\right]\frac{1}{3}\left(a - \frac{1}{3}b\right) - \\ \frac{1}{3}\left(a - \frac{1}{3}b\right)\frac{2}{3}b \end{aligned} \tag{111}$$

$$\pi_i^{t+1} = \frac{1}{18}a^2 - \frac{1}{27}ab + \frac{1}{162}b^2 \tag{112}$$

Period one Walras playing firm, while it's opponent plays Cournot in period one, will achieve profits in period two, given it plays Cournot strategies in period two while it's opponent plays Walrasian strategies in period two, of $\frac{1}{18}a^2 - \frac{1}{27}ab + \frac{1}{162}b^2$. Aggregation over 2 periods yields:

$$\begin{aligned} \Pi_i = \hat{\pi}_{-i}^t + \pi_i^{t+1} = \frac{5}{72}(a-b)^2 + \frac{1}{18}a^2 - \frac{1}{27}ab + \frac{1}{162}b^2 = \\ \frac{1}{8}a^2 - \frac{19}{108}ab + \frac{49}{648}b^2 \end{aligned} \tag{113}$$

16. Walras plays Cournot in period two

Period one Walrasian player achieves the following period two profit:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*R,t+1}\right) - \left(y_{-i}^{*t+1}\right)\right]\left(y_i^{*R,t+1}\right) - \frac{2}{3}b\left(y_i^{*R,t+1}\right) \tag{114}$$

$$\pi_i^{t+1} = \left[a - \frac{1}{2}\left(a - \frac{2}{3}b\right) - \frac{1}{3}\left(a - \frac{4}{3}b\right)\right]\frac{1}{2}\left(a - \frac{2}{3}b\right) - \frac{1}{2}\left(a - \frac{2}{3}b\right)\frac{2}{3}b \tag{115}$$

$$\pi_i^{t+1} = \frac{1}{12}a^2 - \frac{1}{27}b^2 \tag{116}$$

The period one Walras playing firm, while it's opponent plays Cournot in period one, will make a profit in period two, given that it plays a Walrasian strategy in period two while its opponent plays a Cournot strategy in period two, of $\frac{1}{12}a^2 - \frac{1}{27}b^2$. Aggregation over 2 periods yields:

$$\Pi_i = \hat{\pi}_{-i}^t + \pi_i^{t+1} = \frac{5}{72}(a-b)^2 + \frac{1}{12}a^2 - \frac{1}{27}b^2 = \frac{11}{72}a^2 - \frac{5}{36}ab + \frac{7}{216}b^2 \tag{117}$$

3.6 Sequential Moves: Absolute Stackelberg

Optimal quantities are found through backward induction. Contrary to the previously analyzed simultaneous moves game, the sequential moves model reveals the first movers choices to the second mover. This, however, is known to the first mover, and she is able to include this information in her decision, as she knows how the second mover will react to her choice. Thus, the sequential moves game is one where information is common knowledge. Backward induction analysis starts with the reaction function of the second mover, which is equal to that of the Cournot reaction function computed early on in the simultaneous moves game. This reaction function is then substituted directly into the first mover's profit function. This process is straight forward, if the second mover can perfectly observe the quantity produced by the first mover, and the first mover knows exactly how the second mover will react to it's produced quantity, then the first mover can simply include this information into it's objective function and maximize it. The terminology in the Stackelberg model names the first mover "leader" and the second mover "follower." The terminology will be used interchangeably henceforth. In the following I use the subscript i for the leader and $-i$ for the follower. Often times it will not be necessary to make this distinction, as seen previously under simultaneous moves, however, due to the sequential nature of the game, it will help keep structure. I use absolute Stackelberg to indicate the absolute profit maximizing motivation of the players and in the following subsection relative Stackelberg to mean that firms choose strategies following a relative profit maximizing course. All the same basic assumptions about the duopoly market, as considered under simultaneous decision making, hold.

The follower's reaction function (equals the Cournot reaction function of simultaneous moves):

$$R^t_{-i} : y^t_{-i}(y^t_i) = \frac{1}{2}(a-b) - \frac{1}{2}y^t_i \tag{118}$$

The follower's reaction function will be substituted directly into the leader's profit function:

$$\max_{y^t_i} \pi^t_i = \left[a - y^t_i - \left(\frac{1}{2}(a-b) - \frac{1}{2}y^t_i\right)\right] y^t_i - by^t_i \tag{119}$$

$$\frac{\partial \pi^t_i}{\partial y^t_i} = a - 2y^t_i - \frac{1}{2}(a-b) + y^t_i - b = 0 \tag{120}$$

The first mover's absolute profit maximizing strategy in period one equals:

$$y^{*t}_i = \frac{1}{2}(a-b) \tag{121}$$

The Follower's optimal reaction to the leader's output is:

$$R^t_{-i} : y^t_{-i}(y^{*t}_i) = \frac{1}{2}(a-b) - \frac{1}{2}\left(\frac{1}{2}(a-b)\right) \tag{122}$$

$$y^{*t}_{-i} = \frac{1}{4}(a-b) \tag{123}$$

3.7 Sequential Moves: Relative Stackelberg

Relative Stackelberg, just as absolute Stackelberg, is computed backwards. The follower's reaction function is identical to that computed under Walrasian relative profit maximization (simultaneous moves) and independent of the first mover's output quantity. Due to this independence, common knowledge does not affect outcomes, as it did with absolute Stackelberg, and neither firm could "care less" about the information brought about by the sequential nature of the game. The second mover's optimal output is substituted into the first mover's profit function in order to compute the first mover's strategy. However, does the leader really need this information to maximize its relative profit? The answer is no! Just as the follower's optimal output quantity is independent of that of the leader, so is the leader's decision about its own optimal relative profit maximizing quantity. The computation below shows that when substituting the follower's optimal quantity into the leader's profit function, the leader chooses the same quantity as seen under Walrasian relative profit maximization and, in this case, also, as under absolute Stackelberg. The leader will always choose to produce $\frac{1}{2}(a-b)$, irrespective of whether it's motives are of absolute profit maximizing or relative profit maximizing nature, and the outcome of this sequential game in period one depends solely on the follower's decision to maximize absolute or relative profits.

The second mover's optimal output (equal to the Walrasian output in the simultaneous moves game) is:

$$\max_{y_{-i}^t} \pi_{-i}^{R,t} = \left(a - y_i^t - y_{-i}^t\right) y_{-i}^t - b y_{-i}^t - \left[\left(a - y_i^t - y_{-i}^t\right) y_i^t - b y_i^t\right] \tag{124}$$

$$\frac{\partial \pi_{-i}^{R,t}}{\partial y_{-i}^t} = a - 2y_{-i}^t - y_i^t - b + y_i^t = 0 \tag{125}$$

The second mover's relative profit maximizing strategy in period one is independent of the leader's choice and equals:

$$y_{-i}^{*R,t} = \frac{1}{2}(a-b) \tag{126}$$

The first mover's relative profit function is:

$$\max_{y_i^t} \pi_i^{R,t} = \left(a - y_i^t - y_{-i}^t\right) y_i^t - b y_i^t - \left[\left(a - y_i^t - y_{-i}^t\right) y_{-i}^t - b y_{-i}^t\right] \tag{127}$$

Substitution of the second mover's optimal output into the first mover's objective function yields:

$$\begin{gathered}\max_{y_i^t} \pi_i^{R,t} = \left(a - y_i^t - \frac{1}{2}(a-b)\right) y_i^t - b y_i^t - \\ \left[\left(a - y_i^t - \frac{1}{2}(a-b)\right) \frac{1}{2}(a-b) - b\frac{1}{2}(a-b)\right]\end{gathered} \tag{128}$$

$$\frac{\partial \pi_i^{R,t}}{\partial y_i^t} = a - 2y_i^t - \frac{1}{2}(a-b) - b + \frac{1}{2}(a-b) = 0 \tag{129}$$

The second mover's quantity cancels out and the function is independent of the second mover's output. This is the outcome under Walrasian competition and confirms the earlier conjecture that common knowledge in this sequential relative moves game does not change the outcome due to the reaction function's independence of the opponent's choice. The first mover's relative profit maximizing strategy in period one is independent of the second mover's choice and equals:

$$y_i^{*R,t} = \frac{1}{2}(a-b) \tag{130}$$

Now that sequential moves strategies in period one have been computed, I will continue and analyze the two resulting cases, i.e. the absolute (or relative) profit maximizing first mover plays the absolute profit maximizing second mover and the absolute (or relative) profit maximizing first mover plays the relative profit maximizing second mover. As the first mover will always play $\frac{1}{2}(a-b)$ in period one, there is no distinguishing, in terms of quantity, as to what motivated the first mover to choose this particular strategy. As soon as the model turns asymmetric though, absolute and relative profit maximizing strategies will no longer share the same output level, as will be seen in the further analysis. As mentioned, the outcome in this first period will only depend on the quantity decision of the second mover, another characteristic lost as soon as the model turns asymmetric. I continue by computing outcomes in period one brought about by the 2 cases of period one.

3.8 Profit Computations Sequential Moves

From the above computations optimal quantity choices were derived. For the sequential moves game only 2 strategy combinations exist. The outcomes of these two combinations depend only on the adopted strategy of the second mover, as the first mover's choice will always be $\frac{1}{2}(a-b)$. Therefore, the 2 cases are:

i. Stackelberg leader plays absolute profit maximizing Stackelberg follower This is the standard Stackelberg model where both players' objective is absolute profit maximization (as mentioned before, for the leader it makes no difference, in terms of output, if absolute or relative profit maximization is the objective). As opposed to simultaneous moves, sequential moves will result in different profits for the firms if both firms maximize absolute profits. This also means that the leader will generate a cost advantage in period two while the follower is left with the same cost function as in period one. In period two the model becomes asymmetric due to the different cost functions and, for the leader, absolute and relative profit maximizing strategies are no longer identical in terms of quantity.

ii. Stackelberg leader plays relative profit maximizing Stackelberg follower The model's outcome is different from i., as determined by the second mover's choice to maximize relative profits. Both firms produce the same output and achieve the same zero profit outcome, due to symmetry in the first period and the fact that optimal choices are independent of the other firms output. The model stays symmetric in the second (last) period. One might wonder about the follower's preference to play a relative profit maximizing strategy, as there is no way it could result in a desirable cost advantage in period two and profits in period one are lower than under an absolute profit maximizing strategy. However, it may be the second mover's intend to prevent such a cost advantage for the first mover and by selecting a relative profit maximizing strategy the second mover erases the first movers advantage in period two. Further considerations may include punishment of the leader for gaining an "unfair" cost advantage in period two and inequality aversion of the follower may provide the motive to choose a relative profit maximum in period one, as selecting the same quantity as the first mover will drive profits for both firms to zero.

i. Stackelberg leader plays absolute profit maximizing Stackelberg follower $\left[\frac{1}{2}(a-b), \frac{1}{4}(a-b)\right]$

The leader's profits in period one:

$$\pi_i^t = \left[a - \left(y_i^{*t}\right) - \left(y_{-i}^{*t}\right)\right]\left(y_i^{*t}\right) - b\left(y_i^{*t}\right) \tag{131}$$

$$\pi_i^t = \left(a - \frac{1}{2}(a-b) - \frac{1}{4}(a-b)\right)\frac{1}{2}(a-b) - \frac{1}{2}(a-b)\,b \tag{132}$$

$$\pi_i^t = \frac{1}{8}(a-b)^2 \tag{133}$$

The follower's profit in period one:

$$\pi_{-i}^{t} = \left[a - \left(y_i^{*t}\right) - \left(y_{-i}^{*t}\right)\right]\left(y_{-i}^{*t}\right) - b\left(y_{-i}^{*t}\right) \tag{134}$$

$$\pi_{-i}^{t} = \left(a - \frac{1}{2}(a-b) - \frac{1}{4}(a-b)\right)\frac{1}{4}(a-b) - \frac{1}{4}(a-b)\,b \tag{135}$$

$$\pi_{-i}^{t} = \frac{1}{16}(a-b)^2 \tag{136}$$

As the first mover's output is twice that of the second mover, and both firms face the same market price, and all output is sold in the market, the first mover's profit is double that of the second mover. The first mover's positive relative profit results in an investment into cost-saving technologies, which successfully lowers marginal cost in period two. The investment undertaken by the firm is equal to:

$$I_i^t = \frac{\pi_i^t - \pi_{-i}^t}{2} \tag{137}$$

$$I_i^t = \frac{\frac{1}{8}(a-b)^2 - \frac{1}{16}(a-b)^2}{2} \tag{138}$$

$$I_i^t = \frac{1}{32}(a-b)^2 \tag{139}$$

Given the investment of the first mover into cost-saving technologies, thereby reducing marginal cost in period two, the true profit of the first mover in period one ($\hat{\pi}$) is the absolute profit computed above minus the investment:

$$\hat{\pi}_i^t = \pi_i^t - I_i^t = \frac{1}{8}(a-b)^2 - \frac{1}{32}(a-b)^2 \tag{140}$$

$$\hat{\pi}_i^t = \frac{3}{32}(a-b)^2 \tag{141}$$

The investment will lead to the following cost reduction (δ):

$$\delta_i = \frac{I_i^t}{\pi_i^t}2 \tag{142}$$

$$\delta_i = \frac{\frac{1}{32}(a-b)^2}{\frac{1}{8}(a-b)^2}2 \tag{143}$$

$$\delta_{-i} = \frac{1}{2} \tag{144}$$

The leader's new cost function in period two is:

$$C^{t+1}(y_i^{t+1}) = b(1 - \delta_i)y_i^{t+1} \tag{145}$$

$$C^{t+1}(y_i^{t+1}) = \frac{1}{2}by_i^{t+1} \tag{146}$$

The follower's cost function in period two remains to be:

$$C^{t+1}(y_{-i}^{t+1}) = by_{-i}^{t+1} \tag{147}$$

ii. Stackelberg leader plays relative profit maximizing Stackelberg follower $\left[\frac{1}{2}(a-b), \frac{1}{2}(a-b)\right]$

The leader's profit in period one, which is equal to that of the follower, as both firms play the same quantity, i.e. $\frac{1}{2}(a-b)$, is:

$$\pi_i^t = \left[a - \left(y_i^{*R,t}\right) - \left(y_{-i}^{*R,t}\right)\right]\left(y_i^{*R,t}\right) - b\left(y_i^{*R,t}\right) \tag{148}$$

The superscript R for the first mover's strategy is rather unnecessary as there is no difference in quantity between absolute and relative profit maximizing strategies. I am using it here to highlight that the 2 different strategies have the same quantity.

$$\pi_i^t = \pi_{-i}^t = \left(a - \frac{1}{2}(a-b) - \frac{1}{2}(a-b)\right)\frac{1}{2}(a-b) - \frac{1}{2}(a-b)\,b \tag{149}$$

$$\pi_i^t = \pi_{-i}^t = 0 \tag{150}$$

There exist no opportunity for either firm to lower marginal cost for period two.

3.9 Sequential Moves Strategies in Period Two

As with the simultaneous moves game, optimal quantity choices in period two depend on the outcomes in period one. In case the second mover sets out to maximize relative profits in period one, both firms face the same cost function in period two and, thus, the same maximization problem in period two. In case the second mover maximizes absolute profits in period one, the first mover establishes a competitive advantage in period two, i.e. lower marginal costs, while the follower has to optimize period two with period one's cost function. It follows that if the second mover maximizes relative profits in period one, both end up with the same strategies and profits in period two that they had in period one, and outcomes, just as in period one, are determined solely by the follower's choice to either maximize absolute or relative profit. If the **second mover plays a relative profit maximizing strategy**, the model stays symmetric in period two and outcomes consist of period one outcomes:

i. Stackelberg leader plays absolute profit maximizing Stackelberg follower in period two

$$y_i^{*t+1} = \frac{1}{2}(a-b) \tag{151}$$

$$\pi_i^{t+1} = \frac{1}{8}(a-b)^2 \tag{152}$$

$$y_{-i}^{*t+1} = \frac{1}{4}(a-b) \tag{153}$$

$$\pi_{-i}^{t+1} = \frac{1}{16}(a-b)^2 \tag{154}$$

ii. Stackelberg leader plays relative profit maximizing Stackelberg follower in period two

$$y_i^{*R,t+1} = y_{-i}^{*R,t+1} = \frac{1}{2}(a-b) \tag{155}$$

$$\pi_i^{t+1} = \pi_{-i}^{t+1} = 0 \tag{156}$$

Asymmetry in period two can only be created if **the second mover chooses to play absolute profit maximizing strategies in period one**, i.e. the standard Stackelberg model. The model to be considered in period two is:

Inverse demand:

$$P^{t+1}(Y^{t+1}) = a - Y^{t+1} \tag{157}$$

Second period's cost function for the first mover:

$$C^{t+1}(y_i^{t+1}) = \frac{1}{2}by_i^{t+1} \tag{158}$$

Second period's cost function for the second mover:

$$C^{t+1}(y_{-i}^{t+1}) = by_{-i}^{t+1} \tag{159}$$

Taking the first mover's reduced cost into account, absolute profit maximizing strategies in period two, given a resulting asymmetric setting from period one, shows the following strategies for the leader and follower:

The second mover's reaction function (equal to Cournot) is:

$$R_{-i}^{t+1} : y_{-i}^{t+1}(y_i^{t+1}) = \frac{1}{2}(a-b) - \frac{1}{2}y_i^{t+1} \tag{160}$$

Substitution into the first mover's profit function yields:

$$\max_{y_i^{t+1}} \pi_i^{t+1} = \left[a - \left(y_i^{t+1}\right) - \left(y_{-i}^{t+1}\right)\right]\left(y_i^{t+1}\right) - \frac{1}{2}b\left(y_i^{t+1}\right) \tag{161}$$

$$\max_{y_i^{t+1}} \pi_i^{t+1} = \left[a - \left(y_i^{t+1}\right) - \left(\frac{1}{2}(a-b) - \frac{1}{2}y_i^{t+1}\right)\right]\left(y_i^{t+1}\right) - \frac{1}{2}b\left(y_i^{t+1}\right) \tag{162}$$

$$\frac{\partial \pi_i^{t+1}}{\partial y_i^{t+1}} = a - 2y_i^{t+1} - \frac{1}{2}(a-b) + y_i^{t+1} - \frac{1}{2}b = 0 \tag{163}$$

$$y_i^{*t+1} = \frac{1}{2}a \tag{164}$$

The second mover's optimal quantity in period two is:

$$R_{-i}^{t+1} : y_{-i}^{t+1}(y_i^{*t+1}) = \frac{1}{2}(a-b) - \frac{1}{4}a \tag{165}$$

$$y_{-i}^{*t+1} = \frac{1}{4}a - \frac{1}{2}b \tag{166}$$

Relative profit maximizing quantities in period two, considering the first mover's lower cost function and contrary to the symmetric model in period one, will result in in a difference between absolute and relative profit maximizing strategies for the first mover.

The follower's output (equal to Walras) does not change as it's cost function is the same as it was in period one:

$$y_{-i}^{*R,t+1} = \frac{1}{2}(a-b) \tag{167}$$

Substitution into the leader's profit function yields:

$$\begin{aligned} \max_{y_i^{t+1}} \pi_i^{R,t+1} = &\left[a - \left(y_i^{t+1}\right) - \left(y_{-i}^{*R,t+1}\right)\right]\left(y_i^{t+1}\right) - \frac{1}{2}b\left(y_i^{t+1}\right) - \\ &\left[\left(a - \left(y_i^{t+1}\right) - \left(y_{-i}^{*R,t+1}\right)\right)\left(y_{-i}^{*R,t+1}\right) - b\left(y_{-i}^{*R,t+1}\right)\right] \end{aligned} \tag{168}$$

$$\begin{aligned} \max_{y_i^{t+1}} \pi_i^{R,t+1} = &\left(a - \left(y_i^{t+1}\right) - \frac{1}{2}(a-b)\right)\left(y_i^{t+1}\right) - \frac{1}{2}b\left(y_i^{t+1}\right) - \\ &\left[\left(a - \left(y_i^{t+1}\right) - \frac{1}{2}(a-b)\right)\frac{1}{2}(a-b) - b\frac{1}{2}(a-b)\right] \end{aligned} \tag{169}$$

$$\frac{\partial \pi_i^{R,t+1}}{\partial y_i^{t+1}} = a - 2y_i^{t+1} - \frac{1}{2}(a-b) - \frac{1}{2}b + \frac{1}{2}(a-b) = 0 \tag{170}$$

$$y_i^{*R,t+1} = \frac{1}{2}a - \frac{1}{4}b \tag{171}$$

There is one more strategy that needs to be considered here, which is clearly distinguished from the strategies under simultaneous moves. Due to common knowledge, i.e. the follower's ability to observe the the leader's quantity, the follower can choose to play an absolute profit maximizing strategy given the leader played a relative profit maximizing strategy (which in this case is clearly distinct from its absolute profit maximizing quantity, contrary to period one). In this particular case, the absolute profit maximizing strategy is not equal to that computed above, where both firms choose to be absolute profit maximizers. The follower includes the leaders relative profit maximizing quantity in her reaction function and optimally reacts as follows:

The leader's relative profit maximizing quantity in period two is:

$$y_i^{*R,t+1} = \frac{1}{2}a - \frac{1}{4}b \tag{172}$$

The follower's reaction function (equal to Cournot) is:

$$R_{-i}^{t+1} : y_{-i}^{t+1}(y_i^{*R,t+1}) = \frac{1}{2}(a-b) - \frac{1}{2}y_i^{*R,t+1} \tag{173}$$

$$y_{-i}^{t+1}(y_i^{*R,t+1}) = \frac{1}{2}(a-b) - \frac{1}{2}\left(\frac{1}{2}a - \frac{1}{4}b\right) \tag{174}$$

The follower's optimal absolute profit maximizing reply to the leader's relative profit maximizing quantity is:

$$y_{-i}^{*t+1} = \frac{1}{4}a - \frac{3}{8}b \tag{175}$$

3.10 Period Two Profit Computations Sequential Moves

Strategies for period two have been computed and, in order to finish the preparatory steps for the backward induction analysis, outcomes in period two are computed in this subsection, and, along with the results obtained in period one, aggregated. Just as under simultaneous moves, sequential moves outcomes in period two depend on the choices of period one (cases of period one). Therefore, all computations below are based on a certain outcome of period one and labeled as such. Contrary to simultaneous moves, the sequential moves model has only 2 outcomes resulting from period one. If both firms choose relative profit maximizing strategies, period two model is equal to period one model with 2 outcomes in period two. If both firms behave in accordance with the absolute profit maximizing model (absolute Stackelberg), thus, establishing a difference in the two firms' cost functions in period two, firms now have 4 possible outcome in period two to consider. This makes for a total of 6 outcomes that need to be analyzed through backward induction.

3.10.1 Case 1. Stackelberg Leader Plays Relative Profit Maximizing Stackelberg Follower in Period One

Neither firm creates a cost advantages in period two, which means, both firms face the same maximization problem in period two that they did in period one and outcomes in period two must therefore reflect outcomes of period one.

1. Stackelberg leader plays absolute profit maximizing Stackelberg follower in period two

Results for the Leader:

$$\pi_i^{t+1} = \frac{1}{8}(a-b)^2 \tag{176}$$

$$\Pi_i = \pi_i^t + \pi_i^{t+1} = 0 + \frac{1}{8}(a-b)^2 = \frac{1}{8}(a-b)^2 \tag{177}$$

Results for the follower:

$$\pi_{-i}^{t+1} = \frac{1}{16}(a-b)^2 \tag{178}$$

$$\Pi_{-i} = \pi_{-i}^t + \pi_{-i}^{t+1} = 0 + \frac{1}{16}(a-b)^2 = \frac{1}{16}(a-b)^2 \tag{179}$$

2. Stackelberg leader plays relative profit maximizing Stackelberg follower in period two

Results for the leader and follower :

$$\pi_i^{t+1} = \pi_{-i}^{t+1} = 0 \tag{180}$$

$$\Pi_i = \pi_i^t + \pi_{-i}^{t+1} = 0 + 0 = 0 \tag{181}$$

3.10.2 Case 2. Stackelberg Leader Plays Absolute Profit Maximizing Stackelberg Follower in Period One

The first mover outperforms the second mover in period one, which leads to a cost advantage for the first mover over the second mover in period two. The market is no longer equally split and absolute and relative profit maximizing strategies no longer align for the first mover.

3. Absolute profit maximizing Stackelberg leader plays absolute profit maximizing Stackelberg follower in period two

Results for the Leader:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*t+1}\right) - \left(y_{-i}^{*t+1}\right)\right]\left(y_i^{*t+1}\right) - \frac{1}{2}b\left(y_i^{*t+1}\right) \tag{182}$$

$$\pi_i^{t+1} = \left[a - \frac{1}{2}a - \left(\frac{1}{4}a - \frac{1}{2}b\right)\right]\left(\frac{1}{2}a\right) - \frac{1}{2}b\frac{1}{2}a \tag{183}$$

$$\pi_i^{t+1} = \frac{1}{8}a^2 \tag{184}$$

Aggregation over 2 periods yields:

$$\Pi_i = \hat{\pi}_i^t + \pi_i^{t+1} = \frac{3}{32}(a-b)^2 + \frac{1}{8}a^2 = \frac{7}{32}a^2 - \frac{3}{16}ab + \frac{3}{32}b^2 \tag{185}$$

Results for the follower:

$$\pi_{-i}^{t+1} = \left[a - \left(y_i^{*t+1}\right) - \left(y_{-i}^{*t+1}\right)\right]\left(y_{-i}^{*t+1}\right) - b\left(y_{-i}^{*t+1}\right) \tag{186}$$

$$\pi_{-i}^{t+1} = \left[a - \frac{1}{2}a - \left(\frac{1}{4}a - \frac{1}{2}b\right)\right]\left(\frac{1}{4}a - \frac{1}{2}b\right) - \left(\frac{1}{4}a - \frac{1}{2}\right)b \tag{187}$$

$$\pi_{-i}^{t+1} = \left(\frac{1}{4}a - \frac{1}{2}b\right)^2 \tag{188}$$

Aggregation over 2 periods:

$$\Pi_{-i} = \pi_{-i}^t + \pi_{-i}^{t+1} = \frac{1}{16}(a-b)^2 + \left(\frac{1}{4}a - \frac{1}{2}b\right)^2 = \frac{1}{8}a^2 - \frac{3}{8}ab + \frac{5}{16}b^2 \tag{189}$$

4. Relative profit maximizing Stackelberg leader plays relative profit maximizing Stackelberg follower in period two

Once again, as under simultaneous moves, playing relative profit maximizing strategies in period two must stem from other-regarding preferences as, in terms of pure profit seeking agents, no better quantity than the absolute profit maximizing quantity exists.

Results for the Leader:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*R,t+1}\right) - \left(y_{-i}^{*R,t+1}\right)\right]\left(y_i^{*R,t+1}\right) - \frac{1}{2}b\left(y_i^{*R,t+1}\right) \tag{190}$$

$$\pi_i^{t+1} = \left[a - \left(\frac{1}{2}a - \frac{1}{4}b\right) - \frac{1}{2}(a-b)\right]\left(\frac{1}{2}a - \frac{1}{4}b\right) - \frac{1}{2}b\left(\frac{1}{2}a - \frac{1}{4}b\right) \tag{191}$$

$$\pi_i^{t+1} = \frac{1}{8}ab - \frac{1}{16}b^2 \tag{192}$$

Aggregation over 2 periods:

$$\Pi_i = \hat{\pi}_i^t + \pi_i^{t+1} = \frac{3}{32}(a-b)^2 + \frac{1}{8}ab - \frac{1}{16}b^2 = \frac{3}{32}a^2 - \frac{1}{16}ab + \frac{1}{32}b^2 \tag{193}$$

Results for the follower:

$$\pi_{-i}^{t+1} = \left[a - \left(y_i^{*R,t+1}\right) - \left(y_{-i}^{*R,t+1}\right)\right]\left(y_{-i}^{*R,t+1}\right) - b\left(y_{-i}^{*R,t+1}\right) \tag{194}$$

$$\pi_{-i}^{t+1} = \left[a - \left(\frac{1}{2}a - \frac{1}{4}b\right) - \frac{1}{2}(a-b)\right]\frac{1}{2}(a-b) - \frac{1}{2}(a-b)\,b \tag{195}$$

$$\pi_{-i}^{t+1} = \frac{1}{8}b^2 - \frac{1}{8}ab \tag{196}$$

Aggregation over 2 periods:

$$\Pi_{-i} = \pi_{-i}^t + \pi_{-i}^{t+1} = \frac{1}{16}(a-b)^2 + \frac{1}{8}b^2 - \frac{1}{8}ab = \frac{1}{16}a^2 - \frac{1}{4}ab + \frac{3}{16}b^2 \tag{197}$$

5. Absolute profit maximizing Stackelberg leader plays relative profit maximizing Stackelberg follower in period two

Results for the Leader:

$$\pi_i^{t+1} = \left[a - \left(y_i^{*t+1}\right) - \left(y_{-i}^{*R,t+1}\right)\right]\left(y_i^{*t+1}\right) - \frac{1}{2}b\left(y_i^{*t+1}\right) \tag{198}$$

$$\pi_i^{t+1} = \left[a - \frac{1}{2}a - \frac{1}{2}(a-b)\right]\frac{1}{2}a - \frac{1}{2}b\left(\frac{1}{2}a\right) \tag{199}$$

$$\pi_i^{t+1} = 0 \tag{200}$$

Aggregation over 2 periods:

$$\Pi_i = \hat{\pi}_i^t + \pi_i^{t+1} = \frac{3}{32}(a-b)^2 + 0 = \frac{3}{32}(a-b)^2 \tag{201}$$

Results for the follower:

$$\pi_{-i}^{t+1} = \left[a - \left(y_i^{*t+1}\right) - \left(y_{-i}^{*R,t+1}\right)\right]\left(y_{-i}^{*R,t+1}\right) - b\left(y_{-i}^{*R,t+1}\right) \tag{202}$$

$$\pi_{-i}^{t+1} = \left[a - \frac{1}{2}a - \frac{1}{2}(a-b)\right]\frac{1}{2}(a-b) - b\left(\frac{1}{2}(a-b)\right) \tag{203}$$

$$\pi_{-i}^{t+1} = \frac{1}{4}b^2 - \frac{1}{4}ab \tag{204}$$

Aggregation over 2 periods:

$$\Pi_{-i} = \pi_{-i}^{t} + \pi_{-i}^{t+1} = \frac{1}{16}(a-b) + \frac{1}{4}b^2 - \frac{1}{4}ab = \frac{1}{16}a^2 - \frac{3}{8}ab + \frac{5}{16}b^2 \tag{205}$$

6. Relative profit maximizing Stackelberg leader plays absolute profit maximizing Stackelberg follower in period two

Results for the Leader:

$$\pi_{i}^{t+1} = \left[a - \left(y_i^{*R,t+1}\right) - \left(y_{-i}^{*t+1}\right)\right]\left(y_i^{*R,t+1}\right) - \frac{1}{2}b\left(y_i^{*R,t+1}\right) \tag{206}$$

$$\begin{aligned}\pi_{i}^{t+1} = \left[a - \left(\frac{1}{2}a - \frac{1}{4}b\right) - \left(\frac{1}{4}a - \frac{3}{8}b\right)\right]\left(\frac{1}{2}a - \frac{1}{4}b\right) - \\ \frac{1}{2}b\left(\frac{1}{2}a - \frac{1}{4}b\right)\end{aligned} \tag{207}$$

$$\pi_{i}^{t+1} = \frac{1}{8}a^2 - \frac{1}{32}b^2 \tag{208}$$

Aggregation over 2 periods:

$$\Pi_{i} = \hat{\pi}_{i}^{t} + \pi_{i}^{t+1} = \frac{3}{32}(a-b)^2 + \frac{1}{8}a^2 - \frac{1}{32}b^2 = \frac{7}{32}a^2 - \frac{3}{16}ab + \frac{1}{16}b^2 \tag{209}$$

Results for the follower:

$$\pi_{-i}^{t+1} = \left[a - \left(y_i^{*R,t+1}\right) - \left(y_{-i}^{*t+1}\right)\right]\left(y_{-i}^{*t+1}\right) - b\left(y_{-i}^{*t+1}\right) \tag{210}$$

$$\pi_{-i}^{t+1} = \left[a - \left(\frac{1}{2}a - \frac{1}{4}b\right) - \left(\frac{1}{4}a - \frac{3}{8}b\right)\right]\left(\frac{1}{4}a - \frac{3}{8}b\right) - b\left(\frac{1}{4}a - \frac{3}{8}b\right) \tag{211}$$

$$\pi_{-i}^{t+1} = \left(\frac{1}{4}a - \frac{3}{8}b\right)^2 \tag{212}$$

Aggregation over 2 periods:

$$\Pi_{-i} = \pi_{-i}^{t} + \pi_{-i}^{t+1} = \frac{1}{16}(a-b) + \left(\frac{1}{4}a - \frac{3}{8}b\right)^2 = \frac{1}{8}a^2 - \frac{5}{16}ab + \frac{13}{64}b^2 \tag{213}$$

3.11 Backward Induction - Finding the Nash Equilibria

Now that all strategies and outcomes have been computed, its time to find the Nash equilibria to obtain a theoretical solution to both the simultaneous and sequential moves games. I therefore present both games in game tree form, which also allows for a convenient overview of all strategies and aggregated outcome previously computed, and then use backward induction to derive the Nash equilibria. Although the games are, mathematically speaking, rather straight forward, they are also somewhat tedious, due their dynamic character, and its easy to get lost within the games. I show that for the simultaneous moves game 2 asymmetric Nash equilibria in pure strategies exist and that the mixed strategy equilibrium yields an expected payoff of:

$$\Pi_i = \Pi_{-i} = \frac{75}{389}a^2 - \frac{367}{991}ab + \frac{82}{431}b^2 \tag{214}$$

The sequential moves game is much more straight forward and one sub-game perfect Nash equilibrium in pure strategies exists at absolute profit maximizing Stackelberg throughout. Consequently, the first mover establishes a cost advantage in period two turning the game asymmetric. The lower marginal cost in period two also creates a scenario where a relative profit maximizing strategy for the first mover in period two is smaller than the absolute profit maximizing strategy in period two. While in the symmetric model relative profit maximizing strategies usually means increasing output beyond the absolute optimum, here, the first mover can use its substantial cost advantage and actually lower output below the absolute profit maximizing quantity, using it's competitive advantage to create an even larger distance between itself and its competition. Another interesting aspect about this model is that if the first mover did establish a cost advantage in period two and chooses dominant absolute profit maximizing strategy in period two, than a relative profit maximizing Stackelberg follower, albeit not a dominant strategy, will actually generate negative profits. The outcomes in equilibrium for the sequential moves games are:

$$\Pi_i = \frac{7}{32}a^2 - \frac{3}{16}ab + \frac{3}{32}b^2 \tag{215}$$

$$\Pi_{-i} = \frac{1}{8}a^2 - \frac{3}{8}ab + \frac{5}{16}b^2 \tag{216}$$

Overall, the equilibrium quantity in the sequential moves game is larger than the mixed or pure strategy equilibria in the simultaneous moves game, rendering the sequential moves game more efficient in terms of total welfare.

3.11.1 Game Tree: Simultaneous Moves

The game tree (figure 1) can easily be solved with backward induction. However, one needs to account for imperfect information due to the simultaneous move nature of the game. In period two both players choose Cournot strategies and the restriction to perfectly identify the opponent's choice (imperfect information) does not limit the players in their decision to choose Cournot as it is always the dominant strategy. Thus, the game can be reduced to a one period game (figure 2 and table 1) when adding period two result to the outcomes of the game in period one. This result can also be confirmed intuitively: If no successive period exists and therefore no incentives are provided to further lower cost by outperforming competition, then it seems reasonable to assume that firms play Cournot strategies in the last period maximizing absolute profits. This, however, does not consider spiteful motives. In the presence of spite a relative profit maximizing strategy may still prevail despite a no-future scenario. The notation means: C (Cournot strategy) and W (Walrasian strategy)

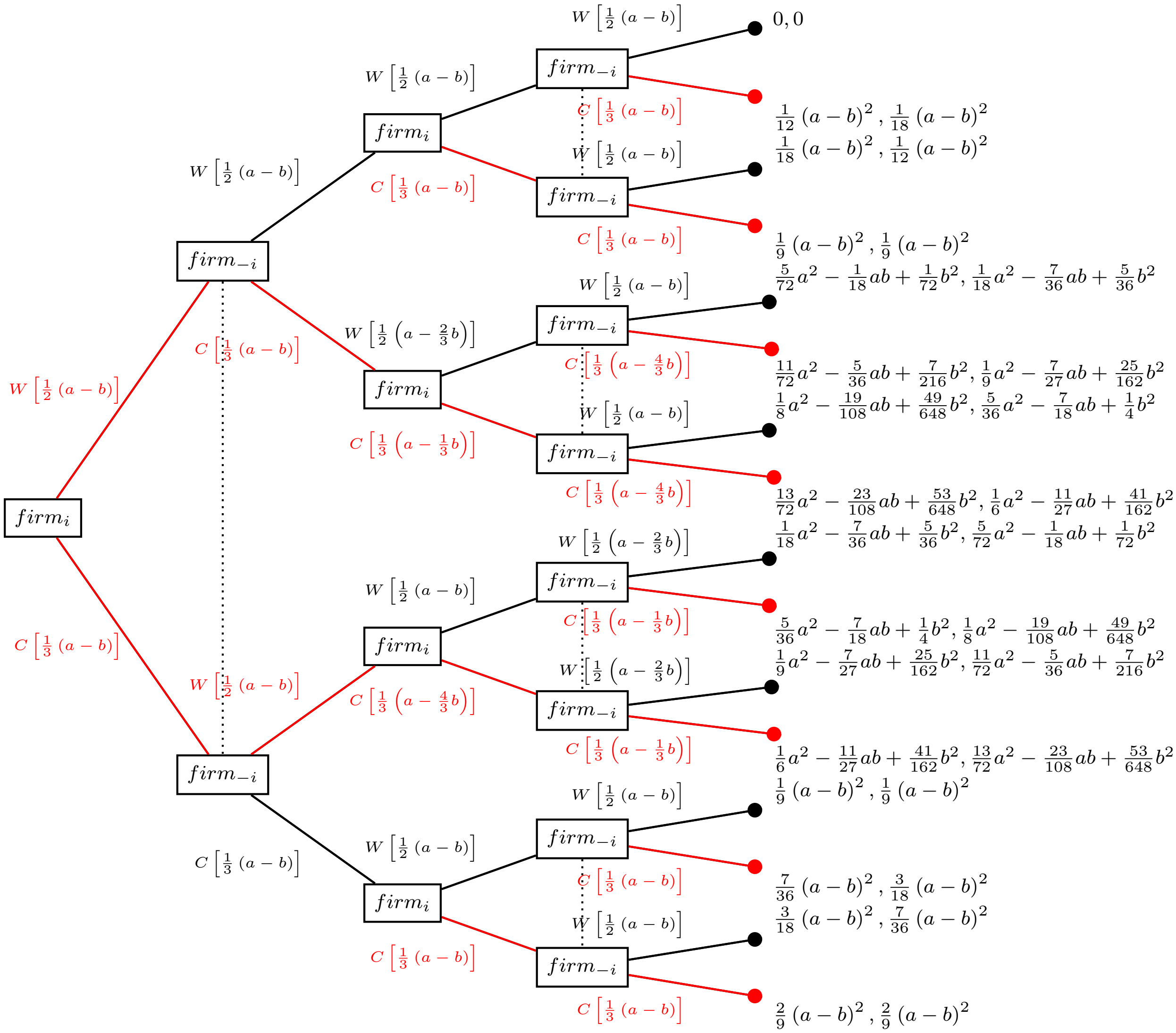

Figure 1: Game tree Cournot game

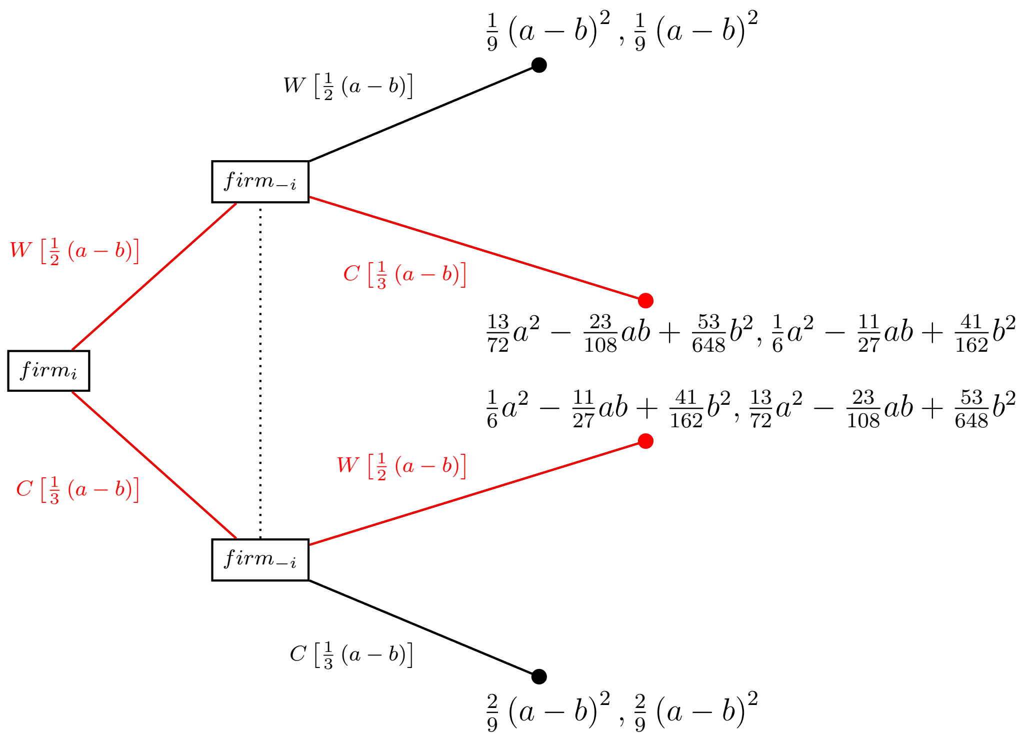

Figure 2: Reduced game tree Cournot game

	Walras $\left[\frac{1}{2}(a-b)\right]$	Cournot$\left[\frac{1}{3}(a-b)\right]$
Walras$\left[\frac{1}{2}(a-b)\right]$	$\frac{1}{9}(a-b)^2, \frac{1}{9}(a-b)^2$	$\frac{13}{72}a^2 - \frac{23}{108}ab + \frac{53}{648}b^2, \frac{1}{6}a^2 - \frac{11}{27}ab + \frac{41}{162}b^2$
Cournot$\left[\frac{1}{3}(a-b)\right]$	$\frac{1}{6}a^2 - \frac{11}{27}ab + \frac{41}{162}b^2, \frac{13}{72}a^2 - \frac{23}{108}ab + \frac{53}{648}b^2$	$\frac{2}{9}(a-b)^2, \frac{2}{9}(a-b)^2$ 4

Table 1: Strategic Form of the reduced game tree (Cournot game)

Both extensive and strategic form show two asymmetric sub-game perfect Nash equilibria at [Walras, Cournot] and [Cournot, Walras]. In the extensive form (game tree), the equilibrium path is highlighted in red. The strategic form (two by two table) shows both equilibria at (up-right, down-left). Unfortunately, due to the asymmetric character of the 2 Nash equilibria, neither firm can be sure about which equilibrium will be reached. The derived game is a game of chicken and can be further analyzed using mixed strategies, assuming both firms are indifferent between either strategy, i.e. indifferent between either choosing Cournot $\left[\frac{1}{3}(a-b)\right]$ or Walras $\left[\frac{1}{2}(a-b)\right]$. Due to the fact that the above game is symmetric (albeit asymmetric equilibria) it is sufficient to solve for only one firm with the following results:

$$\begin{gathered}\pi_{i,Walras} = \left[\frac{1}{9}(a-b)^2\right]p + \left[\frac{13}{72}a^2 - \frac{23}{108}ab + \frac{53}{648}b^2\right](1-p) = \\ \left[\frac{1}{6}a^2 - \frac{11}{27}ab + \frac{41}{162}b^2\right]p + \left[\frac{2}{9}(a-b)^2\right](1-p) = \pi_{i,Cournot}\end{gathered} \tag{217}$$

$$p = \frac{77}{265} = 29.1\% \text{ (Walras)} \tag{218}$$

$$(1-p) = \frac{188}{265} = 70.9\% \text{ (Cournot)} \tag{219}$$

The Nash equilibrium in mixed strategies will have both firms choose Walrasian strategies roughly 29% of the time and Cournot Strategies about 71% of the time. Thus, the following percentages can be determined:

	Walras $[\frac{77}{265}(29.1\%)]$	Cournot $[\frac{188}{265}(70.9\%)]$
Walras $[\frac{77}{265}(29.1\%)]$	$\frac{45}{533}(8.4\%)$	$\frac{47}{228}(20.6\%)$
Cournot $[\frac{188}{265}(70.9\%)]$	$\frac{47}{228}(20.6\%)$	$\frac{229}{455}(50.3\%)$

Table 2: Mixed strategies in strategic Form (Cournot game)

The expected payoff for the mixed strategy equilibrium is:

$$\begin{gathered}\Pi_i = \Pi_{-i} = \frac{45}{265}\left(\frac{1}{9}(a-b)^2\right) + \frac{47}{228}\left(\frac{13}{72}a^2 - \frac{23}{108}ab + \frac{53}{648}b^2\right) + \\ \frac{47}{228}\left(\frac{1}{6}a^2 - \frac{11}{27}ab + \frac{41}{162}b^2\right) + \frac{229}{455}\left(\frac{2}{9}(a-b)^2\right)\end{gathered} \tag{220}$$

$$\Pi_i = \Pi_{-i} = \frac{75}{389}a^2 - \frac{367}{991}ab + \frac{82}{431}b^2 \tag{221}$$

The mixed strategy outcome shows that the absolute profit maximizing strategy combination (Cournot,Cournot) will be played 50.3% of the time, while the relative profit maximizing quantity at (Walras,Walras) will only be played about 8.4% of the time. The two pure Nash equilibria derived through backward induction, i.e. (Walras,Cournot) and (Cournot,Walras), will each be played 20.6% of the time. It follows that at approximately 41.2% of the time will one of the firm generate a competitive advantage by successfully bringing marginal cost in period two below that of it's competitor and creating a chance to reap extra large profits in absolute terms or outperform it's competitor by a larger relative amount than possible in period one.

3.11.2 Game Tree: Sequential Moves

From the sequential moves computation it is known that whether a firm is an absolute profit maximizing Stackelberg leader or a relative profit maximizing Stackelberg leader, it will choose the same quantity, i.e. $y_i = \frac{1}{2}(a-b)$. This explains the choice vector at the first node, where the first mover's absolute and relative profit maximizing strategies align, i.e. only 1 quantity is optimal in both relative and absolute terms. If the game continues to be symmetric in period two, the first and second mover are confronted with same optimal relative and absolute profit maximizing quantities and the first mover will select the same quantity as in period one, whether the objective is absolute or relative profit maximization. The Notation used in figure 3 is short for: SL (Stackelberg leader), SF (Stackelberg follower), subscript A (absolute profit maximizing strategy), and subscript R (relative profit maximizing strategy). Once again, the sub-game perfect Nash equilibrium path is highlighted in red and consists of absolute profit maximizing strategies throughout the entire game, resulting in the Stackelberg leader employing her first mover's advantage to the fullest and creating a cost advantage in period two, leading to an even bigger gap between the Stackelberg leader's and Stackelberg follower's optimal quantity.

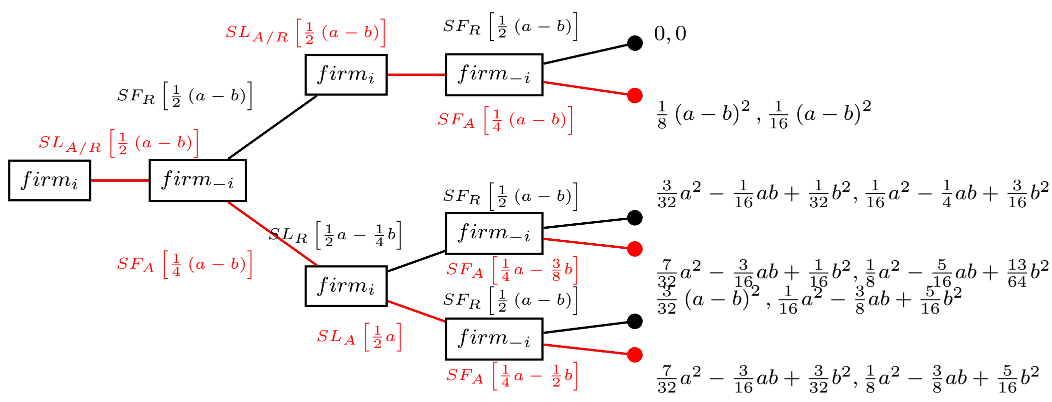

Figure 3: Game tree Stackelberg model

4 The Experimental Model

The Experimental model is simply a parameterized version of the general model, which is why I decided to not go into further detail about the mathematical derivation of each and every equation[9]. The choice vector for the simultaneous and the sequential moves model in period one consists of four choices. I decided to always give player four options in order to make sure that they could not just merely choose between the absolute and relative profit maximizing quantities, thus, giving them more "food for thought." Due to the 2-period structure, it seemed unwise to include more options as it would have made the experiment more difficult, as more combination options in period one would result in more possibilities in period two rendering the experiment much more complex and maybe too time-consuming for players to make an educated choice. A choice vector of four seemed the most appropriate in terms of timing and complexity. The Choices are a low quantity, the absolute profit maximizing quantity, a high quantity, and the relative profit maximizing quantity. Both absolute and relative quantity are computed for the respective Cournot or Stackelberg model. The low and high quantities are fitted equally, in terms of quantity distance, below and between the absolute and relative profit maximizing quantity. In the Cournot game the low quantity was always below the Cournot quantity, while the high quantity was always between the Cournot and the Walrasian quantity, with the Walrasian quantity being the highest quantity. In the Stackelberg game, due to the sequential nature of the model, this was somewhat different, in that, absolute and relative profit maximizing quantities may be reversed in their order. This means that for some scenarios in period two a low quantity may not exist as the relative Stackelberg quantity represents the lowest quantity (this particular scenario is theoretically possible but experimental results show that it never actually occurred during the experiment). Additionally, in period one, the Stackelberg leader's quantity vector consisted of one extra quantity, which was the Cournot quantity. As I showed in the general model (previous section), absolute and relative profit maximizing strategies for the Stackelberg leader coincide, decreasing her choices to three options only. I added the Cournot quantity (40) to give the first mover the option to signal the second mover that she is willing to cooperate instead of being competitive, in order to avoid possible punishment. The following shows some of the mathematics

[9] Please see appendix H for a more detailed math workup.

for the parameterized model.

Consider the following 2-period duopoly model with a one time possibility (period one) to invest into cost saving technologies, lowering period two's marginal cost.

Inverse Demand:

$$P^t(Y^t) = 160 - Y^t, \text{ where } Y^t = \sum_{i=1}^{2} y_i^t \tag{222}$$

Both firms face the following cost function:

$$C^t(y_i^t) = 40(1 - \delta_i^t)y_i^t, \text{ where} \tag{223}$$

$$\delta_i^t = \frac{I_i^{t-1}}{\pi_i^{t-1}}2, \text{ and} \tag{224}$$

$$I_i^{t-1} = \frac{\pi_i^{t-1} - \pi_{-i}^{t-1}}{2} \forall\ \pi_i^{t-1} > \pi_{-i}^{t-1} > 0, \text{ else } I_i^{t-1} = 0 \tag{225}$$

$$\delta_i^t = \frac{\pi_i^{t-1} - \pi_{-i}^{t-1}}{\pi_i^{t-1}} \tag{226}$$

Again, it makes sense to assume that in the experiment the lower marginal cost of period two did not "magically" appear as some kind of extra gratification, but rather brought about by an investment into, say, new technologies, which then reduce production cost.

Both firms start out in symmetry, as the cost function's δ_i^t does not yet exist, assuming t being the first ever period. Thus, in period one, firms' cost functions are:

$$C(y_i) = 40y_i \tag{227}$$

The Investment is non-optional if one firm reaches positive relative profits.

$$I_i^t = \frac{\pi_i^t - \pi_{-i}^t}{2}\ \forall\ \pi_i^t > \pi_{-i}^t > 0, \text{ else } I_i^t = 0 \tag{228}$$

4.1 Simultaneous Moves

Deriving the Cournot quantity:

$$\max_{y_i} \pi_i = P(Y)y_i - C(y_i) \tag{229}$$

FOC:

$$\frac{\partial \pi_i}{\partial y_i} = 120 - 2y_i - y_{-i} = 0 \tag{230}$$

Reaction function:

$$R_i : y_i(y_{-i}) = 60 - \frac{1}{2}y_{-i} \tag{231}$$

Optimal quantities:

$$y_i^* = y_{-i}^* = 40 \tag{232}$$

Deriving the Walrasian quantity:

$$\max_{y_i}(\pi_i - \pi_{-i}) = \max_{y_i} \pi_i^R \tag{233}$$

Best reply function (independent of the other firm):

$$\max_{y_i} \pi_i^R = (160 - y_i - y_{-i})\, y_i - 40y_i - [(160 - y_i - y_{-i})\, y_{-i} - 40y_{-i}] \tag{234}$$

FOC:

$$\frac{\partial \pi_i^R}{\partial y_i} = 120 - 2y_i = 0 \tag{235}$$

Optimal quantities:

$$y_i^* = y_{-i}^* = 60 \tag{236}$$

Obviously, both Cournot and Walrasian quantities may not be an optimal quantity in period two, if one of the players achieved positive realtive profits, i.e. if players choose different strategies in period one, (40|60) or (60|40), creating asymmetry in period two. I have already computed these cases in the general model. Hence, I will here simply substitute the parameters into the results derived earlier. Let us assume firm i is the Walrasian player while firm -i is the Cournot player.

Cournot outcomes - Optimizing period two for (60|40):

This means that the period one Walrasian player lowers marginal cost by roughly 33% and its new cost function looks like this is:

$$C(y_i) = 26\frac{2}{3}y_i \tag{237}$$

Objective function:

$$\max_{y_i} \pi_i = (160 - y_i - y_{-i})\, y_i - 26\frac{2}{3}y_i \tag{238}$$

FOCs[10]

$$\frac{\partial \pi_i}{\partial y_i} = 133\frac{1}{3} - 2y_i - y_{-i} = 0 \tag{239}$$

and the FOC already computed in period one for firm -i:

$$\frac{\partial \pi_{-i}}{\partial y_{-i}} = 120 - 2y_{-i} - y_i = 0 \tag{240}$$

Reaction functions:

$$R_{-i} : y_{-i}(y_i) = 60 - \frac{1}{2}y_i \tag{241}$$

Optimal quantities in period two:

$$y_i^* = 48\frac{8}{9} \tag{242}$$

$$y_{-i}^* = 35\frac{5}{9} \tag{243}$$

This leaves only one other quantity to be computed, the Walrasian quantity for the player with the cost advantage in period two. The Cournot-playing firm from period one faces the same Walrasian quantity in period two due to its unchanged marginal cost.

Walrasian outcomes - Optimizing period two for (60|40):

Deriving the Walrasian quantity:

$$\max_{y_i}(\pi_i - \pi_{-i}) = \max_{y_i} \pi_i^R \tag{244}$$

[10] Due to the asymmetry stemming from period one, there are two different objective function.

Best reply function (independent of the other firm):

$$\max_{y_i} \pi_i^R = (160 - y_i - y_{-i})\, y_i - 26\frac{2}{3} y_i - [(160 - y_i - y_{-i})\, y_{-i} - 40 y_{-i}] \quad (245)$$

FOC:

$$\frac{\partial \pi_i^R}{\partial y_i} = 133\frac{1}{3} - 2y_i = 0 \quad (246)$$

Optimal quantities:

$$y_i^* = 66\frac{2}{3} \quad (247)$$

Firm -i's optimal Walrasian output remains unchanged.

$$y_{-i}^* = 60 \quad (248)$$

The game tree (figure 4) and reduced from (figure 5) summarize strategies and outcomes in the Cournot game. It does not include the low and high quantity that were added to increase the choice vector. Adding the low and high quantity would have created a game tree too large to be displayed here. Also, it seems more appropriate to focus on the equilibrium paths in each game, and low and high quantities do not play any role in deriving the equilibrium in either one of the games.

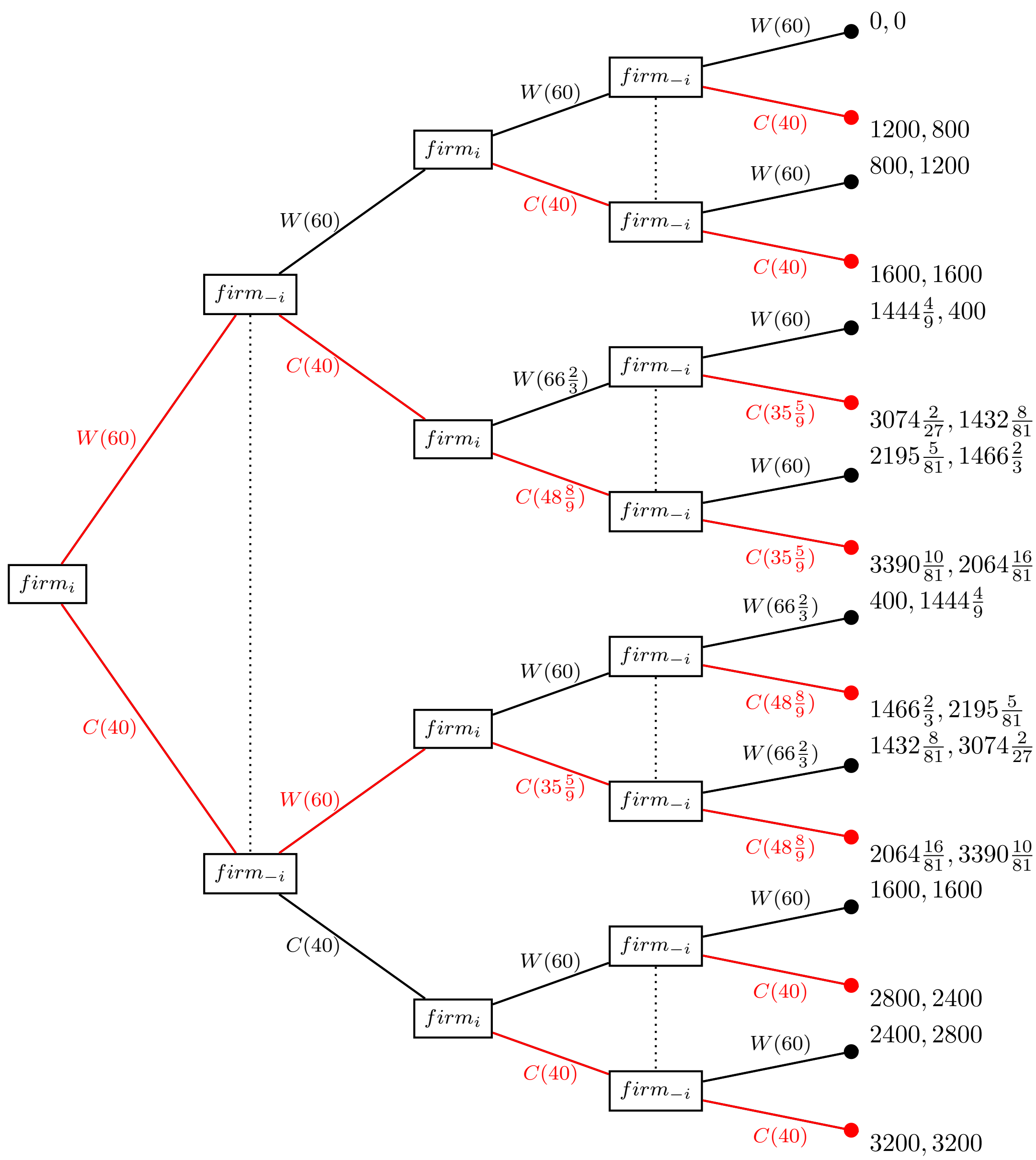

Figure 4: Game tree showing two sub-game perfect equilibria in pure strategies at $[(C|W), (C|C)]$ and $[(W|C), (C|C)]$.

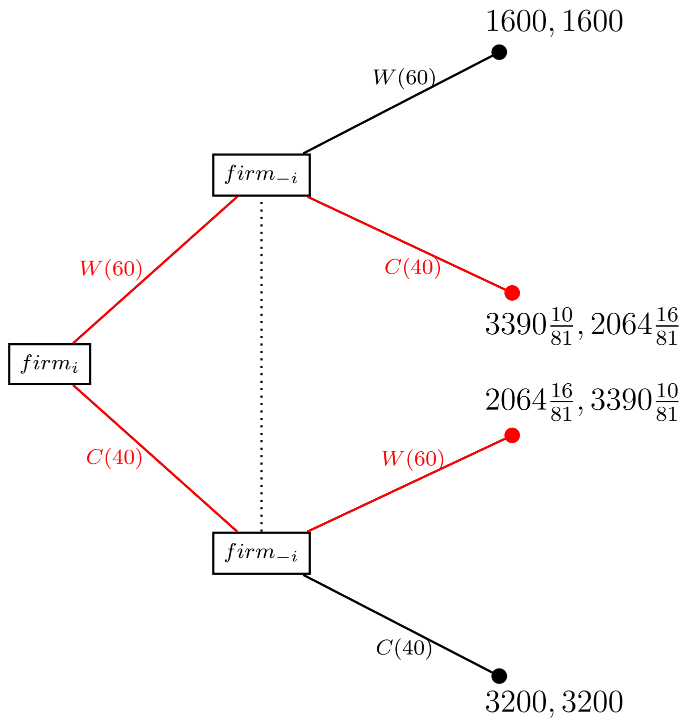

Figure 5: Reduced game tree with all players choosing Cournot quantities in period two

The reduced form of the game tree, see figure 5, is created by adding Cournot outcomes of period two to all strategies in period one. I can simply add these outcomes to period one as I know from the analysis that all players choose absolute profit maximizing strategies in period two. The resulting tree is much more user-friendly and the two sub-game perfect Nash equilibria are easily identified. The reduced form can also be depicted in a two by two table (table 3) indicating the same two Nash equilibria at $[(W|C)$ and $(C|W)]$. I then used mixed strategies to analyze further, assuming both firms are indifferent between either strategy, i.e. Cournot or Walras. Due to the fact that the above game is symmetric (though asymmetric equilibria) it is sufficient to solve for only one firm.

	Walras	Cournot
Walras	$1600, 1600$	$3390\frac{10}{81}, 2064\frac{16}{81}$
Cournot	$2064\frac{16}{81}, 3390\frac{10}{81}$	$3200, 3200$

Table 3: Strategic form with two Nash equilibria at $[(W|C)$ and $(C|W)$

$$\pi_{i,Walras} = 1600p + 3390\frac{10}{81}(1-p) = 2064\frac{16}{81}p + 3200(1-p) = \pi_{i,Cournot} \quad (249)$$

The general model results can be confirmed at:

$$p = 0.29 \text{ (Walras)} \quad (250)$$

$$p = 0.71 \text{ (Cournot)} \quad (251)$$

The mixing percentages are shown in table 4. The expected mixed strategy

	Walras (29%)	Cournot(71%)
Walras (29%)	8.4%	20.6%
Cournot (71%)	20.6%	50.3%

Table 4: Two by two table showing the mixed strategy Nash equilibrium

equilibrium profits is:

$$\begin{aligned} \Pi_i = \Pi_{-i} = 0.084\,(1600) + 0.206\left(3391\frac{10}{81}\right) + \\ 0.206\left(2064\frac{16}{81}\right) + 0.504\,(3200) \end{aligned} \quad (252)$$

$$\Pi_i = \Pi_{-i} = 2870 \quad (253)$$

It follows that if player behave in accordance with their mixed strategy Nash equilibrium they can expect a payoff of 2870 in every game of the simultaneous moves experiment.

4.2 Sequential Moves

The general model computation showed that whether a firm is an absolute profit maximizing Stackelberg leader or a relative profit maximizing Stackelberg leader in period one (symmetry), it will choose the same quantity, i.e. 60. The outcome, therefore, in period one solely depends on the follower's decision to either maximizer absolute profits (30) or relative profits (60). A Cournot quantity (40) as computed in the simultaneous moves game is not part of the optimal quantity vector. I decided to keep the Cournot quantity "alive" in this sequential moves model for players seeking for example, equality in profits or for the Stackelberg leader to avoid punishment by the Stackelberg follower for choosing a competitive strategy; clearly though, not an equilibrium path. The notation goes as follows: SL (Stackelberg leader), SF (Stackelberg follower), subscript A (absolute profit maximizing strategy), subscript R (relative profit maximizing strategy), and subscript C (Cournot quantity).

The follower's optimal reply function is equal to the reply function computed under Cournot:

$$R_{-i} : y_{-i}(y_i) = 60 - \frac{1}{2}y_i \tag{254}$$

The leader's profit function:

$$\max_{y_i} \pi_i = \left[160 - y_i - \left(60 - \frac{1}{2}y_i\right)\right] y_i - 40y_i \tag{255}$$

$$\frac{\partial \pi_i}{\partial y_i} = 60 - y_i = 0 \tag{256}$$

The leader in optimum will choose :

$$y_i^* = 60 \tag{257}$$

The follower's quantity is:

$$R_{-i} : y_{-i}(60) = 60 - \frac{1}{2}60 \tag{258}$$

$$y_{-i}^* = 30 \tag{259}$$

The absolute profit maximizing Stackelberg leader will produce 60 while the absolute Stackelberg follower will produce 30. Thus, contrary to the simultaneous moves model, if both firms act in accordance with absolute profit maximizing strategies, the Stackelberg leader will have a cost advantage in period two.

Relative profit maximizing strategies have already been calculated above (see Walrasian strategies of simultaneous moves).

The follower objective function is:

$$\max_{y_{-i}} \pi^R_{-i} = (160 - y_i - y_{-i})\, y_{-i} - 40y_{-i} - [(160 - y_i - y_{-i})\, y_i - 40y_i] \quad (260)$$

FOC:

$$\frac{\partial \pi^R_{-i}}{\partial y_{-i}} = 120 - 2y_{-i} = 0 \quad (261)$$

The follower's optimal reply function is independent of the other firm's output:

$$y^*_{-i} = 60 \quad (262)$$

Thus, the leaders optimal profit, under consideration of the followers optimal quantity choice:

$$\max_{y_i} \pi^R_i = \left(160 - y_i - y^*_{-i}\right) y_i - 40y_i - \left[\left(160 - y_i - y^*_{-i}\right) y^*_{-i} - 40y^*_{-i}\right] \quad (263)$$

The leader's optimal quantity is also 60, as her quantity decision in this symmetric model is independent of the followers output decision, and vice versa.

$$\frac{\partial \pi^R_i}{\partial y_i} = 120 - 2y_i = 0 \quad (264)$$

Hence:

$$y^*_i = 60 \quad (265)$$

Strategies in period one for the Stackelberg leader consist of only one quantity in the choice vector, namely, 60. The outcome in period one and consequently the respective quantity option in period two, solely depend on the Stackelberg follower. This explains why the Stackelberg leader may have to "fear" possible punishment due to her first mover advantage. This is the reason why I decided to include the Cournot quantity (40) of the simultaneous moves game as part of the choice vector in period one[11]. It follows that

[11] Mathematical derivation of best relies to quantity 40, which will not play a role in the equilibrium path, can be found in appendix H.

a possible asymmetric setting in period one is created by the Stackelberg follower. It is up to her to decide whether she gives the first mover a cost advantage in period two or chooses a zero payoff for both players in period one, keeping the model symmetric in period two. There are two possible outcomes in period one, [(60|30)(60|60)], whereas (60|30) create asymmetry in period two while (60|60) keeps things symmetric in period two.

Absolute Profit maximizing outcomes in period two for (60|60):

As the model remains symmetric, there are no changes in the cost structure for neither one of the firms, quantity options are identical to those in period one, i.e. the Stackelberg leader chooses 60 whether she is a relative or absolute profit maximizer and the Stackelberg follower chooses between 30 has her absolute profit maximizing quantity or 60 as her relative profit maximizing quantity. If the Stackelberg follower plays 60 in both periods, both firms will leave the game earning a payoff equal to zero. It seems likely that even if the Stackelberg follower plays 60 in period one, she will choose 30 (the absolute profit maximizing quantity) in period two, in order to not leave the game without any payoff.

Absolute Profit maximizing outcomes in period two for (60|30)[12]:

The Stackelberg follower's optimal reply to whatever strategy the leader will choose is, again, and due to the fact that it's cost function did not change, the same as derived under standard Cournot:

$$R_{-i} : y_{-i}(y_i) = 60 - \frac{1}{2}y_i$$

Substituting firm -i's best response into firm i's profit function yields the following optimal quantity for the Stackelberg leader in period two:

$$\max_{y_i} \pi_i = \left[160 - y_i - \left(60 - \frac{1}{2}y_i\right)\right] y_i - 20y_i \tag{266}$$

$$\frac{\partial \pi_i}{\partial y_i} = 80 - y_i = 0 \tag{267}$$

[12] In addition to the first mover's larger payoff in period one, she also decreases her marginal cost to half their original size, i.e. 20 in period two.

The leader in optimum will choose :

$$y_i^* = 80 \tag{268}$$

The follower's quantity is:

$$R_{-i} : y_{-i}(80) = 60 - \frac{1}{2}80 \tag{269}$$

Thus, the follower in optimum will choose :

$$y_{-i}^* = 20 \tag{270}$$

Relative Profit maximizing outcomes in period two for $(60|30)$:

The Stackelberg follower faces the same cost function in period two as she did in period one, i.e. marginal cost equal 40, as she did not achieve positive relative profits on accounts of her chosen quantity being lower than that of her competitor. Therefore, her relative profit maximizing quantity in period two is, just as in period one, 60.

The Stackelberg leader's objective function is:

$$\max_{y_i} \pi_i^R = (160 - y_i - y_{-i})\, y_i - 20y_i - [(160 - y_i - y_{-i})\, y_{-i} - 40y_{-i}] \tag{271}$$

FOC:

$$\frac{\partial \pi_i^R}{\partial y_i} = 140 - 2y_i = 0 \tag{272}$$

The Stackelberg leader's new relative profit maximizing quantity, at marginal cost equal to 20, is:

$$y_i^* = 70 \tag{273}$$

It is important to not forget one possible quantity for the Stackelberg follower. Given the sequential nature of the model, the Stackelberg follower has a best reply, in terms of absolute profits, to the Stackelberg leader's relative profit maximizing quantity. One must, therefore, ask, how does the second mover optimally respond if the first mover plays its relative profit maximizing quantity (70)?

The Stackelberg follower's optimal reply to the leader's relative profit maximizing quantity is:

$$R_{-i} : y_{-i}(y_i) = 60 - \frac{1}{2}70 \tag{274}$$

An absolute profit maximizer chooses:

$$y^*_{-i} = 25 \tag{275}$$

The game tree (figure 6) summarized the above computations and allows for a concise way to find the sub-game perfect Nash equilibrium in pure strategies. The equilibrium path is highlighted in red and constitutes absolute profit maximizing Stackelberg play throughout. This makes it fundamentally different from the simultaneous moves game, where the investment possibility changed the game from two Nash equilibria in pure strategies to one with a Nash equilibrium in mixed strategies. Thus, in this Stackelberg model, theory predicts the usual Stackelberg outcome 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.

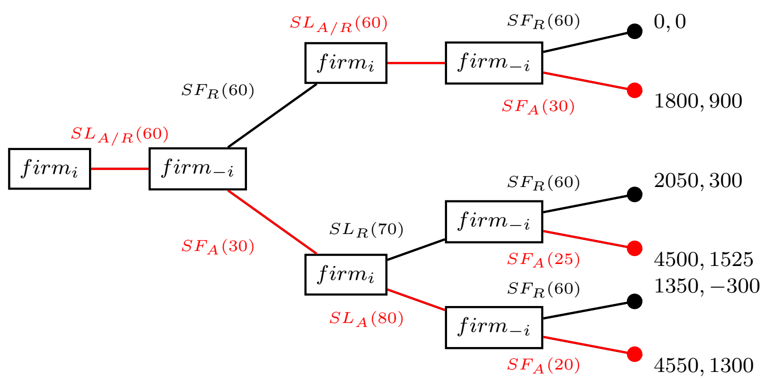

Figure 6: Game tree for the sequential moves game with one sub-game perfect Nash equilibrium in pure strategies at [(60|30) and (80|20)].

Game tree, figure 7, includes the Cournot quantity (green branch). It is not part of the equilibrium path, however, may present an important feature, as players may be inequality averse and, thus, choose Cournot quantities to ensure equal payoff distributing (computations for the Cournot branch are in Appendix H).

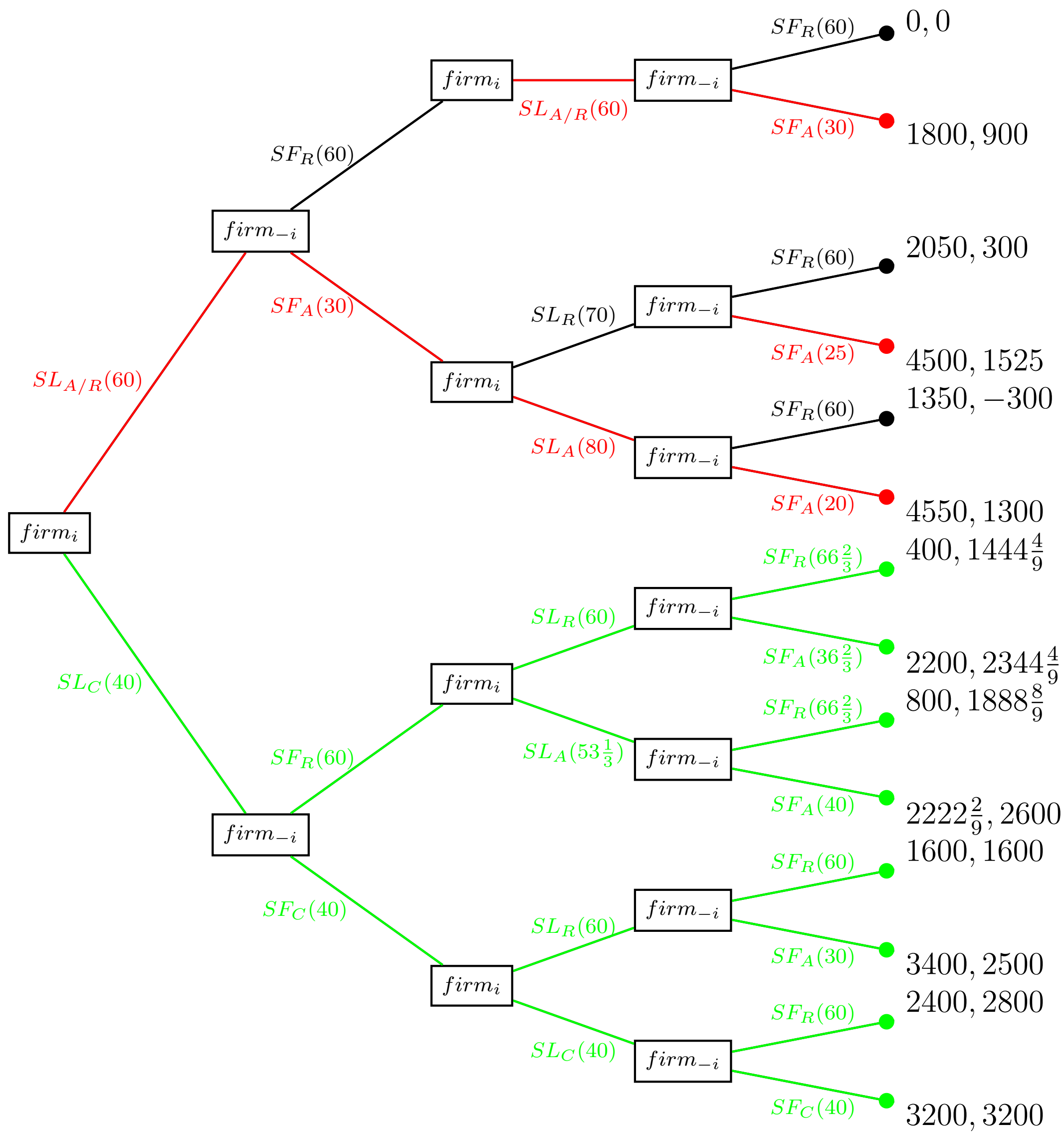

Figure 7: Sequential moves game tree with the addition of the Cournot quantity for inequality averse player.

4.3 Short Preliminary Summary

So far I have introduced the general and experimental model upon which the dissertation is based. The model is split into a simultaneous moves game and a sequential moves game. In the simultaneous moves game first and second period strategies and outcomes were computed and possible changes from the symmetric to an asymmetric setting through the achievement of positive relative profits were distinguished. To be more specific, two outcomes in period one resulted in a change from symmetry in period one to asymmetry in period two, i.e. in case firms choses different strategies in period one, meaning Cournot quantities or Walrasian quantities. The other 2 cases resulted in essentially the same strategy options in period two as in period one. Two Nash equilibria in pure strategies were found and indicated as such, which constituted a game of chicken. Further analysis showed a Nash equilibrium in mixed strategies. Strategies and outcome in the sequential model were somewhat different. The outcome in period one depends only on the strategy of the Stackelberg follower as the Stackelberg leader's absolute and relative profit maximizing strategy align, i.e. they are the same quantity (60). Asymmetry was created if the follower chooses any strategy other than the quantity chosen by the Stackelberg leader in period one. The sequential moves model resulted in only one Nash equilibrium in pure strategies. No further analysis was necessary. In a second game tree Cournot quantities were added to the sequential moves game to indicate that players may hold preferences other than selfish profit maximization. This, however, was not part of the equilibrium analysis - but will become important in the following experiment.

5 Experimental Procedures

Both the simultaneous moves model and the sequential moves model were put to the test experimentally. This was done at the marketing laboratory for economic and marketing research at the University of Kaiserslautern, Germany[13] in May 2012. Participants for both experiments were recruited in class or 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. In total 47 students were invited to take part in the experiments. For the simultaneous moves experiment (May 02, 2012) 24 students were invited, all of whom showed at the designated time and location, and 20 took part in the actual experiment[14]. For the sequential moves experiment (May 30, 2012) 23 students were invited. All 23 students showed up for the experiment. During the introduction phase, it turned out that one participant had not understood the experiment and was replaced by another student. Two students, plus the one student that did not understand the game, were randomly selected, paid 15.00 EUR, and sent home.

Both simultaneous and sequential moves model were "pen and paper" based and did not involve any special economics laboratory software, but instead, involved a computer-based spreadsheet from which participants were able to select quantities. In both experiments subjects were randomly assigned to a specific computer in the laboratory, which ensure random matching of the participants, as it was predefined which computer would play another computer. After the instructions (see Appendix A and B) were read and the spreadsheet thoroughly explained, participants were encouraged to ask questions, which were answered on an individual level. I also proceeded to go from computer to computer to ensure everyone had understood the instructions

[13]I would like to thank Professor Dr. Stefan Roth and the department of marketing for letting me use their lab to run both experiments and for their help with all IT related issues in the laboratory.

[14]I invited 24 in case of no-shows and in case I had to replace certain participants in the event that someone did not understand the experiment. As everyone understood the instructions - tested by a short questionnaire, I sent 4 participants (that were randomly selected) home with a pay of 15.00 (EUR). this may seem like a rather large amount of money, however, in oder to make sure everyone understood the experiment participants had to sit through about 45 minutes of introduction and preparatory work.

and to see if there were questions or problems that needed clarification. Participants, then, were asked to fill out a short questionnaire (see Appendix C and D) to verify if, in fact, all participants had understood the experiments. Both experiments consisted of ten games consisting of 2 periods each, which players were informed about[15]. Quantity options in both simultaneous and sequential games, consisted of four choices, including the absolute profit maximizing quantity, the relative profit maximizing quantity, a quantity between the absolute and relative profit maximizing quantity and a quantity below which ever quantity (absolute or relative profit maximizing) was lowest. In the simultaneous moves game the absolute profit maximizing quantity was always lower than the relative profit maximizing quantity. In the sequential moves game, the order depended on the outcome in period one, meaning, for certain outcomes in period 1, the relative profit maximizing quantity in period 2 may be lower that the absolute profit maximizing quantity (this, however, was merely a theoretical possibility and did not occur in the experiment).

Players were also informed that they would receive a participation payment of 7.00 EUR and additionally would receive the amount (payoff) earned in each period of the game. 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. In every period, Participants would note their quantity choice on a record sheet (Appendix E). We would then walk from player to player and note their decision on the experimenters' record sheet (Appendix F) and report the opponent's choice in each period. This made for quite a bit of walking back and forth between players but ensure a doubling up on reported quantities and ensured no falsification of previous quantities. Additionally, and after both quantities (their own and their opponents) were reported to all players, the experimenter indicated (by filling in the designated space on the players' record sheet) the players and its opponent's payoff. Thus, there were four entries to be made on each player's record sheet. The player's quantity (noted by the player herself), the opponent's quantity, and the payoffs of both players (all three made by the experimenter). Experimenters

[15]Experimental evidence suggest that, except for a possible end effect, finite and infinite time horizons show no significant behavioral difference, see Selten and Stoecken (1986) [42].

used a special pen to ensure that players were unable to change or falsify quantities and payoffs. This procedure was then repeated for all 10 games, i.e. 20 periods.

5.1 Simultaneous Moves Model (Cournot Game)

All 20 players were informed that they are facing a market with two participants (duopoly) in which they would play a randomly selected opponent each period. They were also informed that they would play a new opponent every period and would never meet the same opponent twice, thus, the Cournot game was designed to be a random treatment in order to minimize the effects resulting from coordination[16]. After the instructions were read to them, the experimenter introduced the computer-based spread sheet (see figure 8). The spreadsheet was installed and opened at every computer and all participants had their own computer and were unable to see other players choices. Each player worked with the same spreadsheet and each computer screen showed the same information to each player. Spreadsheets worked the following way: Players could only select two cells, which included a drop-down menu consisting of four different quantities in period 1 - 30, 40, 50, and 60. The two selectable cells were the the player's quantity and the opponent's quantity. Depending on which quantities were selected, the spreadsheet would produce a payoff table for period 1 and period 2. Additionally, each player was given a payoff table for period 1 (Appendix G) consisting of all quantity combinations and their respective profits, payoffs, investments, and cost for period 2. The printed payoff tables gave players a complete view of all options in period 1.

Players were asked to make a quantity decision in period one. If they successfully outperformed their opponent in terms of profits, then their firm would invest into cost-saving technologies driving down production cost in period two, thus creating a competitive advantage in period two. The amount the outperforming firm invests is equal to half of the difference of the firms' profits. If the firm got outperformed in terms of profit, then the opponent would

[16]The author gained some experience from a different experiment run at the University of Magdeburg in 2007 during which players that remained in fixed pairs appeared to develop some form of tacit mutual coordination, where players developed a switching dynamic to gain extra ordinary profits. this was an unexpected, though interesting result, but was not part of the research question here, see Kecinski and Riechmann (2010) [24].

invest into cost-saving technologies generating a competitive advantage in period two. Each Player's payoff in period one is the difference between their firm's profit and investment. The Spreadsheet included all information of the printed payoff table and additionally would show the respective quantity options for period two and its respective payoffs. It seemed rather inconvenient to print all possible outcomes in period two resulting from choices made in period one, as this would have resulted in too many payoff tables. Thus, players had to turn to their spreadsheet, which helped them simulate all combinations in period one and the respective option in period two. For example: If in period one both players chose a quantity of 40, both firms made the same profit and both players received the same payoff on account of no investments, as relative profits were equal to zero. If, however, one firm produces more than it's opponent, than, the firm with the larger output invests into cost-saving technologies lowering marginal cost in period two, creating an advantage over it's competitor. The resulting quantity options in period two are now different from period one and different from it's opponent (asymmetric setting). Depending on the size of the investment different quantity choices for the firms are available in period two. Therefore, it seemed easier for firms to simulate all outcomes in a spreadsheet and understand how period two choices are generated. After all players were done testing the spreadsheet and considering all options for period one and two, the actual experiment started.

5.2 Sequential Moves Model (Stackelberg Game)

All 20 players were informed that they are facing a duopolistic market in which they would play the same opponent, which had been randomly selected, for all 10 games. I decided to keep players in fixed pairs as I was interested to see if there would be play that qualifies as inequality averse, see Fehr and Schmidt (1999) [13] and Bolton and Ockenfels (2000)[10], either through punishment of the Stackelberg follower, i.e. by deliberately playing above absolute profit maximizing Stackelberg follower's quantities to shrink Stackelberg leader's payoff and to avoid being outperformed in terms of relative profits, and, thus, giving the first mover an even bigger advantage in period two; or through cooperative behavior of the Stackelberg leader, i.e. choosing below profit maximizing Stackelberg leader's quantity to avoid a possible punishment by the second mover. After the instructions were read out loud, the experimenter continued explaining the computer-based

Period 1	
Your Quantity	60
Your Opponent	40

Enter the Quantities!

Profit		Investment		Payoff		Cost Period 2	
You	Opponent	You	Opponent	You	Opponent	You	Opponent
1.20	0.80	0.20	0.00	1.00	0.80	26.67	40.00

		Your Opponent's Quantities							
	Payoff Table	23		36		48		60	
	Period 2	Payoff		Payoff		Payoff		Payoff	
		You	Opponent	You	Opponent	You	Opponent	You	Opponent
Your Quantities	40	2.80	1.32	2.31	1.58	1.82	1.54	1.33	1.20
	49	2.99	1.11	2.39	1.26	1.79	1.11	1.20	0.67
	58	3.02	0.91	2.31	0.95	1.60	0.69	0.90	0.13
	67	2.89	0.70	2.07	0.63	1.26	0.27	0.44	-0.40

Figure 8: Example of simultaneous moves game spreadsheet for period one choices (60|40)

spreadsheet. Due to the sequential nature of the game, two slightly different spreadsheets were used, one for the Stackelberg leaders (see figure 9) and one for the Stackelberg followers (see figure 10). Stackelberg leaders and followers were strategically placed in the laboratory to ensure that no player would be able to visually identify their opponent. Players were asked to first identify if they were first mover or second mover. Just like the simultaneous game, players could only select two cells in the spreadsheet containing a drop-down menu from which they had to select a quantity. For the first mover four different quantity option were available - 30, 40, 50, and 60. Although the second mover was able to simulate all possible quantity-scenarios in the spreadsheet, they had to wait until the Stackelberg leader made its quantity decision in order for them to know what the four quantity options for them were. This is straight forward, as a different quantity from the Stackelberg leader would result in, for example, a different absolute profit maximizing quantity for the Stackelberg follower. Players were given about 20 minutes to practice and simulate all possible outcome for period one and period two. This meant that, while Stackelberg leaders were able to pick quantities they may actually select in the following experiment, Stackelberg followers had to make an assumption about what the Stackelberg leader's quantiy might be and then identify the option that they would select should such case arise.

An important difference in the Stackelberg model, compared to the Cournot model is that for the Stackelberg leader in period one absolute and relative profit maximizing strategies coincide, i.e. 60. I decided to include the Cournot quantity from the simultaneous game, i.e. 40, in order to give first movers the option to offer a quantity to the second mover that seemed "fair" in terms of equal payoff. A second mover that received a quantity of 40 could now decide whether it wanted to outperform its competitor to lower cost for period two or reciprocate by also choosing 40 to generate equal market share and profit. They also had to consider their future relationship, in that, responding competitively to a 40 quantity may destroy future equal play possibilities as the Stackelberg leader may use its first mover advantage to outperform the Stackerlberg follower for the rest of the game. Hence, in the sequential moves game players did not only have to consider the investment into cost-saving technologies and creating a competitive advantage in period two but also strategic play in terms of punishment and cooperation. Payoffs in period one are computed identical to the simultaneous moves game, in that, it is the firm's profit minus the investment. The investment is half of the positive relative difference in firm profits. 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 record sheet. The experimenter reports the quantity to the Stackelberg follower who enters the Stackelberg leaders quantity into the spreadsheet and has four quantity options available to choose from. After the Stackelberg follower decided on its quantity, payoffs in period one are reported to both players. The spreadsheet shows the payoff table for period two, which depend on the quantity choices in period one. The Stackelberg leader, once again, moves first and selects one of four possible quantities, notes it on the record sheet and the experimenter reports it to the second mover, who herself has four possible choices available. This process is repeated for all 10 games. After all players were done testing the spreadsheet the experiment started.

Period 1 You are the first mover

Period 1	
Your Quantity	60
Your Opponent	30

Results Period 1			
Profit		Investment	
Sie	Ihr Gegner	Sie	Ihr Gegner
1.80	0.90	0.45	0.00

Payoff		Cost Period 2	
Sie	Ihr Gegner	Sie	Ihr Gegner
1.35	0.90	20.00	40.00

Quantity Opponent

		Payoff		Cost Period 2		Payoff		Cost Period 2		Payoff		Cost Period 2		Payoff		Cost Period 2	
Period 1		You	Opponent	You	Opponent	You	Opponent	You	Opponent	You	Opponent	You	Opponent	You	Opponent	You	Opponent
		38				45				53				60			
Your Quantity	30	1.58	1.77	40.00	32.00	1.35	1.69	40.00	26.67	1.13	1.55	40.00	22.86	0.90	1.35	40.00	20.00
		30				40				50				60			
	40	1.75	1.50	30.00	40.00	1.60	1.60	40.00	40.00	1.20	1.35	40.00	32.00	0.80	1.00	40.00	26.67
		23				35				48				60			
	50	1.72	1.07	18.00	40.00	1.49	1.23	28.00	40.00	1.10	1.07	38.00	40.00	0.50	0.55	40.00	33.33
		15				30				45				60			
	60	1.69	0.68	10.00	40.00	1.35	0.90	20.00	40.00	0.79	0.68	30.00	40.00	0.00	0.00	40.00	40.00

Period 2 You are the first mover

Quantity Opponent

		Payoff		Payoff		Payoff		Payoff	
Period 2		You	Opponent	You	Opponent	You	Opponent	You	Opponent
		-4		18		39		60	
Your Quantity	85	4.99	-0.15	3.19	0.31	1.38	-0.15	-0.43	-1.50
		0		20		40		60	
	80	4.80	0.00	3.20	0.40	1.60	0.00	0.00	-1.20
		4		23		41		60	
	75	4.59	0.15	3.19	0.51	1.78	0.15	0.38	-0.90
		8		25		43		60	
	70	4.38	0.32	3.15	0.63	1.93	0.32	0.70	-0.60

Figure 9: Example of sequential moves game spreadsheet (Stackelberg leader) for period one choices (60|30)

Period 1 You are the second mover

Period 1	
Your Quantity	30
You Opponent	60

Results Period 1			
Profit		Investment	
You	Opponent	You	Opponent
0.90	1.80	0.00	0.45

Payoff		Cost Period 2	
You	Opponent	You	Opponent
0.90	1.35	40.00	20.00

Your Quantity

		Payoff		Cost Period 2		Payoff		Cost Period 2		Payoff		Cost Period 2		Payoff		Cost Period 2	
Periode 1		Opponent	You	Opponent	You	Opponent	You	Opponent	You	Opponent	You	Opponent	You	Opponent	You	Opponent	You
		38				45				53				60			
Your Opponent's quantity	30	1.58	1.77	40.00	32.00	1.35	1.69	40.00	26.67	1.13	1.55	40.00	22.86	0.90	1.35	40.00	20.00
		30				40				50				60			
	40	1.75	1.50	30.00	40.00	1.60	1.60	40.00	40.00	1.20	1.35	40.00	32.00	0.80	1.00	40.00	26.67
		23				35				48				60			
	50	1.72	1.07	18.00	40.00	1.49	1.23	28.00	40.00	1.10	1.07	38.00	40.00	0.50	0.55	40.00	33.33
		15				30				45				60			
	60	1.69	0.68	10.00	40.00	1.35	0.90	20.00	40.00	0.79	0.68	30.00	40.00	0.00	0.00	40.00	40.00

Period 2 You are the second mover

Your Quantity

		Payoff		Payoff		Payoff		Payoff	
Period 2		Opponent	You	Opponent	You	Opponent	You	Opponent	You
		-4		18		39		60	
Your Opponent's quantity	85	4.99	-0.15	3.19	0.31	1.38	-0.15	-0.43	-1.50
		0		20		40		60	
	80	4.80	0.00	3.20	0.40	1.60	0.00	0.00	-1.20
		4		23		41		60	
	75	4.59	0.15	3.19	0.51	1.78	0.15	0.38	-0.90
		8		25		43		60	
	70	4.38	0.32	3.15	0.63	1.93	0.32	0.70	-0.60

Figure 10: Example of sequential moves game spreadsheet (Stackelberg follower) for period one choices (30|60)

6 Experimental Results

For the simultaneous moves Cournot model, the key questions are:

1. Are there differences in the selected quantities in period one and period two?

2. Do players who choose relative profit maximizing quantities, display such behavior because they receive enjoyment from simply beating other players, or is there another reason to do so, namely, an advantage in market position in period two with lower marginal cost resulting in a competitive advantage, which ensure higher future profits?

For the sequential moves Stackelberg model, the key question are:

3. Are there differences in players quantity decision in period one and period two that are in line with theoretical predictions?

4. Do players try to coordinate behavior in such a way that may be called inequality averse? In this case I expect to see cooperation and punishment attempts.

Payoff comparison between the the two treatments:

5. Are there payoff differences between the treatments and do payoffs deviate from theorized outcomes?

6.1 Cournot Game

Figues 11 and 12 depict players' choices in the simultaneous moves game in period one and in period two. The striking difference is in the number of Cournot plays (C) and the relative profit maximizing quantity, i.e. Walrasian quantity (W) in the two periods.[17] In period one, the Cournot quantity was only the second most popular quantity, and was selected 38 times. While in Period two it is the most popular choice for players, selected 145 times (72% of the time of all choices). The low quantity (L) appears to have no real importance in either period as it was only selected twice in period one and six times in period two. (30|30), which was the combination of $(L|L)$ represents the collusive outcome in the symmetric game. Thus, it can be noted, that collusion does not appear to be of any relevance in this model. The high quantity (H) appears to be more important in period one, selected 55 times (or 27% of the time) while in period two (H) was played 41 time (21% of the time). The Walrasian quantity (W) was the most frequent choice in period one with players selecting (W) 105 times (or 53% of the time), while in period two it was merely chosen 8 time (4% of the time).

Table 5 summarizes all quantity choices in period one and two. Theory predicted that player choose absolute profit maximizing quantities in period two. This seems rather intuitive as no further investment takes place, i.e. there is no third period. However, one cannot forget about players behaving spitefully, trying to beat their opponent in terms of profit. The experimental data suggests that only 4% of all second period choices consisted of Walrasian quantities. The Walrasian quantity, thus, seems like a rather bad prediction for second period behavior. High quantities were chosen 21% of the time, which one may interpret as a mild spite effect, in that players tried to somewhat outdo their competitor but not fully at the expense of their own payoff. Cournot quantities were the most dominant choice in period two falling right in line with the theoretical prediction. Therefore, the Cournot quantity appears to be a rather good prediction for players that have no

[17] Quantities are labeled L for low, this is the quantity below the Cournot quantity; C for Cournot quantity; H for high quantity, signaling an increase from the Cournot quantity; and W for Walrasian quantity. I chose to label the respective quantities in this fashion, as quantities in period two were subject to change resulting from the choices made in period one, i.e. period one's Cournot quantity (40) may not be the Cournot quantity in period two due to the possible asymmetric market in period two.

further incentive to lower marginal cost. Comparing Walrasian and Cournot quantities in both periods, it appears that players act spitefully whenever it serve a purpose, instead of the pure joy received from beating the opponent. It is exactly this purpose, i.e. investment into cost-saving technologies, that gives players the reason to act spitefully. Without such reason, as in period two, players are absolute profit maximizing seeking. Indeed, the Wilcoxon matched-pairs signed-ranks test shows that second period choices are significantly lower (*** at the 1% level, one-tailed)[18].

These results suggest that there appears to be a reason for spiteful play, as period one results are much more competitive than period two results. In fact, in period one, Walrasian quantities represent the median and mode of all quantities chosen. Period two results show that Cournot play does not only represent the median but is also modal. When looking at both periods combined a very interesting observation can be made, that is, theory seems to be a somewhat good prediction for behavior in this particular setup. As I showed in the general model section, there are two pure strategy Nash equilibria at (Cournot|Walras) and (Walras|Cournot) indicating that no other quantity plays a role in the theoretical outcome. This can be confirmed experimentally. Even more interesting is the fact that the mixed strategy equilibrium predicts a Walrasian strategies to be played 29% of the time. This can also be confirmed experimentally, where Walrasian strategies were selected 28.25% of the time. The Cournot quantity, as predicted by theory, is selected most frequently at roughly 45% of the time. This falls short of the mixed strategy prediction of 71%, however, Cournot play is modal, selected 183 times out of 400, throughout the game, leaving the Walrasian quantity in second place at 113. The experimental findings in the Cournot game leave theory as a decent predictor of overall play.

[18]See table 6 for Wilcoxon matched-pairs signed-ranks test computation. I decided to compute statistical results manually as it allows for a better and thorough understanding of ones data - plus, in this particular case the data set was rather small and therefore easy to handle manually.

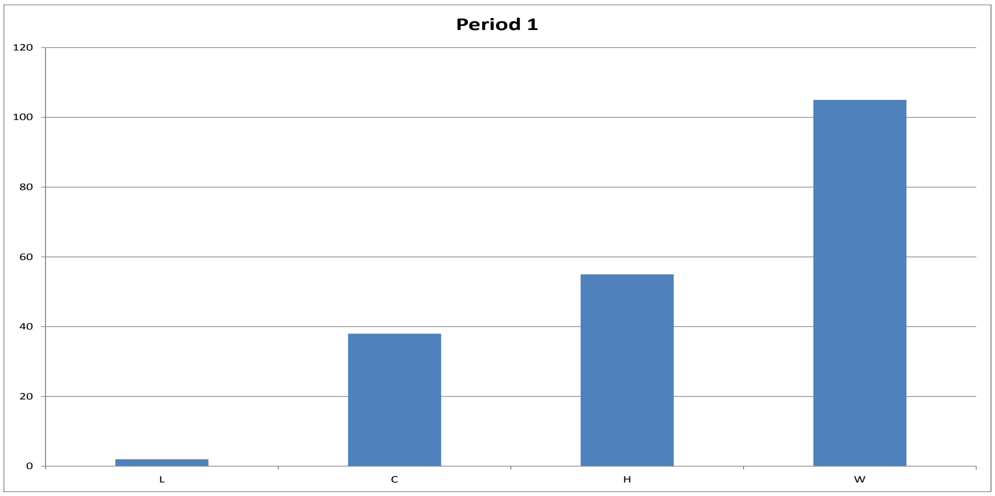

Figure 11: Frequency Distribution of Quantity Choices in Period 1 (Simultaneous Moves)

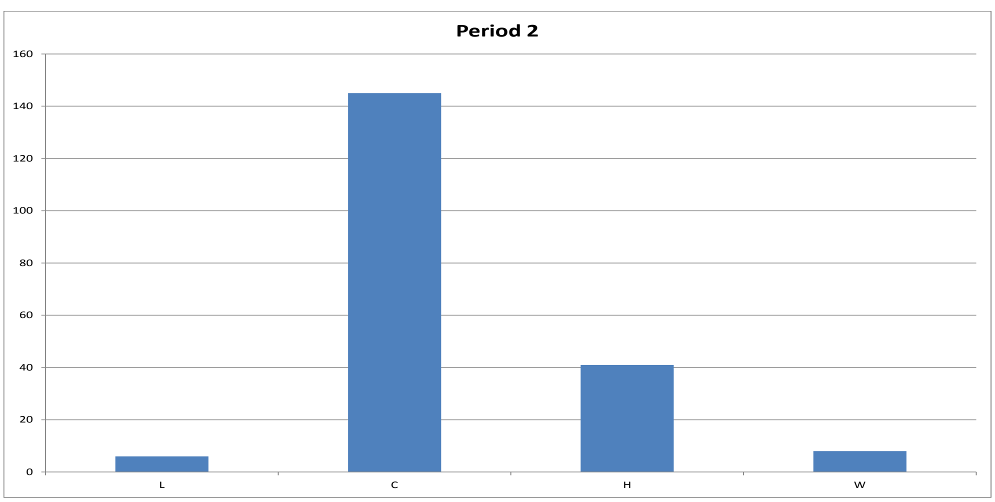

Figure 12: Frequency Distribution of Quantity Choices in Period 2 (Simultaneous Moves)

Period	Quantity	L	C	H	W
1	Count	2	38	55	105
	Percentage	1%	19%	28%	53%
2	Count	6	145	41	8
	Percentage	3%	73%	21%	4%

Table 5: Frequency Distribution of Quantity Choices in Period 1 and 2 (Simultaneous Moves)

	player 1		player 2		player 3		player 4		player 5		player 6		player 7		player 8		player 9		player 10	
game	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
1	50	38	60	60	40	23	60	30	50	30	50	40	60	50	50	40	50	45	60	49
2	60	40	60	44	40	36	50	40	50	45	50	38	50	50	60	40	50	38	60	40
3	60	40	60	44	40	36	40	36	50	49	40	60	40	49	50	40	60	40	60	40
4	50	38	60	50	40	36	50	38	50	49	60	53	60	54	40	36	60	49	60	49
5	60	44	60	49	40	36	60	40	50	45	60	49	60	50	50	45	60	40	40	36
6	60	40	60	50	40	37	50	40	50	38	60	49	60	60	50	40	60	40	40	37
7	50	38	60	50	40	37	50	38	50	40	60	60	50	50	60	40	60	40	40	36
8	50	30	60	50	40	37	50	45	50	38	60	60	60	58	60	40	60	40	40	36
9	50	38	60	40	40	30	40	36	40	40	30	60	60	54	50	38	60	40	40	37
10	60	44	60	67	40	36	40	37	40	36	60	50	60	50	60	40	60	44	60	44
mean	55	39	60	50.4	40	34.4	49	38	48	41	53	51.9	56	52.5	53	39.9	58	41.6	50	40.4
d		16		9.6		5.6		11		7		1.1		3.5		13.1		16.4		9.6
sign		-		-		-		-		-		-		-		-		-		-
signed rank of d		-18		-9		-6		-13		-7		-1		-3		-16		-19		-9
sum of abs T+																				0
sum of abs T-																				210
T=min{T+,T-}																				0
critical value																				43 (for n=20 and alpha=0.01 one-tailed)
significance																				*** (highly significant at the 1% level)
median	55	39	60	50	40	36	50	38	50	40	60	51.5	60	50	50	40	60	40	50	38.5
mode	50	38	60	50	40	36	50	40	50	45	60	60	60	50	50	40	60	40	60	36

	player 11		player 12		player 13		player 14		player 15		player 16		player 17		player 18		player 19		player 20	
game	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
1	60	46	60	50	60	58	60	40	50	50	50	40	60	40	50	40	40	37	40	36
2	60	40	60	40	50	38	60	40	50	40	40	37	60	44	50	40	60	40	60	54
3	60	40	60	40	60	50	50	49	60	58	60	49	60	44	60	49	50	45	50	40
4	60	49	40	36	40	36	60	44	60	50	60	49	60	44	60	44	30	33	50	38
5	60	50	40	37	60	50	60	49	50	49	40	36	60	49	60	40	40	49	40	36
6	40	36	60	40	50	50	60	40	50	55	60	40	60	40	50	45	50	40	60	44
7	50	40	60	40	50	50	60	40	60	50	60	49	60	44	60	40	50	55	60	44
8	40	37	60	44	60	50	40	36	60	60	60	40	60	49	50	40	60	50	50	45
9	40	40	60	49	40	50	60	53	50	49	60	44	60	40	50	45	60	54	60	40
10	40	36	60	49	50	55	60	49	60	50	60	40	60	40	50	49	50	38	50	38
mean	51	41.4	56	42.5	52	48.7	57	44	55	51.1	55	42.4	60	43.4	54	43.2	49	44.1	52	41.5
d		9.6		13.5		3.3		13		3.9		12.6		16.6		10.8		4.9		10.5
sign		-		-		-		-		-		-		-		-		-		-
signed rank of d		-9		-17		-2		-15		-4		-14		-20		-12		-5		-11
median	55	40	60	40	50	50	60	42	55	50	60	40	60	44	50	42	50	42.5	50	40
mode	60	40	60	40	60	50	60	40	50	50	60	40	60	40	50	40	50	40	60	36

Table 6: Complete data set of choices made in the simultaneous moves game. The null hypothesis that the investment opportunity has no quantitative effect on choices can be rejected. In fact, quantity choices in period two are significantly lower (***) that in period one.

6.1.1 Analysis of Individual Behavior

This subsection is designed to discuss some specifically interesting cases on the individual level. As I asked each individual after the experiment was over, to write down their motivation for making choices in period one and in period two, some insight into why players made certain decision may bring a certain amount of clarity into their decision making process; an added extra may be to see if players chose certain strategies for reason other than previously though of or discussed here.

For example, Player one writes that in period one his decision was based on playing high quantities to lower cost in period two. Whereas in period two he expresses his goal to be absolute profit maximization (figures 13 and 14). It is exactly this behavior that motivated me to examine whether there was a reason for spiteful behavior. Player one explains this reason to be more profits in period two. One may conclude from this that spiteful behavior is perfectly in line with absolute profit maximizing behavior, as it may be the a certain amount of foresight, i.e. non-myopic profit maximization. A firm in its quest for higher and higher profits may forgo immediate profits in favor of even higher profits tomorrow and ultimately to gain a monopoly position (or simply larger market share) to reap extraordinary large profits, thus, making up for smaller profits in the short-run. Player eight (figures 15 and 16) reports similar incentives with period one being an investment period and period two setting focus on largest payoff possible. Player nine (figures 17 and 18) explains that her opponents forced her to play the Walrasian quantity and that diverting to a lower quantity would have resulted in a disadvantageous position in period two. For her it was the threat of being outperformed instead of outperforming the opponent. Player 17's (figure 19 and 20) choices in each period consisted of only one quantity, namely, the Walrasian quantity in period one and the Cournot quantity in period two. Player eleven (figures 21 and 22) notes that first she tried to have the lowest possible cost in period two, but then changed to an absolute profit maximizing strategy in period one. Period two consisted of absolute profit maximizing behavior. Perhaps player 12 explained player eleven's behavior best by noting that it was very difficult to make guesses about the other players' period one decisions and maybe the best thing to do is just Cournot throughout resulting in equal payoff distribution in the entire game. However, herein lies the threat of being outperformed and loosing market power.

Player eleven changed her strategy after noting that playing the Walrasian strategy resulted in a zero payoff on account of her opponent also selecting the Walrasian strategy. Her absolute profit maximizing behavior may be the attempt to coordinate behavior, which, given the random matching, was difficult to do.

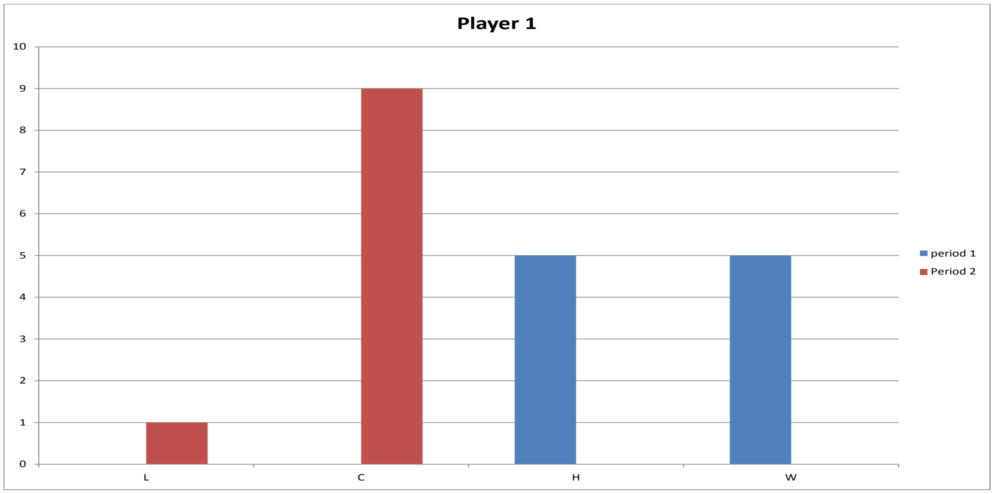

Figure 13: Bar chart of player one's quantity choices

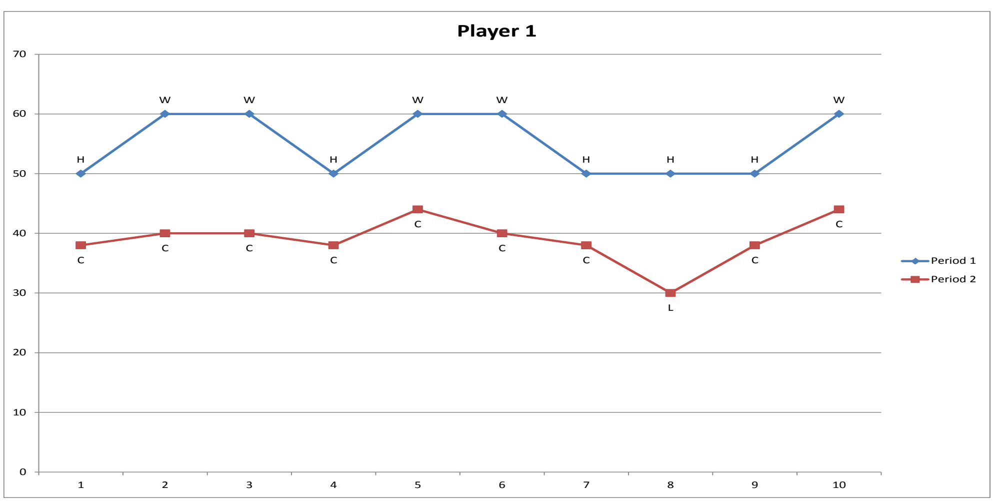

Figure 14: Time series for all 10 games of quantity choices of player one

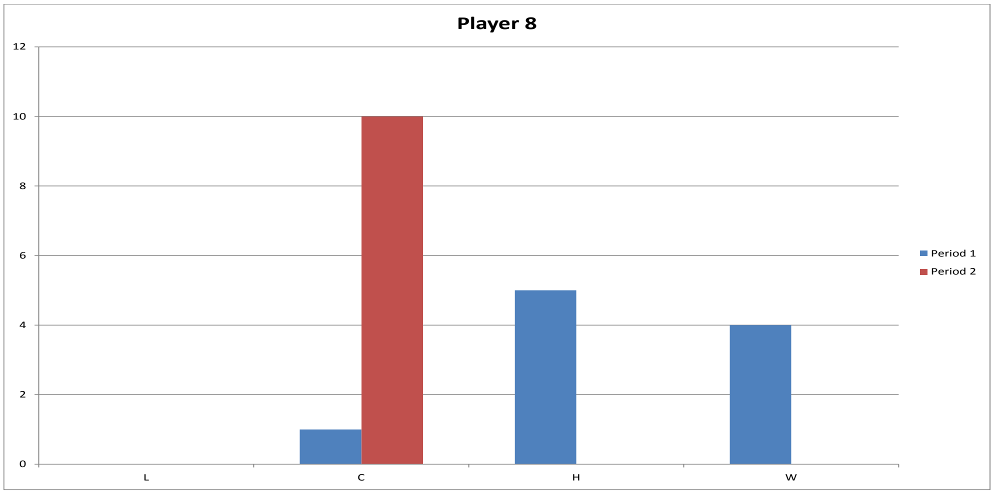

Figure 15: Bar chart of player eight's quantity choices

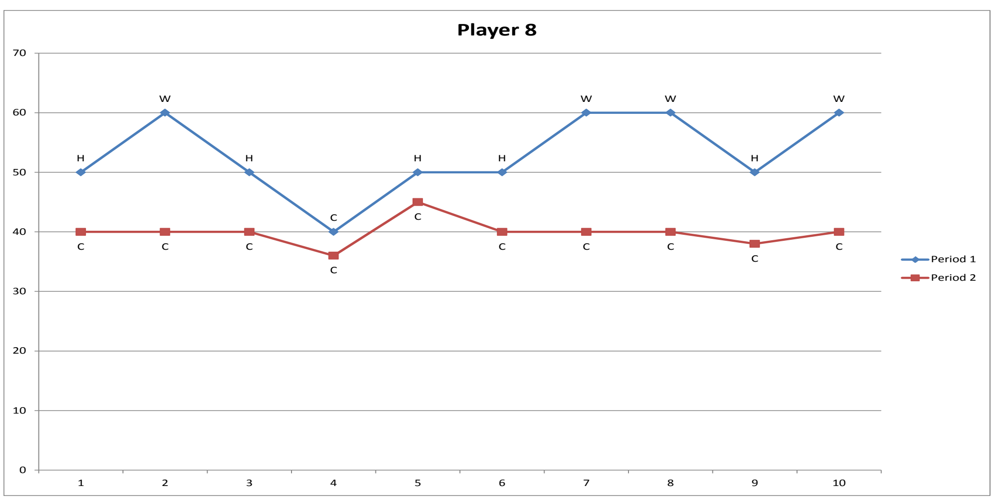

Figure 16: Time series for all 10 games of quantity choices of player eight

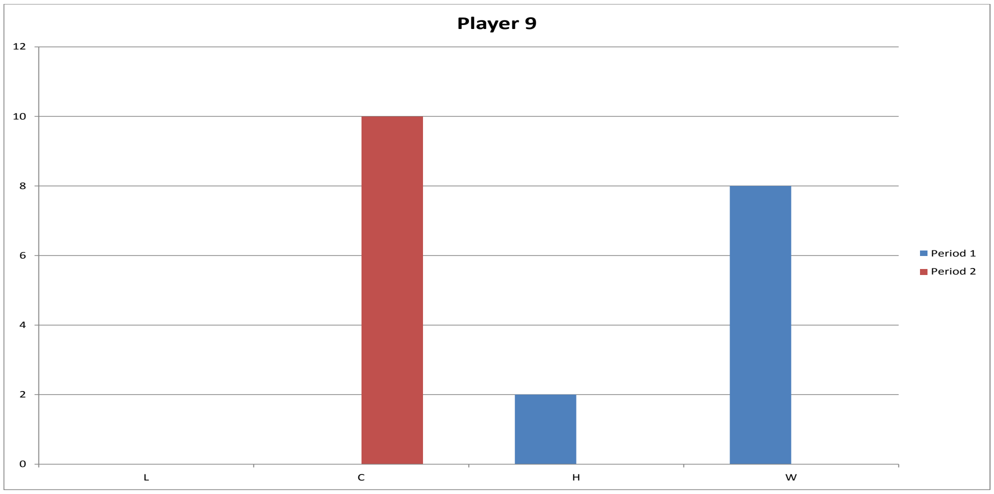

Figure 17: Bar chart of player nine's quantity choices

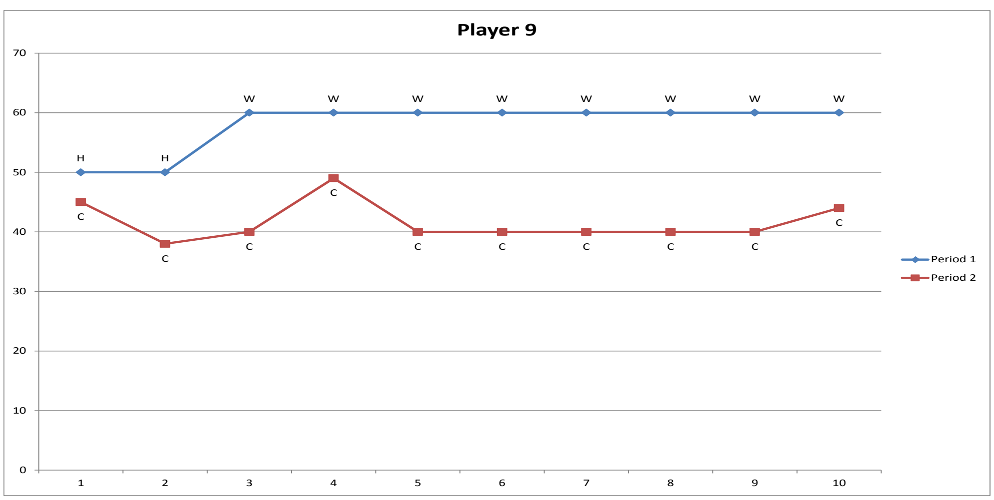

Figure 18: Time series for all 10 games of quantity choices of player nine

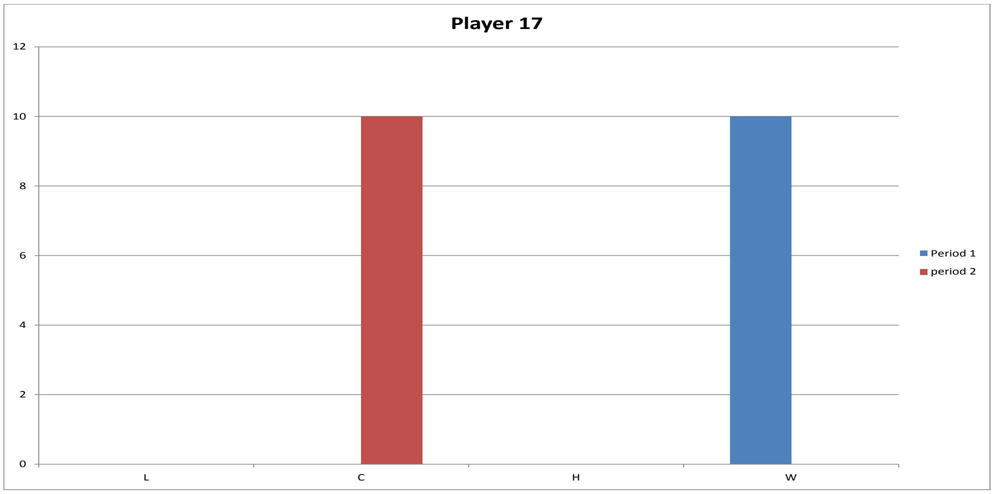

Figure 19: Bar chart of player 17's quantity choices

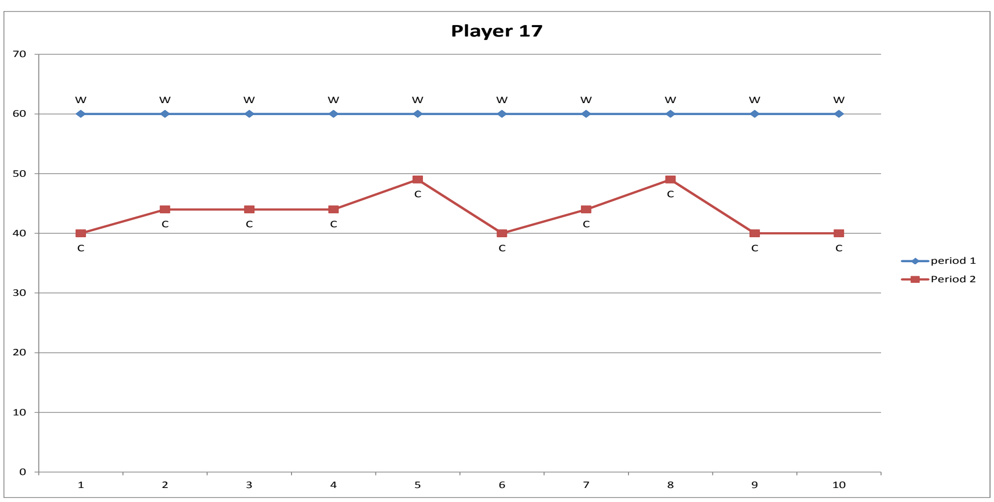

Figure 20: Time series for all 10 games of quantity choices of player 17

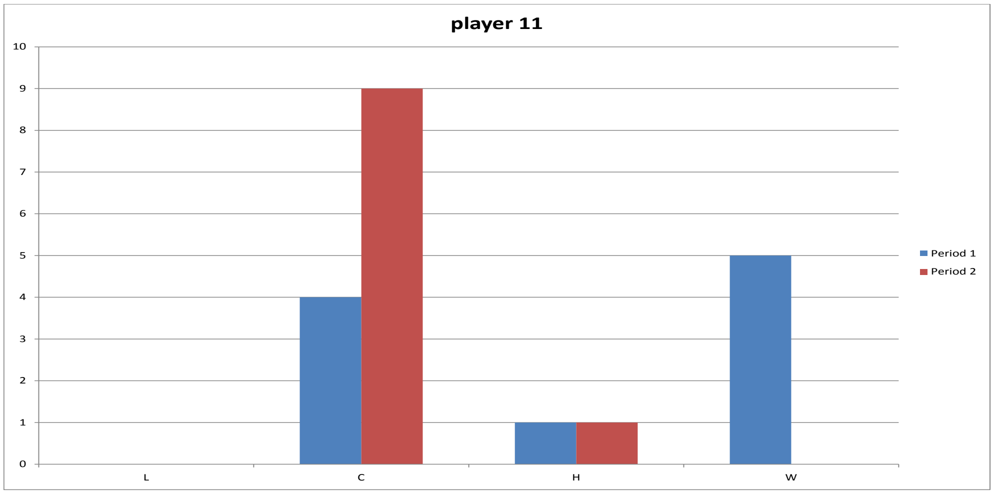

Figure 21: Bar chart of player eleven's quantity choices

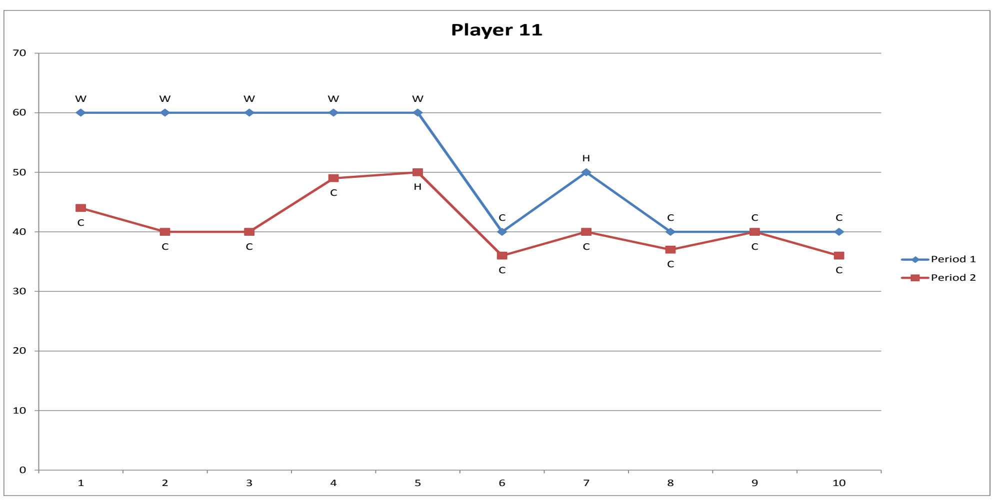

Figure 22: Time series for all 10 games of quantity choices of player eleven

The following results can be concluded by answering the first two questions raised at the beginning of the results section:

1. Are there differences in the selected quantities in period one and period two?

Yes, they are significant at the 1% level, suggesting that spiteful behavior, i.e. choosing Walrasian strategies, in period one serves the purpose of gaining a competitive advantage for period two through lower marginal cost and higher payoff in period two. Thus, players act spitefully not because the receive enjoyment from beating their opponent but for non-myopic reasons of absolute profits maximization.

2. Do players who choose relative profit maximizing quantities, display such behavior because they receive enjoyment from simply beating other players, or is there another reason to do so, namely, an advantage in market position in period two with lower marginal cost resulting in a competitive advantage, which ensure higher future profits.

This can also be confirmed, as period two quantities were significant lower than those in period one, suggesting that spiteful behavior may take on the motive of strictly competitive behavior securing long-term market position rather than short-term payoff maximization. this can be confirmed on the individual level, as well. It was very interesting seeing players choices and reasoning for their decision. Overall players knew exactly what strategy to follow and how this strategy changed from period one to period two.

6.2 Stackelberg Game

The sequential moves game was somewhat more difficult to analyze due to the Stackelberg leader and Stackelberg follower distinction. Unlike the Cournot game, where all players were essentially the same, at least in the beginning of every game, here, the Stackelberg leader was, theoretically, in a more advantageous position to earn extra large profits. Theory predicts, despite the investment possibility, one Nash equilibrium in pure strategies, namely, absolute profit maximizing Stackelberg play throughout for both players. Thus, spiteful motives are theoretically not part of the outcome. However, one need not forget that absolute profit maximizing and relative profit maximizing strategies converge in this particular model, leaving the Stackelberg leader with only one best option in period one. It follows that the prediction for the Stackelberg leader is to use its first movers advantage to exploit the Stackelberg follower, leaving the Stackelberg follower in an even worse situation in period two with a large disadvantage in marginal cost.

Figures 23 and 24 depict all choices in period one and period two of all players. Interestingly, the absolute profit maximizing Stackelberg quantity in period one runs in a close second to last place only being 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%, (H) at 13%, and (RS) at 14% (see table 7). The Cournot quantity in period one was selected 110 out of 200 times and reigns at 55%. Compared to the theoretical prediction, this appears to be very surprising. However, when considering preferences such as inequality aversion, Stackelberg leaders' and Stackelberg followers' choices take on a different shape. If, for example, a Stackelberg leader can choose between an equal payoff split between herself and her opponent, she may be inclined to choose such a quantity, as she may consider her dominant strategy, resulting in a large relative difference in payoff, "unfair." Similarly, a Stackelberg follower who observes a Stackelberg leader playing a quantity that results in a large relative difference in payoff between herself and her opponent, may choose equality in payoffs considerations over the absolute profit maximizing choice and punish her opponent by following suit and eliminate profits for both players in period one. Figures 25-28 may hint into that direction.

The observations show that, in period one, 58% of the time Stackelberg leaders played the Cournot quantity instead of their dominant strategy, i.e. absolute Stackelberg (AS), which was selected only 16 times or 16% of the time. It appears that Stackelberg followers reciprocated by also choosing the Cournot quantity, their best reply in terms of absolute profits, 52% of the time. Interestingly, second movers selected the relative profit maximizing Stackelberg quantity 27 times or 27% of the time. This is may be interpreted as a punishment strategy. If the Stackelberg leader plays any quantity higher than the Cournot quantity, Stackelberg followers can eliminate the Stackelberg leaders profits and cost advantage in period two by choosing any strategy higher than their absolute profit maximizing output in period one. By doing so, they also eliminate their own period one profits, however, they may decide to do so in an effort to change the Stackelberg leader's strategy in the following game. Thus, relative profit maximizing strategies may be viewed as a means to scold the Stackelberg leader for choosing a quantity that results in an unequal payoff distribution, and as the attempt to redirect the first mover's choice to cooperatively choosing Cournot strategies. This will be analyzed more closely when I look at pair-wise comparison in the next part.

Period	Quantity	L	C	AS	H	RS
one	Count	17	110	21	25	27
	percentage	9%	55%	11%	13%	14%
two	Count	29	86	52	17	16
	Percentage	15%	43%	26%	9%	8%

Table 7: Frequency Distribution of Quantity Choices in Period 1 and 2 (Sequential Moves)

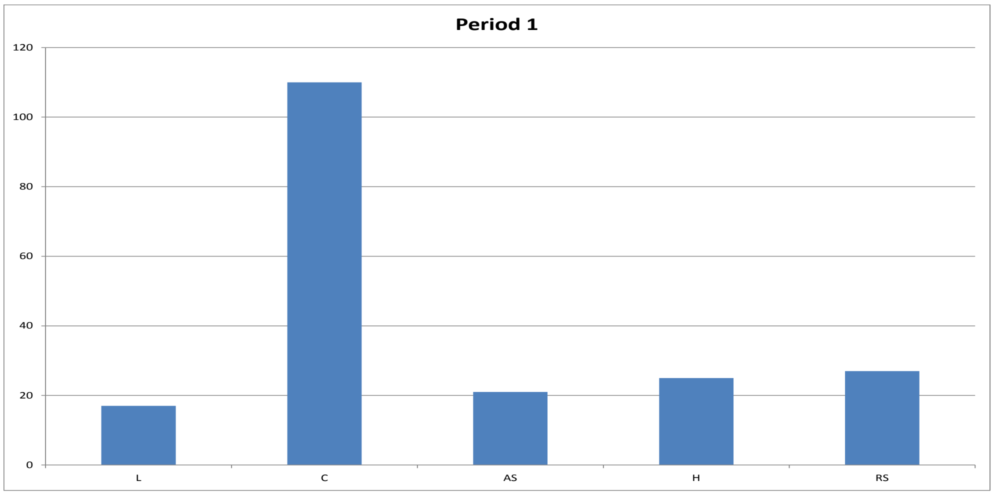

Figure 23: Frequency Distribution of Quantity Choices in Period 1 (Sequential Moves)

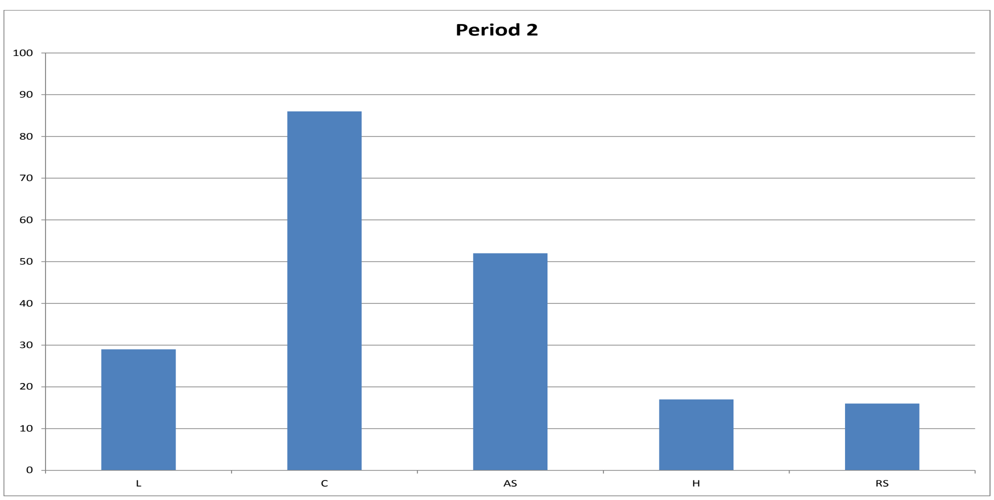

Figure 24: Frequency Distribution of Quantity Choices in Period 2 (Sequential Moves)

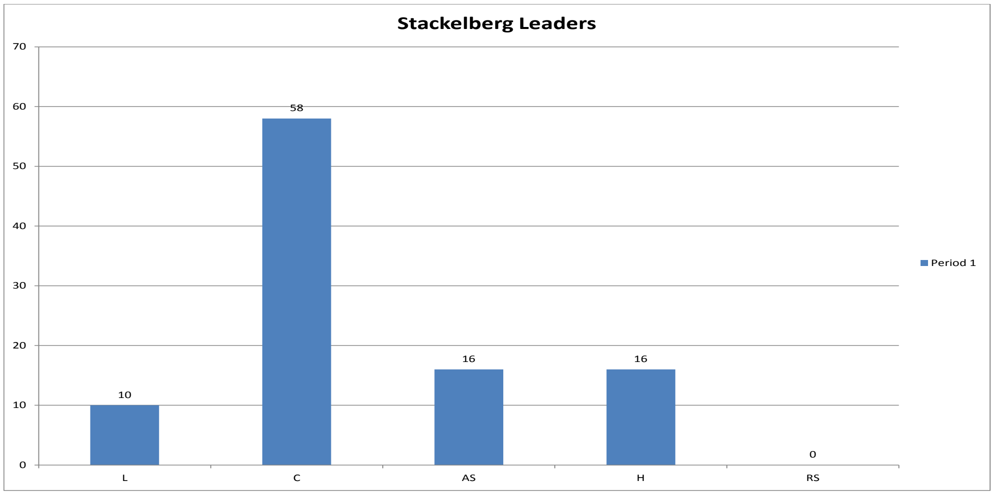

Figure 25: Frequency Distribution of Stackelberg leaders in Period 1

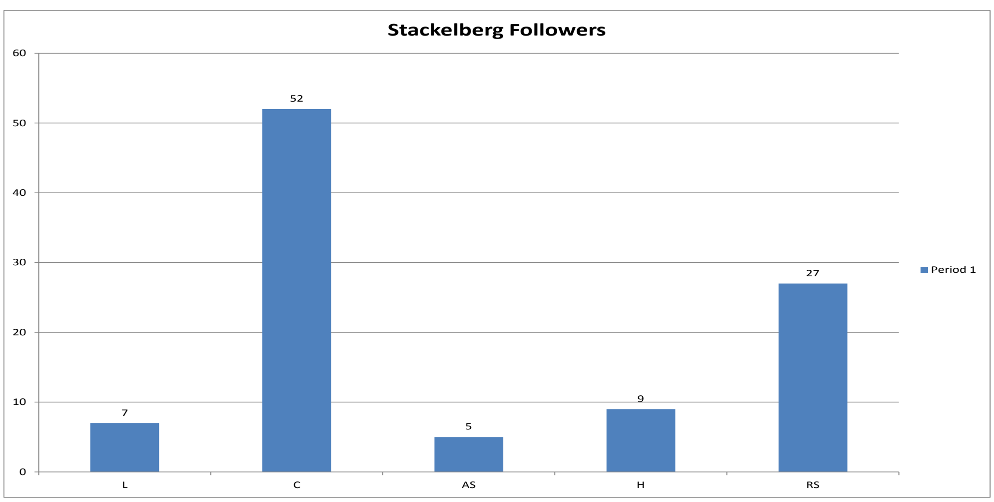

Figure 26: Frequency Distribution of Stackelberg followers in Period 1

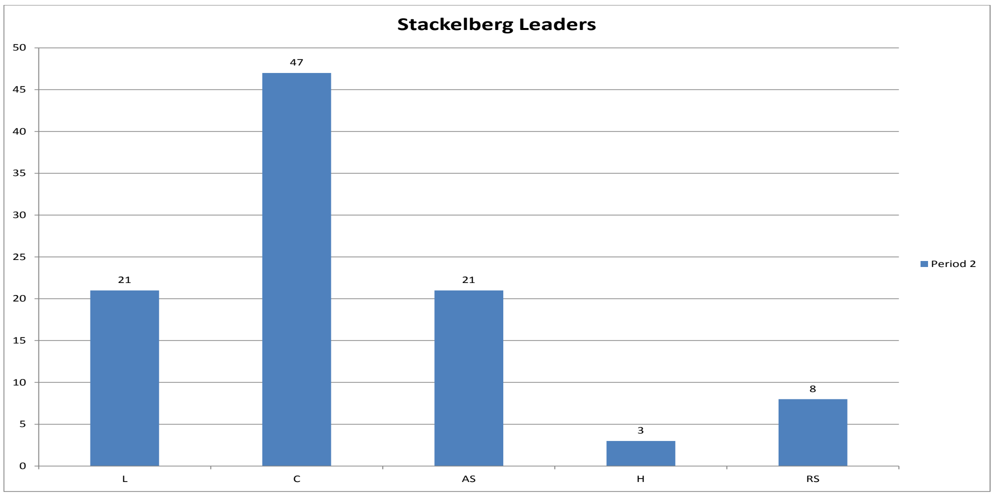

Figure 27: Frequency Distribution of Stackelberg leaders in Period 2

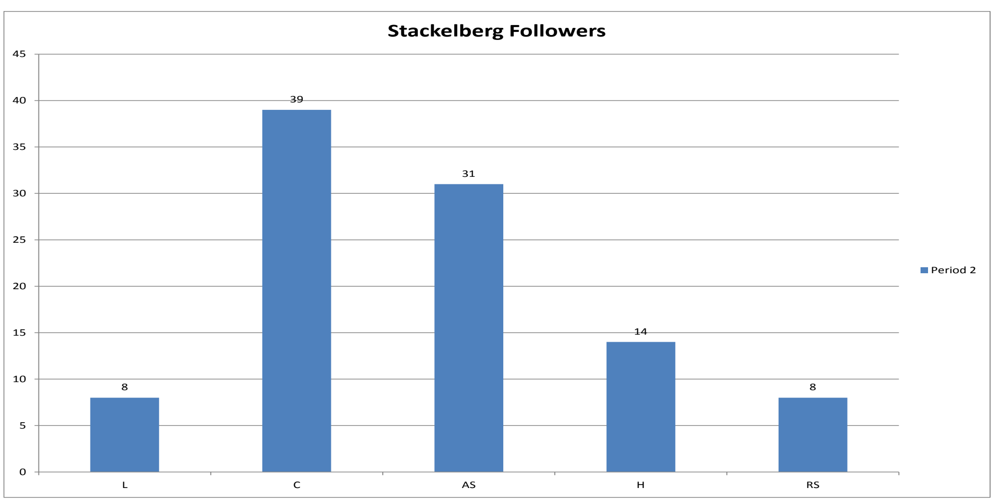

Figure 28: Frequency Distribution of Stackelberg followers in Period 2

Table 8 summarizes the complete Stackelberg game including all choices of Stackelberg leaders and Stackelberg followers. Theory predicted one subgame perfect Nash equilibrium in pure strategies consisting of only absolute profit maximizing behavior creating a large cost advantage for the Stackelberg leader in period two. A Wilcoxon matched-pairs signed-ranks test (two-tailed) shows that there are no significant differences between the periods with respect to chosen quantities. This, however, may be a somewhat inconclusive outcome as the larger Stackelberg leader quantity may be offset by the lower Stackelberg follower quantity. It may more meaningful to analyze mean choices when divided into first and second mover categories. Tables 9 and 10 summarize all choices for Stackelberg leaders and Stackelberg followers, respectively. The Wilcoxon matched-pairs signed-ranks test (one-tailed) shows that for Stackelberg leaders' period two choices are significantly higher (***at the 1% level) compared to period one choices. Stackelberg followers show the reversed outcome, i.e. period one choices are significantly higher (also at the ***1% level) than period two choices. This result hints towards the outcome predicted by theory.

However, Cournot play is modal for both Stackelberg leaders and Stackelberg followers. So how can the differences in the two periods be explained? First one needs to compare the actual strategies in each period to the theoretically predicted outcome. Given the nature of the model, a Cournot quantity in period two can only exist if period one strategies consist of (Cournot|Cournot) or (absolute Stackelberg|relative Stackelberg), i.e. (40|40) or (60|60), rendering the Cournot quantity relatively fragile to minor variations. Additionally, Period two is the last period in each game and punishment may be less likely. It follows that Stackelberg leaders may look for their dominant strategy in period two more so than in period one, as they do not need to fear the Stackelberg follower's choice as much as they did in period one. This effect may be weakened by the fixed pairing applied in the experiment, i.e. Stackelberg leaders knew they would face the same opponent in all games of the experiment. On the other hand, Stackelberg followers incentive to punish Stackelberg leaders in period two may be diminished as no further period exists. This effect too may be weakened due to the fixed pairing. It follows, that Stackelberg leaders and followers may be willing to play absolute profit maximzing quantities more so in period two than in period one. Also, no further investment is possible in period two, which may speak in favor of absolute profit maximizing strategies. Another reason why Stackelberg followers' choices in period two are lower than in period one may lie in punishment in period one, navigating Stackelberg leaders to the Cournot Quantity in the following games. Thus, it may not be the sequential nature of the model that is responsible for the lower (higher) quantities in period one (two) for the Stackelberg leader (follower) but it may be the result of fairness considerations and punishment possibilities that lead to the selected quantities. The latter may explain the non-equal quantity play in both periods and Cournot play being modal for both first and second movers. In fact there is only one successful strategy profile consisting of all abolute profit maximizing strategies, as predicted by theory, and 39 strategy profiles consiting of all Cournot play. One may call this a relatively strong indicator for inequality averse preferences over dominant strategies. These results are similar to Huck et al. (2002) [22] who found that despite theoretical predictions Stackelberg leadership almost never emerges. Instead they found that the Cournot-Nash was achieved in about 50% of all plays. Fonseca et al. (2005)[15] added asymmetry to the model which, theoretically, should strengthen the emergence of Stackelberg leadership of the low-cost firm, just as in this present model. They also confirm that despite the introduced asymmetry Cournot play is the most frequently played quantity.

game	player 1 P1	player 1 P2	player 2 P1	player 2 P2	player 3 P1	player 3 P2	player 4 P1	player 4 P2	player 5 P1	player 5 P2	player 6 P1	player 6 P2	player 7 P1	player 7 P2	player 8 P1	player 8 P2	player 9 P1	player 9 P2	player 10 P1	player 10 P2
1	40	60	50	55	60	40	60	40	60	60	50	55	50	57	60	60	40	60	40	40
2	50	55	40	40	30	45	40	40	60	60	50	57	60	60	50	57	40	60	40	40
3	30	54	40	40	40	54	40	40	50	60	50	55	50	69	60	70	60	60	40	40
4	40	40	40	40	60	60	40	40	50	61	40	56	60	80	50	61	40	54	40	40
5	40	40	40	40	60	65	40	40	50	61	40	40	60	60	30	54	50	55	40	40
6	40	30	40	40	30	54	40	40	40	40	40	40	60	50	40	40	60	60	40	40
7	40	30	40	40	30	54	40	40	40	40	40	53	50	55	40	40	30	50	40	40
8	40	40	40	40	50	61	40	40	40	40	30	54	40	60	40	40	30	60	40	40
9	40	40	40	40	30	54	40	40	40	40	30	56	50	55	40	40	40	58	40	40
10	40	30	40	60	40	40	40	40	40	40	40	50	60	40	40	40	60	60	40	40
mean	40	41.9	41	43.5	43	52.7	42	40	47	50.2	41	51.6	54	58.6	45	50.2	45	57.7	40	40
d		-1.9		-2.5		-9.7		2		-3.2		-10.6		-4.6		-5.2		-12.7		0
sign		+		+		+		-		+		+		+		+		+		
signed rank of d		2		4		15		-3		6		16		8		10		17		0
median	40	40	40	40	40	54	40	40	45	50	40	54.5	55	58.5	40	47	40	60	40	40
mode	40	40	40	40	30	54	40	40	40	40	40	55	60	60	40	40	40	60	40	40

game	player 11 P1	player 11 P2	player 12 P1	player 12 P2	player 13 P1	player 13 P2	player 14 P1	player 14 P2	player 15 P1	player 15 P2	player 16 P1	player 16 P2	player 17 P1	player 17 P2	player 18 P1	player 18 P2	player 19 P1	player 19 P2	player 20 P1	player 20 P2
1	40	30	60	36	60	60	60	50	60	30	60	36	60	35	60	30	40	30	40	40
2	60	50	40	40	60	48	40	40	60	60	60	63	60	30	60	35	40	30	40	40
3	38	37	40	40	50	51	40	40	60	18	60	50	35	26	30	25	60	30	40	40
4	40	40	40	40	60	45	40	40	48	60	50	36	30	20	48	30	50	37	40	40
5	40	30	40	40	45	28	40	40	48	14	40	50	60	60	38	37	60	36	40	40
6	40	38	40	40	38	37	40	40	40	40	40	50	60	60	40	40	60	45	40	40
7	40	38	40	40	38	37	40	40	40	40	60	53	60	50	40	40	45	42	40	40
8	40	30	40	40	48	45	40	40	40	40	38	51	40	60	40	40	45	37	40	40
9	40	30	40	40	38	37	40	40	40	40	38	50	60	50	40	40	50	35	40	40
10	40	38	40	30	40	40	40	40	40	60	60	42	60	40	40	40	60	30	40	40
mean	41.8	36.1	42	38.6	47.7	42.8	42	41	47.6	40.2	50.6	48.1	52.5	43.1	43.6	35.7	51	35.2	40	40
d		5.7		3.4		4.9		1		7.4		2.5		9.4		7.9		15.8		0
sign		-		-		-		-		-		-		-		-		-		
signed rank of d		-11		-7		-9		-1		-12		-4		-14		-13		-18		0
sum of abs T+	78																			
sum of abs T-	92																			
T=min{T+,T-}	78																			
critical value	40 (for n=18 and alpha=0.05 two-tailed)																			
significance	(no significant differences)																			
median	40	37.5	40	40	46.5	42.5	40	40	44	40	55	50	60	45	40	38.5	50	35.5	40	40
mode	40	30	40	40	60	37	40	40	40	40	60	50	60	60	40	40	60	30	40	40

Table 8: Complete data set of choices made in the sequential moves game. There are no significant differences, with respect to output, in the two periods.

game	player 1 P1	player 1 P2	player 2 P1	player 2 P2	player 3 P1	player 3 P2	player 4 P1	player 4 P2	player 5 P1	player 5 P2	player 6 P1	player 6 P2	player 7 P1	player 7 P2	player 8 P1	player 8 P2	player 9 P1	player 9 P2	player 10 P1	player 10 P2
1	40	60	50	55	60	40	60	40	60	60	50	55	50	57	60	60	40	60	40	40
2	50	55	40	40	30	45	40	40	60	60	50	57	60	60	50	57	40	60	40	40
3	30	54	40	40	40	54	40	40	50	60	50	55	50	69	60	70	60	60	40	40
4	40	40	40	40	60	60	40	40	50	61	40	56	60	80	50	61	40	54	40	40
5	40	40	40	40	60	65	40	40	50	61	40	40	60	60	30	54	50	55	40	40
6	40	30	40	40	30	54	40	40	40	40	40	40	60	50	40	40	60	60	40	40
7	40	30	40	40	30	54	40	40	40	40	40	53	50	55	40	40	30	50	40	40
8	40	40	40	40	50	61	40	40	40	40	30	54	40	60	40	40	30	60	40	40
9	40	40	40	40	30	54	40	40	40	40	30	56	50	55	40	40	40	58	40	40
10	40	30	40	60	40	40	40	40	40	40	40	50	60	40	40	40	60	60	40	40
mean	40	41.9	41	43.5	43	52.7	42	40	47	50.2	41	51.6	54	58.6	45	50.2	45	57.7	40	40
d		-1.9		-2.5		-9.7		2		-3.2		-10.6		-4.6		-5.2		-12.7		0
sign		+		+		+		-		+		+		+		+		+		
signed rank of d		2		3		7		-1		4		8		5		6		9		
sum of abs T+											44									
sum of abs T-											1									
T=min{T+,T-}											1									
critical value											3 (for n=9 and alpha=0.01 one-tailed)									
significance											(*** significant at the 1% level)									
median	40	40	40	40	40	54	40	40	45	50	40	54.5	55	58.5	40	47	40	60	40	40
mode	40	40	40	40	30	54	40	40	40	40	40	55	60	60	40	40	40	60	40	40

Table 9: Complete data set of choices made by Stackelberg leaders. The Wilcoxon matched-pairs signed-ranks test (one-tailed) shows that output in Period two is significantly higher that output in period one at the 1% level.

game	player 11 P1	player 11 P2	player 12 P1	player 12 P2	player 13 P1	player 13 P2	player 14 P1	player 14 P2	player 15 P1	player 15 P2	player 16 P1	player 16 P2	player 17 P1	player 17 P2	player 18 P1	player 18 P2	player 19 P1	player 19 P2	player 20 P1	player 20 P2
1	40	30	60	36	60	60	60	50	60	30	60	36	60	35	60	30	40	30	40	40
2	60	50	40	40	60	48	40	40	60	60	60	63	60	30	60	35	40	30	40	40
3	38	37	40	40	50	51	40	40	60	18	60	50	35	26	30	25	60	30	40	40
4	40	40	40	40	60	45	40	40	48	60	50	36	30	20	48	30	50	37	40	40
5	40	30	40	40	45	28	40	40	48	14	40	50	60	60	38	37	60	36	40	40
6	40	38	40	40	38	37	40	40	40	40	40	50	60	60	40	40	60	45	40	40
7	40	38	40	40	38	37	40	40	40	40	60	53	60	50	40	40	45	42	40	40
8	40	30	40	40	48	45	40	40	40	40	38	51	40	60	40	40	45	37	40	40
9	40	30	40	40	38	37	40	40	40	40	38	50	60	50	40	40	50	35	40	40
10	40	38	40	30	40	40	40	40	40	60	60	42	60	40	40	40	60	30	40	40
mean	41.8	36.1	42	38.6	47.7	42.8	42	41	47.6	40.2	50.6	48.1	52.5	43.1	43.6	35.7	51	35.2	40	40
d		5.7		3.4		4.9		1		7.4		2.5		9.4		7.9		15.8		0
sign		-		-		-		-		-		-		-		-		-		
signed rank of d		-5		-3		-4		-1		-6		-2		-8		-7		-9		
sum of abs T+											0									
sum of abs T-											45									
T=min{T+,T-}											0									
critical value											3 (for n=9 and alpha=0.01 one-tailed)									
significance											(*** significant at the 1% level)									
median	40	37.5	40	40	46.5	42.5	40	40	44	40	55	50	60	45	40	38.5	50	35.5	40	40
mode	40	30	40	40	60	37	40	40	40	40	60	50	60	60	40	40	60	30	40	40

Table 10: Complete data set of choices made by Stackelberg followers. The Wilcoxon matched-pairs signed-ranks test (one-tailed) shows that output in Period two is significantly lower that output in period one at the 1% level.

6.2.1 Analysis of Individual Behavior

Individual behavior in the sequential game is of particular interest due to strong deviation from theoretical prediction, i.e. Stackelberg quantities throughout (theoretical outcome) and Cournot play (experimental modal play). Therefore, this section is meant to break things down to the individual level and find out how competitors behaved throughout the ten games. Just like in the simultaneous moves game, I asked players to indicate what their motivation to choose a particular strategy in both periods was. More specifically, I am looking for cooperation and punishment behavior and whether players' explanations as to why they selected a certain strategy matches their behavior.

Figures 29 and 30 show the behavior of player Player 4 (Stackelberg leader) and player 14 (Stackelberg follower). The Stackelberg follower appears to play quantities that reward the first mover for cooperative behavior (Cournot) and punish him for more competitive play, e.g. in game 1 the Stackelberg follower plays its relative profit maximizing quantity following an absolute profit maximizing quantity, thus, punishing the first mover by erasing all profits, while in game 2 the Stackelberg follower rewards the Stackelberg leader with cooperation by playing Cournot following a Cournot quantity. Player 14 notes that his behavior in period 1 is driven by ensuring that the opponent is not earning higher profits than he does. In period 2 it was absolute profit maximization that drove his behavior, however, not at the expense of breaking the cooperation that had emerged. Quantities higher than Cournot are punished with competitive play while Cournot is rewarded with cooperation. Player 4 responds to payer 14's behavior by only selecting Cournot quantities starting game 2. Player 2 (Stackelberg leader) and player 12 (Stackelberg follower) quickly developed Cournot play, see figure 31. Here it was vice versa, namely, the Stackelberg leader was trying to avoid punishment and was interested in equal payoff distribution until the very last game, game 10 period 2, were he no longer had to maintain cooperation. Figure 32 shows the end effect, which stresses the fact that it was not only inequality aversion that made player 2 play Cournot but, due to the fixed pairing, fear of punishment by the Stackelberg follower. Player 2 notes that he was trying to "get a feel" for his opponent and noticed right away that cooperation was possible. Player 12 writes that her behavior was strict profit maximization, which worked out well for her as her opponent offered Cournot quantities resulting in the Cournot quantity as a best reply.

Figure 33 and Figure 34 depict Player 5 (Stackelberg leader) and player 15 (Stackelberg follower). 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. Player 10 (Stackelberg leader) and player 20 (Stackelberg follower) cooperated from the first to the last period at the Cournot quantity. Figures 35 and 36 show perfect Cournot play without an end effect. Player 10 notes that he was looking for the largest payoff without provoking the opponent to punish. Player 20 writes that she was interested in the highest payoff possible but careful about how her choice would effect period two outcomes.

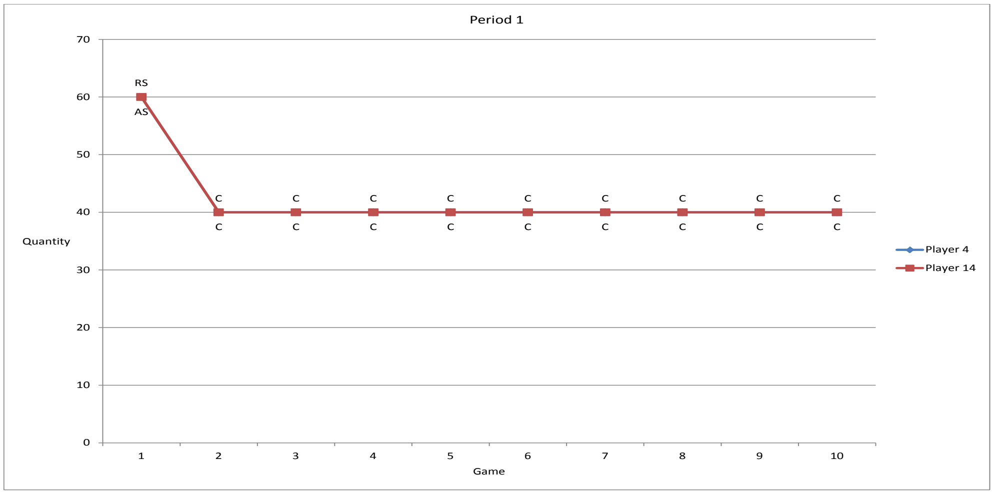

Figure 29: Strategies Player 4 and 14 Period 1 (Stackelberg Game)

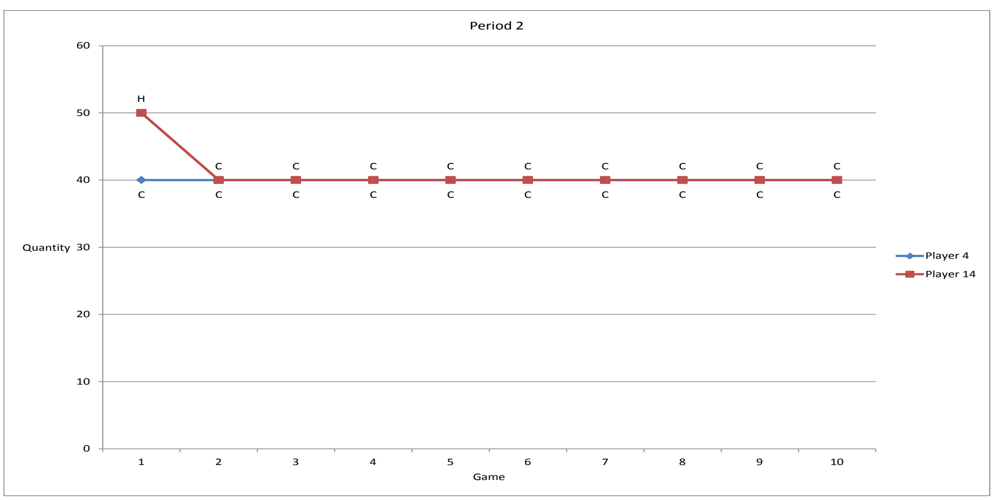

Figure 30: Strategies Player 4 and 14 Period 2 (Stackelberg Game)

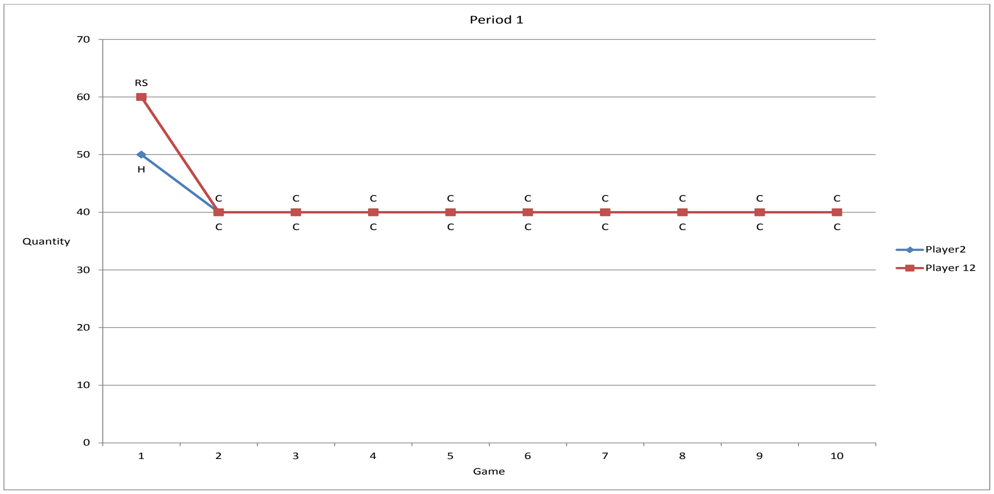

Figure 31: Strategies Player 2 and 12 Period 1 (Stackelberg Game)

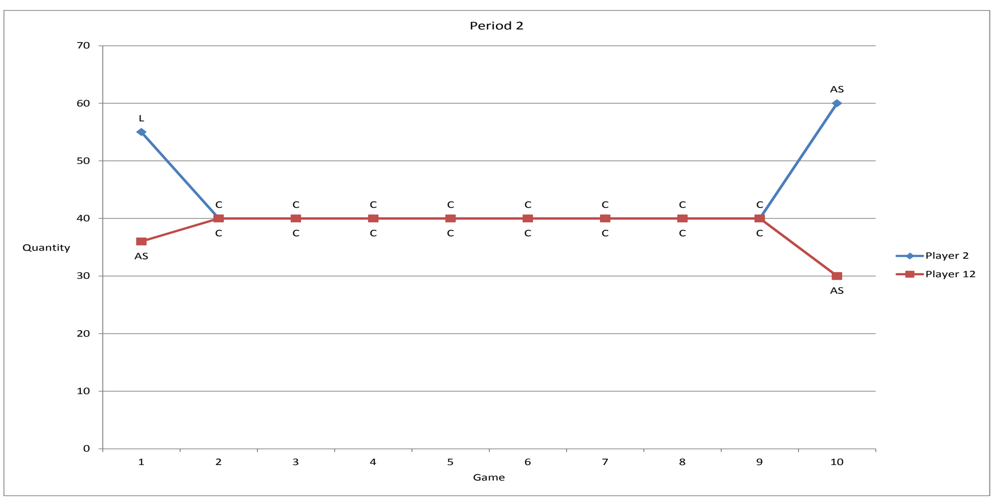

Figure 32: Strategies Player 2 and 12 Period 2 (Stackelberg Game)

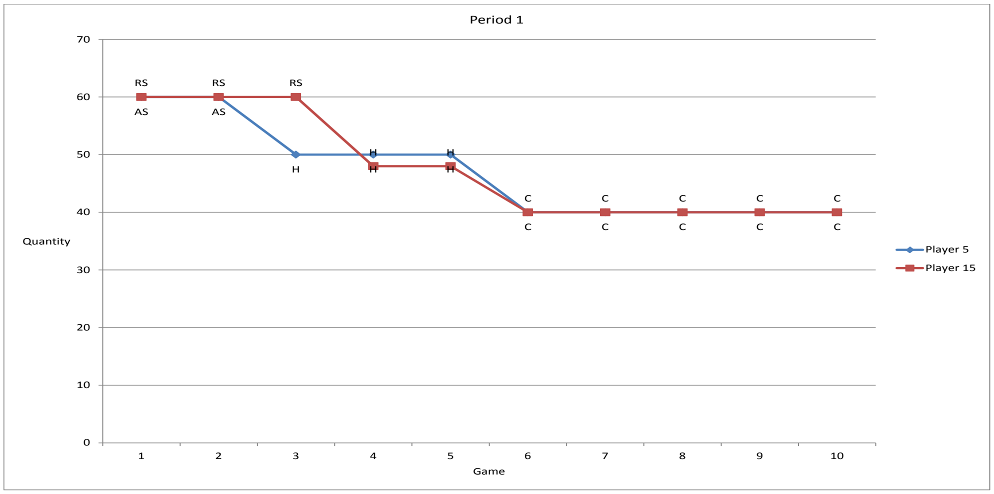

Figure 33: Strategies Player 5 and 15 Period 1 (Stackelberg Game)

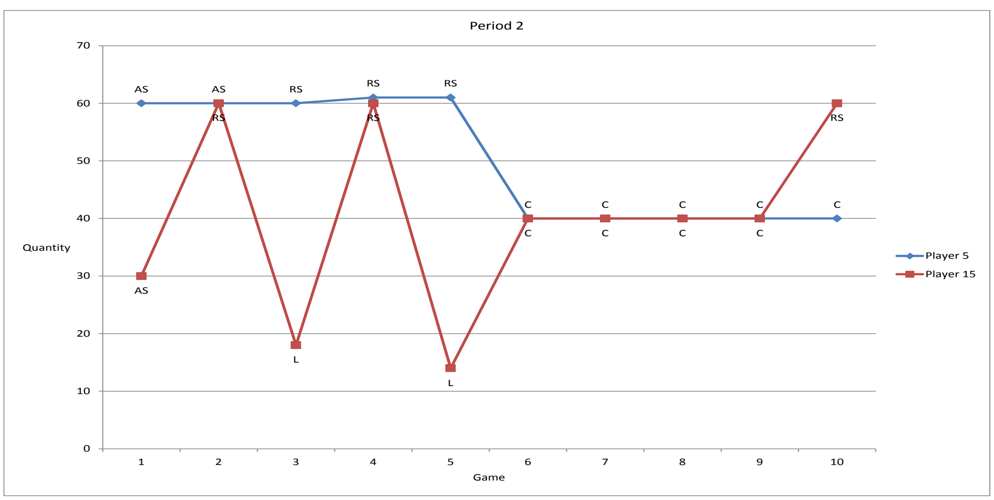

Figure 34: Strategies Player 5 and 15 Period 2 (Stackelberg Game)

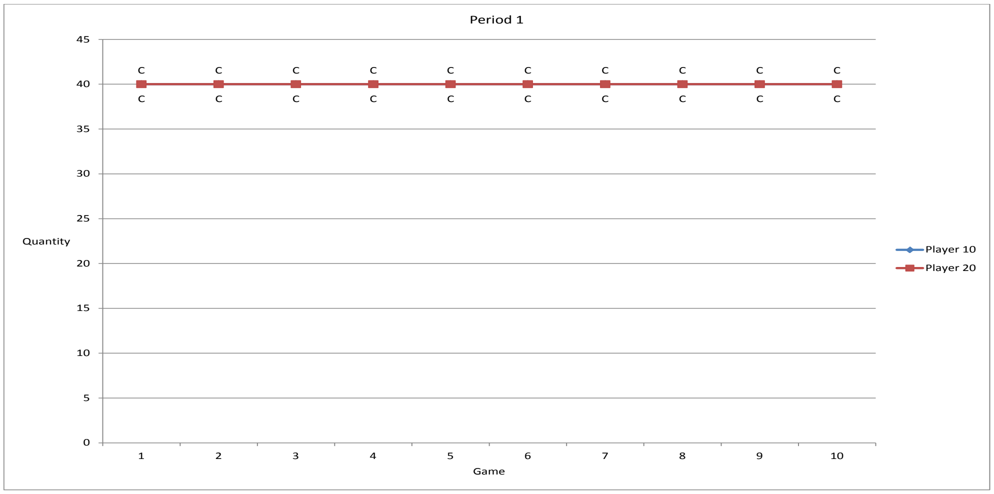

Figure 35: Strategies Player 10 and 20 Period 1 (Stackelberg Game)

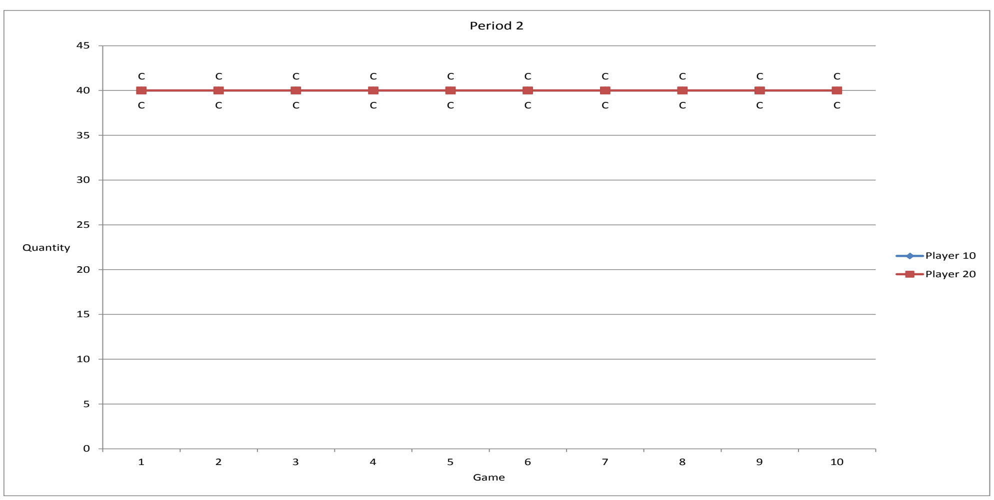

Figure 36: Strategies Player 10 and 20 Period 2 (Stackelberg Game)

The following results can be concluded by answering questions 3 and 4:

3. Are there differences in players quantity decision in period one and period two that are in line with theoretical predictions?

For Stackelberg leaders, quantities in period two were significantly higher than in period one. The opposite is true for Stackelberg followers, whose quantities in period two were significantly lower than in period one. This direction is predicted by theory, too. However, actual play was far from the Stackelberg predictions and the pure strategy Nash equilibrium was played only once out of 100 (10 games times ten duopolies). Cournot play was modal for Stackelberg leaders and Stackelberg followers, suggesting that theoretical prediction fail to explain behavior in this particular setup. The reason for the quantity differences in period one and period two may be explained by fairness considerations and inequality aversion. So, the answer is: Yes, there are large differences and Cournot quantities appear to be a much better predictor than absolute profit maximizing Stackelberg quantities.

4. Do players try to coordinate behavior in such a way that may be called inequality averse? In this case I expect to see cooperation and punishment attempts.

One may wonder why Cournot play is modal at 39 out of 100 cases (consisting of perfect Cournot play), considering players were easily able to identify their dominant strategy. So, why did Stackelberg leaders not use their first movers advantage, any more than they did, to outperform their competition? The answer lies in fairness considerations, punishment for bad behavior, and reward for good behavior. This may be indicated by the 27 cases of relative profit maximizing quantity choices of Stackelberg followers in period one. Indeed, 12 out of 20 players noted that they either were afraid of punishment or considered punishment for bad behavior as a key motivator for choosing certain 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 so than dominant strategies, resulting in Cournot play being modal. To answer the question: Yes, players do coordinate behavior and cooperation is observed.

6.3 Income Comparison

This last results subsection is designed to analyzing the payoffs in the two treatments. Theory predicts that the sequential moves model yields slightly higher average payoffs than the simultaneous moves model, i.e. the mixed strategy equilibrium payoff in the Cournot game is 2870 while the Stackelberg leader earns an equilibrium payoff of 4550 and the Stackelberg follower earns, in equilibrium, 1300. I averaged the equilibrium payoff for first and second mover resulting in expected equilibrium payoff outcome in the Stackelberg model of 2955, which is slightly higher than the Cournot prediction. Figures 37 and 38 depict the average per player payoff including theorized outcomes. In general I would expect an average payoffs in the Stackelberg game to be higher than in the Cournot game, due to its more competitive experimental results. Indeed, comparing averages in each game by means of a Mann-Whitney U-test across both Cournot and Stackelberg treatment shows that payoffs in the Stackelberg game are significantly larger than in the Cournot game (***at the 1% level)[19]. Mean play in the Cournot game ($\mu_C = 2162$) was below the the theoretical prediction of 2870, which suggest that play was more competitive than predicted by theory. This was already suggest earlier when I analyzed quantities.

The Stackelberg game depicts large deviations from theorized outcomes. Overall and combining Stackelberg leaders and followers, the average payoff in the sequential moves game is 2591. Comparing this result to the averaged theorized outcome $\left(\frac{\pi_{Stacklead}+\pi_{Stackfollow}}{2} = 2955\right)$ it can be reported that the experimental result shows slightly lower payoffs than predicted by theory. However, when considering Stacklberg leaders and Stackelberg followers separately large difference emerge. The experimental results show that Stackelberg leaders earn on average 2676 compared to 4550 (theoretical prediction) and Stackelberg followers earn 2507 compared to 1300 (theoretical prediction). Why is there such large discrepancy between experiment and theory? The answer is that this falls right in line with inequality averse preferences, punishment of Stackelberg followers, and fear of punishment by Stackelberg leaders. These preferences result in a much more equal payoff distributing between first and second mover than predicted by theory.

[19]Again, I manually compute the Mann-Whitney U-test without the use of statistical software, see table 11.

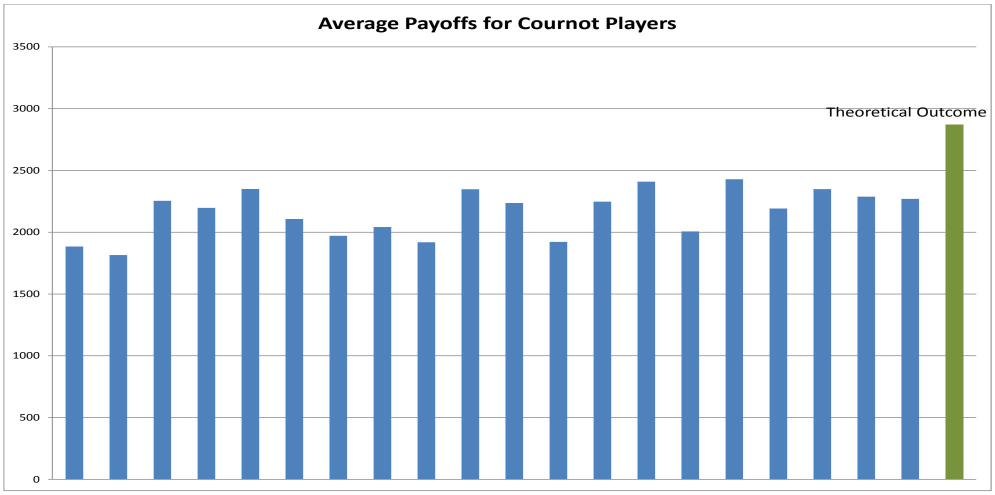

Figure 37: Average payoffs per player in the Cournot game.

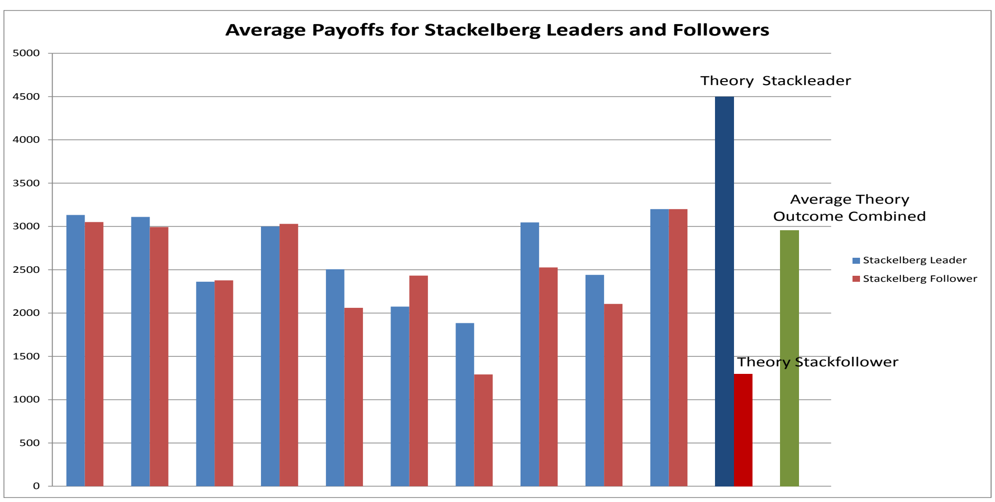

Figure 38: Average payoffs per player in the Stackelberg game.

Cournot			Stackelberg		
game	average income	rank	game	average income	rank
1	2227	9	1	2001	2
2	2205	8	2	2090	6
3	2073	4	3	2603	14
4	2335	12	4	2545	13
5	2242	10	5	2612	15
6	2124	7	6	2679	16
7	1986	1	7	2907	19
8	2038	3	8	2835	18
9	2308	11	9	2926	20
10	2077	5	10	2714	17
R1		70	R2		140
U1	85		U2	15	
U			15		
critical value			19 (0.01 one-tailed)		
significance			(***significant at the 1% level)		

Table 11: Payoff comparison between the simultaneous moves game and the sequential moves game.

The following results can be concluded by answering question 5:

5. Are there payoff differences between the treatments and do payoffs deviate from theorized outcomes?

Yes and Yes/No! Yes, as payoffs in the Stackelberg game are significantly larger than in the Cournot game. This is due to the increased competitiveness in Cournot game, where average payoffs fall short of theoretical prediction and the establishment of coordination in the Stackelberg game. Yes/No, as theory does predict slightly larger payoffs in Stackelberg model than in the Cournot model but it does not predict the rather narrow difference in payoffs between Stackelberg leaders and Stackelberg followers due to successful coordination of behavior around the Cournot quantities.

7 Summary and Concluding Remarks

In this dissertation I strive to gain a deeper insight into how and why firms act spitefully, i.e. select quantities in oligopoly quantity games that result in lower absolute payoffs (compared to an absolute profit maximum) for themselves if it results in even lower absolute profits for their opponent. I set up a 2-period model in which players have a possibility to lower marginal cost after period one to produce cheaper in period two, thus gaining the opportunity to earn larger profits in period two and increase market share. Firms are able to lower marginal cost whenever they outperformed their competition in terms of profit, i.e. whenever they show positive relative profits. The idea is that whenever firms earn the same profit, both firms, by assumption, could invest the same amount into cost-saving technologies and lower marginal cost by the same degree. Only if one firm has an advantage over the other firm, in terms of profit, will it be able to invest more than its competitor and consequently produce cheaper due to lower marginal cost. Truly spiteful players choose relative profit maximizing strategies in both periods, as they receive satisfaction form beating their opponent, while selectively spiteful player will show a different behavior in either period. If a firm is spiteful in order to gain competitive advantage, thus securing its long-term position in the market, then period one will consist of relative profit maximizing behavior while period two, as no more lowering of marginal cost is possible, will consist of absolute profit maximizing behavior. This may be interpreted as a firms ultimate quest towards monopolistic power, changing spiteful behavior to something inherently absolute rather than relative, in a sense that firms merely forgo myopic best responses in order to maximize absolute profits in the long run by achieving a monopolistic position in the market, compare Rosenthal et al. (1984) [34]. It follows that choosing relative profit maximizing strategies in the short-run, i.e. spiteful behavior, is a means to maximize long-run absolute profits.

In order to test the 2-period model, I decided to run two laboratory experiments, with the first experiments consisting of a Cournot quantity game in which players select quantities simultaneously, and the second one a Stackelberg game, in which players made their choices sequentially. Theory predicts a mixed strategy outcome in the Cournot game (with the Cournot quantity being selected 71% of the time) while the Stackelberg model resulted in one sub-game perfect Nash equilibrium in pure strategies consisting of absolute profit maximizing quantities throughout. Experimental results show that, in the Cournot game, period one was significantly more competitive than period two, i.e. quantities in period one were significantly higher than in period two. Walrasian quantities were by far the strongest quantity in period one while Cournot quantities dominated period two. These results suggest that players are selectively spiteful, i.e. selecting relative profit maximizing strategies whenever they have a chance to increase future profits or to insulate against loosing market share against their opponent. As period two is dominated by Cournot play one may infer that players behave spitefully whenever it serves a particular purpose, here that purpose is lower marginal cost for future periods, thus, indirectly, achieving maximal absolute profits in the future. It follows that spiteful behavior is more than the gain in utility over beating ones' competition.

Experimental results in the sequential moves game show large discrepancies between theorized outcomes and experimental data. As mentioned above, theory predicted absolute profit maximizing behavior throughout the entire game, meaning the Stackelberg leader can fully use its first mover's advantage to capture two-thirds of the market for herself, resulting in an even more extreme payoff split in period two, due to the lower marginal cost of the Stackelberg leader in period two. However, this did not happen in the experiment. Stackelberg leaders' quantities fall way below theoretical prediction while Stackelberg followers' quantities are much higher than theorized. Cournot play was modal in the Stackelberg game. This can be explained by considering other-regarding preferences, which appear to dominate strict profit maximizing behavior, in that, Stackelberg leaders' and Stackelberg followers' preferences for an equal payoff distribution may trump absolute profit maxima. Additionally, Stackelberg leaders had to fear possible punishment by Stackelberg followers for playing above Cournot quantity strategies, as Cournot quantities, when chosen by both players would result in equal payoff for both players. In fact, in period one, Stackelberg followers chose a punishment quantity 27 times, which may have been the attempt to change Stackelberg leaders' minds about choosing quantities that result in an unequal payoff split. Thus, in the sequential moves game, spiteful behavior was selected to serve a purpose other than gaining utility from just being better in relative terms. Spiteful play, i.e. relative profit maximizing strategies, were selected to punish Stackelberg leaders if they used their first movers advantage to gain larger profits than Stackelberg followers. This was quite effective as first and second movers output where much closer to each other than to the outcome predicted by theory - as Weimann (1994) [50] points out, "...co-operation is a real fact of human societies..." Comparing payoffs between the two treatments, Stackelberg players, on average, earned significantly larger profits than Cournot players, suggesting that the less competitive outcome in Stackelberg model beats Cournot competition, where especially first period outcomes were very competitive with Walrasian quantities most frequently selected.

What is the contribution of this dissertation? Firstly, to the best of this author's knowledge no other article has tested this particular model experimentally, which in itself makes for an interesting approach. Secondly, I set out to gain a deeper understanding of how and when firms play more competitively, choose spiteful strategies, and when firms rather cooperate and sustain from competition in favor of equal payoffs. With this in mind, I was able to show that firms are very much aware of when and when not to behave in accordance with relative profit maximization. This I was able to show in the simultaneous moves game where first period choices were much more competitive than choices in period two, suggesting long-term profit maximization and the fear of being outperformed by one's competitor more important than myopic best replies and receiving utility from simply beating one's competition. In the sequential moves model I showed that players used relative profit maximizing quantities to punish Stackelberg leaders if they tried to exploit Stackelberg followers by using their first movers advantage. Here, too, relative profit maximizing quantities are not chosen for the pure joy of beating competition, but to ensure equal payoffs, in line with preferences exhibiting inequality aversion. Thus, I was able to gain some insight into why and when players choose to exhibit spiteful behavior.

There are certainly short-comings and further research needs to be done in order to extrapolate to other settings. For example, it would be interesting to see how players behave in a Stackelberg game wherein players did not play the same opponent in every game. Punishment would still be possible, however, the attempt to change a Stackelberg leaders minds about playing her leader's advantage is somewhat lost, as in each game players face a new opponent. Another factor that may change things is time. One could open the time horizon to more than just two time periods allowing for more periods of potential investments into cost-saving technologies to build market share.

Also, one may consider running the simultaneous moves game in fixed pairs throughout the entire experiment to see if coordination changes first period results to more Cournot play, and consequently higher payoffs for both players, moving closer to the experimental Stackelberg outcome. One could also allow for players to chose if they want to invest into cost-saving technologies instead of making it non-optional, this would add a finer understanding of the difference between gaining utility from beating competition and gaining utility from future absolute profits. As always, there is much more that can be research adding to the ever growing field of behavioral economics.

References

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

[2] C. Alós-Ferrer. Cournot versus walras in dynamic oligopolies with memory. *International Journal of Industrial Organization*, 22(2):193–217, 2004.

[3] C. Alós-Ferrer and A.B. Ania. The evolutionary stability of perfectly competitive behavior. *Economic Theory*, 26(3):497–516, 2005.

[4] J. Apesteguia, S. Huck, and J. Oechssler. Imitation–theory and experimental evidence. *Journal of Economic Theory*, 136(1):217–235, 2007.

[5] J. Apesteguia, S. Huck, J. Oechssler, and S. Weidenholzer. Imitation and the evolution of walrasian behavior: Theoretically fragile but behaviorally robust. *Journal of Economic Theory*, 145(5):1603–1617, 2010.

[6] W.J. Baumol. On the theory of oligopoly. *Economica*, 25(99):187–198, 1958.

[7] J. Bergin and D. Bernhardt. Cooperation through imitation. *Games and Economic Behavior*, 67(2):376–388, 2009.

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

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

[10] G.E. Bolton and A. Ockenfels. Erc: A theory of equity, reciprocity, and competition. *American economic review*, pages 166–193, 2000.

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

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

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

[14] C. Fershtman and K.L. Judd. Equilibrium incentives in oligopoly. *The American Economic Review*, pages 927–940, 1987.

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

[16] M. Friedman. *Essays in positive economics*. University of Chicago Press, 1953.

[17] J.H. Hamilton and S.M. Slutsky. Endogenous timing in duopoly games: Stackelberg or cournot equilibria. *Games and Economic Behavior*, 2(1):29–46, 1990.

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

[19] 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.

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

[21] 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.

[22] 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.

[23] S. Huck, H.T. Normann, and J. Oechssler. Through trial and error to collusion*. *International Economic Review*, 45(1):205–224, 2004.

[24] M. Kecinski and T. Riechmann. *Walrasian Strategies in Cournot Games: Theory and Experimental Investigation*. Techn. Univ., Fachgebiete Volkswirtschaftslehre/Wirtschaftspolitik, 2010.

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

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

[27] J. Nash. Non-cooperative games. *The Annals of Mathematics*, 54(2):286–295, 1951.

[28] T. Offerman, J. Potters, and J. Sonnemans. Imitation and belief learning in an oligopoly experiment. *Review of Economic Studies*, 69(4):973–997, 2002.

[29] 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.

[30] 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.

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

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

[33] T. Riechmann. Spieltheorie. 2., vollständig überarbeitete auflage. *München: Vahlen*, 2008.

[34] AW Rosenthal and A. Rubinstein. Repeated two-player games with ruin. *International Journal of Game Theory*, 13(3):155–177, 1984.

[35] G. Saloner. Cournot duopoly with two production periods. *Journal of Economic Theory*, 42(1):183–187, 1987.

[36] M.E. Schaffer. Evolutionarily stable strategies for a finite population and a variable contest size*. *Journal of theoretical biology*, 132(4):469–478, 1988.

[37] 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.

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

[39] K.H. Schlag. Why imitate, and if so, how?* 1,* 2:: A boundedly rational approach to multi-armed bandits. *Journal of Economic Theory*, 78(1):130–156, 1998.

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

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

[42] R. Selten and R. Stoecker. End behavior in sequences of finite prisoner's dilemma supergames a learning theory approach. *Journal of Economic Behavior & Organization*, 7(1):47–70, 1986.

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

[44] M. Spence. Cost reduction, competition, and industry performance. *Econometrica: Journal of the Econometric Society*, pages 101–121, 1984.

[45] B.J. Spencer and J.A. Brander. International r&d rivalry and industrial strategy, 1983.

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

[47] Y. Tanaka. Long run equilibria in an asymmetric oligopoly. *Economic Theory*, 14(3):705–715, 1999.

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

[49] 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.

[50] J. Weimann. Individual behaviour in a free riding experiment. *Journal of Public Economics*, 54(2):185–200, 1994.

A Experimental Instruction (Cournot Game)

Experimental Instruction in German (all experiments were conducted in German language)

Willkommen zum Experiment! (Bitte Sprechen Sie mit niemandem außer den Mitarbeitern, ansonsten müssen wir Sie von dem Experiment ausschlieen) Bitte lesen Sie in den nächsten Minuten die Instruktionen stumm mit, während wir Sie laut vorlesen. Wenn Sie danach eine Frage haben, melden Sie sich bitte und ein Mitarbeiter wird Ihnen helfen. In dem Laborexperiment, an dem Sie jetzt teilnehmen, können Sie in Abhängigkeit Ihrer Entscheidungen und der Entscheidungen Ihrer Mitspieler Bargeld in €verdienen. Ihre Entscheidungen im Experiment treffen Sie anonym. Bitte stellen Sie ihre Taschen an die Seite und schalten Sie ihre Telefone aus! Im Experiment werden Sie Entscheidungen in 10 Spielen treffen. Jedes dieser Spiele besteht aus 2 Perioden. Nach jedem Spiel bekommen Sie einen neuen Gegner zugewiesen, der per Zufall ausgewählt wurde. In den 10 Spielen werden Sie nie zweimal gegen den gleichen Gegner spielen.

Die Entscheidungssituation

Sie sind Eigentümer einer Firma in einem Markt der aus 2 Firmen besteht, d.h. Ihre Firma und die Firma Ihres Gegners. Beide Firmen produzieren ein identisches Gut und haben in Periode 1 identische Produktionskosten, die 40 Euro betragen. Ihre Aufgabe ist es sich für eine Produktionsmenge zu entscheiden, die Sie auf dem Markt verkaufen. Ihr Gegner tut das Gleiche. Die zur Verfügung stehenden Produktionsmengen sind in Periode 1 für beide Spieler identisch und bestehen aus 30, 40, 50 oder 60. Der Markt ist so ausgerichtet, dass alle produzierten Einheiten auch verkauft werden. Nachdem beide Spieler ihre Entscheidung in Periode 1 getroffen haben, werden Sie gebeten auch fr Periode 2 eine Produktionsmenge auszuwählen. Die Produktionsmengen die in Periode 2 zur Auswahl stehen ergeben sich aus den Produktionsmengen aus Periode 1. Sie können die Produktionsmengen und Auszahlungen in Periode 2 der Auszahlungstabelle fr Periode 2 in Ihrem Excelprogramm entnehmen. Neben diesen Instruktionen finden Sie an Ihrem Platz noch eine Informationstabelle fr Periode 1, einen Stift, einen Fragebogen und Ihren Entscheidungsbogen. Folgende Informationen können Sie der Informationstabelle fr Periode 1 entnehmen: Den Gewinn beider Firmen, die möglichen kostensenkenden Investitionen beider Firmen, die Auszahlungen beider Spieler und die Produktionskosten fr Periode 2.

Erklärungen zu den Positionen auf der Informationstabelle:

Gewinn: Dies ist der Gewinn Ihrer Firma auf dem Markt, der von Ihrer und der Ihres Gegners gewählten Produktionsmenge abhängt. Investition: Falls Ihre Firma mehr Gewinn als die Firma Ihres Gegners erwirtschaftet, wird für Sie die Hälfte der Differenz zwischen den Gewinnen in kostensenkende Technologien investiert, so dass Sie in Periode 2 günstiger produzieren können und einen kompetitiven Vorteil erlangen. Falls Ihre Firma weniger Gewinn macht als die Ihres Gegners investieren Sie nichts und haben in Periode 2 die gleichen Produktionskosten wie in Periode 1 (in diesem Fall investiert Ihr Gegner in kostensenkende Technologien und kann in Periode 2 günstiger als Sie produzieren). Falls beide Firmen den gleichen Gewinn erwirtschaften, kann keine der beiden Firmen investieren und beide Firmen haben die gleichen Produktionskosten wie schon in Periode 1 (40 Euro). Auszahlung: Die Auszahlung ist das Geld, was Sie von uns ausgezahlt bekommen. Es ist der Gewinn Ihrer Firma minus der Investition. Produktionskosten für Periode 2: Die Kosten der Periode 2 sind abhängig von der Investition in Periode 1. Je mehr Sie in Periode 1 investieren können, desto geringer sind die Kosten in Periode 2, d.h. je größer die positive Differenz zwischen dem Gewinn Ihrer Firma und dem Gewinn Ihres Gegners ist, desto günstiger produzieren Sie in Periode 2 und desto mehr können Sie in Periode 2 verdienen.

Die auf Ihrem Computer angelegte Excel-Datei ist dazu gedacht, dass Sie ein besseres Verständnis fr das Spiel bekommen. Es wird Ihnen in Ihrer Entscheidungsfindung helfen. Sie können jede mögliche Situation für Periode 1 simulieren und sehen welche möglichen Szenarien sich dadurch für Sie in Periode 2 ergeben. Bitte üben Sie sehr sorgfältig und intensiv bevor wir mit dem eigentlichen Experiment beginnen. Generell können Sie als leitenden Faden folgendes erwarten: Je größer Ihre Investition in Periode 1, d.h. je höher der Gewinn Ihrer Firma über dem Ihres Gegners liegt, umso größer wird Ihre Auszahlung in Periode 2 ausfallen. Falls Ihre Firma und die ihres Gegners in Periode 1 den gleichen Gewinn erwirtschaften, ist die Entscheidungssituation in Periode 2 die gleiche wie in Periode 1. Je größer die Investition Ihres Gegners, d.h. je höher der Gewinn Ihres Gegners über Ihrem liegt, desto geringer ist die mögliche Auszahlung fr Sie in Periode 2.

Entscheidungsprozess und Auszahlungsregel

1. Sie erhalten zur Teilnahme an dem Experiment 7 Euro

2. In jeder Periode erhalten Sie zusätzlich die von Ihnen erwirtschaftete Auszahlung (seien Sie vorsichtig, es sind auch negative Auszahlung möglich wie Sie Ihrer Simulation entnehmen können. In diesem Fall würde sich Ihre Auszahlung verringern.) Beispiel 1. Falls Sie und Ihr Gegner in Periode 1 beide die Produktionsmenge 30 wählen, ist der Gewinn beider Firmen 1.80 EUR in Periode 1. Keiner der beiden Firmen investiert, da beide Firmen den gleichen Gewinn erwirtschaftet haben. Ihre Auszahlung und die Ihres Gegners ist auch 1.80 EUR, da Gewinn abzgl. der Investition (1.80 0.00) gleich 1.80 EUR sind. Beide Firmen haben die gleichen Kosten in Periode 2, wie auch schon in Periode 1, nämlich 40 EUR. Bespiel 2. Falls Sie in Periode 1, 60 produzieren während Ihr Gegner 40 produziert, erwirtschaftet Ihre Firma 1.20 EUR während die Firma Ihres Gegners 0.80 EUR erwirtschaftet. Ihre Firma investiert die Hälfte der Differenz (0.20 EUR). Ihre Auszahlung ist 1.00 EUR (1.20 0.20) und die Ihres Gegners 0.80 EUR. Ihre Produktionskosten in Periode 2 sind 26.67 EUR während die Ihres Gegner 40 EUR betragen. Beispiel 3. Sie: 30 Einheiten Ihr Gegner: 50 Einheiten Folgende Ergebnisse ergeben sich für Periode 1: (Graphic, hier nicht beigefügt)

Sie können sehen, dass die Auszahlungstabelle für Periode 2 von den Entscheidungen in Periode 1 abhängen. Je größer die Investition in Periode 1, desto höher die möglichen Auszahlungen in Periode 2. Bitte machen Sie sich mit dem Programm vertraut, da Ihre Entscheidungen davon abhängen. Sowie Sie sich für eine Produktionsmenge entschieden haben, tragen Sie diese in Ihren Entscheidungsbogen und in der Ecxeltabelle ein. Nachdem wir Ihnen die Menge Ihres Gegners mittgeteilt haben, tragen Sie diese auch in die Exceltabelle ein. Sie sehen jetzt welche Möglichkeiten sich in Periode 2 ergeben. Nachdem Sie sich für eine Produktionsmenge entschieden haben, tragen Sie diese auch in den Entscheidungsbogen ein. Wie zuvor, ergänzen wir Ihren Entscheidungsbogen um die Menge Ihres Gegners sowie die Auszahlungen. Danach startet der gleiche Prozess (Spiel 2) mit einem neuen Gegner. Zur Eingabe der Menge brauchen Sie nur auf das jeweilige Feld zu klicken und die Menge aus der Liste auszuwählen. Bitte machen Sie keine Einträge mit Hilfe der Tastatur, da es sonst zu einer Fehlermeldung kommt. Bitte scheuen

Sie nicht uns jeder Zeit Fragen zu stellen, auch noch so triviale, denn es ist entscheidend, dass alle Spieler das Experiment verstehen. Bitte fragen Sie nie ihren Nachbarn oder einen anderen Spieler, weil dadurch die gesammelten Daten unbrauchbar werden. Bitte heben Sie bei Fragen die Hand und wir werden zu Ihnen an den Platz kommen. Wir werden Ihnen jetzt die Excel-Datei erklären.

B Experimental Instruction (Stackelberg Game)

Experimental Instruction in German (all experiments were conducted in German language)

Willkommen zum Experiment!

(Bitte Sprechen Sie mit niemandem auer den Mitarbeitern, ansonsten müssen wir Sie von dem Experiment ausschlieen) Bitte lesen Sie in den nächsten Minuten die Instruktionen stumm mit, während wir Sie laut vorlesen. Wenn Sie danach eine Frage haben, melden Sie sich bitte und ein Mitarbeiter wird Ihnen helfen. In dem Laborexperiment, an dem Sie jetzt teilnehmen, können Sie in Abhängigkeit Ihrer Entscheidungen und der Entscheidungen Ihrer Mitspieler Bargeld in €verdienen. Ihre Entscheidungen im Experiment treffen Sie anonym. Bitte stellen Sie ihre Taschen an die Seite und schalten Sie ihre Telefone aus! Im Experiment werden Sie Entscheidungen in 10 Spielen treffen. Jedes dieser Spiele besteht aus 2 Perioden. Sie spielen im gesamte Spiel gegen den gleichen Gegner, der per Zufall ausgewählt wurde.

Die Entscheidungssituation

Sie sind Eigentümer einer Firma in einem Markt der aus 2 Firmen besteht, d.h. Ihre Firma und die Firma Ihres Gegners. Beide Firmen produzieren ein identisches Gut und haben in Periode 1 identische Produktionskosten, die 40 Euro betragen. Allerdings entscheiden die beiden Firmen sich zu unteschiedlichen Zeitpunkten über ihre Produktionsmengen, d.h. eine Firma entscheidet sich zuerest für eine Menge (Erstziehende). Die erstziehende Firma wurde per Zufall ausgewählt und bleibt erstziehende Firma für das gesamte Spiel. Nachdem sich die erstziehende Firma für eine Menge entschieden hat, wird die zweitziehende Firma über die Menge der erstziehenden Firma informiert. Danach entscheidet sich auch die zweitziehende Firma für eine Produktionsmenge. Die Firma die den größeren Gewinn erwirtschaftet, investiert in kostensenkende Technologien und kann in Periode 2 günstiger produzieren und einen größeren Gewinn erwirtschaften als der Gegner.

Die zur Verfügung stehenden Produktionsmengen sind in Periode 1 für den erstziehenden Spieler 30, 40, 50 oder 60. Die Menge für den Zweitziehenden ergeben sich aus der Menge des Erstziehenden. Der Markt ist so ausgerichtet, dass alle produzierten Einheiten auch verkauft werden. Nachdem beide Spieler ihre Entscheidung in Periode 1 getroffen haben, werden Sie gebeten auch fr Periode 2 eine Produktionsmenge auszuwählen. Die Produktionsmengen, die in Periode 2 zur Auswahl stehen, ergeben sich aus den Produktionsmengen aus Periode 1. Sie können die Produktionsmengen und Auszahlungen in Periode 1 und 2 Ihrem Excelprogramm entnehmen. Der Ablauf in Periode 2 ist identische mit dem in Periode 1, d.h. der erstziehende Spieler entscheidet zuerst und der zweitziehende Spieler nachdem sie über die Menge des Erstziehenden informiert wurde. Neben diesen Instruktionen finden Sie an Ihrem Platz noch einen Stift, einen Fragebogen und Ihren Entscheidungsbogen.

Die auf Ihrem Computer angelegte Excel-Datei gibt Ihnen Auskunft über alle möglichen Situationen die sich aus den Mengen von Erst- und Zweitziehendem ergeben. Sie können jede mögliche Situation fr Periode 1 simulieren und sehen welche möglichen Szenarien sich dadurch für Sie in Periode 2 ergeben. Bitte üben Sie sehr sorgfältig und intensiv bevor wir mit dem eigentlichen Experiment beginnen. Generell können Sie als leitenden Faden folgendes erwarten: Je größer Ihre Investition in Periode 1, d.h. je höher der Gewinn Ihrer Firma über dem Ihres Gegners liegt, umso größer wird Ihre Auszahlung in Periode 2 ausfallen. Falls Ihre Firma und die ihres Gegners in Periode 1 den gleichen Gewinn erwirtschaften, ist die Entscheidungssituation in Periode 2 die gleiche wie in Periode 1. Je größer die Investition Ihres Gegners, d.h. je höher der Gewinn Ihres Gegners über Ihrem liegt, desto geringer ist die mögliche Auszahlung fr Sie in Periode 2. Erklärungen zu den Positionen in der Excel-Datei: Ihre Menge: Die Produktionsmenge für die Sie sich entscheiden können. Menge des Gegners: Die Produktionsmenge für die sich Ihr Gegner entscheiden kann. Ergebnis Periode 1 Gewinn: Dies ist der Gewinn Ihrer Firma auf dem Markt, der von Ihrer und der Ihres Gegners gewählten Produktionsmenge abhängt. Investition: Falls Ihre Firma mehr Gewinn als die Firma Ihres Gegners erwirtschaftet, wird für Sie die Hälfte der Differenz zwischen den Gewinnen in kostensenkende Technologien investiert, so dass Sie in Periode 2 günstiger produzieren können und einen kompetitiven Vorteil erlangen. Falls Ihre Firma weniger Gewinn macht als die Ihres Gegners investieren Sie nichts und haben in Periode 2 die gleichen Produktionskosten wie in Periode 1 (in diesem Fall investiert Ihr Gegner in kostensenkende Technologien und kann in Periode 2 günstiger als Sie produzieren). Falls beide Firmen den gleichen Gewinn erwirtschaften, kann keine der beiden Firmen investieren und beide Firmen haben die gleichen Produktionskosten wie schon in Periode 1 (40 Euro). Auszahlung: Die Auszahlung ist das Geld, was Sie von uns ausgezahlt bekommen. Es ist der Gewinn Ihrer Firma minus der Investition. Produktionskosten für Periode 2: Die Kosten der Periode 2 sind abhängig von der Investition in Periode 1. Je mehr Sie in Periode 1 investieren können, desto geringer sind die Kosten in Periode 2, d.h. je größer die positive Differenz zwischen dem Gewinn Ihrer Firma und dem Gewinn Ihres Gegners ist, desto günstiger produzieren Sie in Periode 2 und desto mehr können Sie in Periode 2 verdienen.

Entscheidungsprozess und Auszahlungsregel

1. Sie erhalten zur Teilnahme an dem Experiment 7 Euro

2. In jeder Periode erhalten Sie zusätzlich die von Ihnen erwirtschaftete Auszahlung (seien Sie vorsichtig, es sind auch negative Auszahlung möglich wie Sie Ihrer Simulation entnehmen können. In diesem Fall würde sich Ihre Auszahlung verringern.) Beispiel 1. Falls sich die erstziehende Firma in Periode 1 für eine Produktionsmenge von 40 entscheidet und die zweitziehende Frima in Periode 1 auch 40 produziert, ist der Gewinn beider Firmen 1.60 EUR in Periode 1. Keiner der beiden Firmen investiert, da beide Firmen den gleichen Gewinn erwirtschaftet haben. Ihre Auszahlung und die Ihres Gegners ist auch 1.60 EUR, da Gewinn abzgl. der Investition (1.60 0.00) gleich 1.60 EUR sind. Beide Firmen haben die gleichen Kosten in Periode 2, wie auch schon in Periode 1, nämlich 40 EUR. Bespiel 2. Falls der Erstziehende in Periode 1, 60 produziert während der Zweitziehende 30 produziert, ist die Auszahlung für den Zuerstziehende 1.35 EUR während der Zweitziehenden 0.90 EUR verdient. Die Produktionskosten in Periode 2 sind 20 EUR für den Erstziehenden und 40 EUR für den Zweitziehenden. Dies bedeutet das der Erstziehende einen grossen Vorteill in Periode

2 hat, wie Sie es der Auszahlungstabelle fr Periode 2 entnehmen können. Beispiel 3. Erstziehender: 50 Einheiten Zweitziehender: 60 Einheiten Folgende Ergebnisse ergeben sich fr Periode 1: Auszahlung Erstziehender: 0.50 EUR Auszahlung Zweitziehender: 0.55 EUR Kosten in Periode 2 Erstziehender: 40 EUR Kosten in Periode 2 Zweitziehender: 33.33 EUR

Sie können sehen, dass die Auszahlungstabelle fr Periode 2 von den Entscheidungen in Periode 1 abhängen. Je größer die Investition in Periode 1, desto höher die möglichen Auszahlungen in Periode 2. Bitte machen Sie sich mit dem Programm vertraut, da Ihre Entscheidungen davon abhängen.

Sowie Sie sich für eine Produktionsmenge entschieden haben, tragen Sie diese in Ihren Entscheidungsbogen und in der Ecxeltabelle ein. Für den Zweitziehenden bedeutet dies natürlich, dass sie erst die Entscheidung des Erstziehenden abwarten muss bevor sie sich selbst entscheiden kann. Nachdem wir Ihnen die Menge Ihres Gegners mittgeteilt haben, tragen Sie diese auch in die Exceltabelle ein.

Sie sehen jetzt welche Möglichkeiten sich in Periode 2 ergeben. Nachdem Sie sich für eine Produktionsmenge entschieden haben, tragen Sie diese auch in den Entscheidungsbogen ein (Zweitzieher müssen wie schon in Periode 1 auf die Menge vom Gegner warten). Wie zuvor, ergänzen wir Ihren Entscheidungsbogen um die Menge Ihres Gegners sowie die Auszahlungen. Danach startet der gleiche Prozess (Spiel 2) mit dem gleichen Gegner. Zur Eingabe der Menge brauchen Sie nur auf das jeweilige Feld zu klicken und die Menge aus der Liste auszuwählen. Bitte machen Sie keine Einträge mit Hilfe der Tastatur, da es sonst zu einer Fehlermeldung kommt. Bitte scheuen Sie nicht uns jeder Zeit Fragen zu stellen, auch noch so triviale, denn es ist entscheidend, dass alle Spieler das Experiment verstehen. Bitte fragen Sie nie ihren Nachbarn oder einen anderen Spieler, weil dadurch die gesammelten Daten unbrauchbar werden. Bitte heben Sie bei Fragen die Hand und wir werden zu Ihnen an den Platz kommen. Wir werden Ihnen jetzt die Excel-Datei erklären.

C Questionnaire Simultaneous Moves

Fragebogen

Frage 1. Sie entscheiden sich in Periode 1 für die Produktionsmenge 30, während Ihr Gegner sich für 60 entscheidet. In Periode 2, was ist die höchste mögliche Auszahlung für:

Sie:
Ihren Gegner:

Und was ist die niedrigste mögliche Auszahlung für: Sie: Ihren Gegner:

Frage 2. Falls Sie und Ihr Gegner in Periode 1 beide 50 spielen, wie hoch ist die Auszahlung in Periode 1 für: Sie:
Ihren Gegner:

Frage 3. Wie hoch sind Ihre Kosten in Periode 2, wenn Sie sich in Periode 1 für 60 entscheiden, und Ihr Gegner 40 spielt?

Frage 4. Sie entscheiden sich für die Produktionsmenge 50 in Periode 1, während Ihr Gegner 40 spielt. Welche Produktionsmengen stehen Ihnen zur Verfügung in Periode 2 und wie hoch sind Ihre Produktionskosten?

Produktionsmengen:
Kosten:

D Questionnaire Sequential Moves

Fragebogen

Frage 1. Der Zuerstziehende entscheiden sich in Periode 1 für die Produktionsmenge 60, worauf sich der Zweitziehende fr 30 entscheidet. In Periode 2, was ist die höchste mögliche Auszahlung für:

Erstziehenden:
Zweitziehenden:

Und was ist die niedrigste mögliche Auszahlung für:

Erstziehenden:
Zweitziehenden:

Frage 2. Falls der Erstziehende 40 spielt und der Zeitziehende darauf auch 40 in Periode 1 spielt, wie hoch ist die Auszahlung in Periode 1 für:

Erstziehenden:
Zweitziehenden:

Frage 3. Wie hoch sind Ihre Kosten in Periode 2, wenn sich der Zuerstziehende in Periode 1 für 50 entscheidet, und der Zweitziehende in Periode 1 35 spielt?

Erstziehenden:
Zweitziehenden:

Frage 4. Der Erstziehende entscheiden sich für die Produktionsmenge 60 in Periode 1, während der Zweitziehende 45 spielt. Welche Produktionsmengen stehen dem Erstziehenden zur Verfügung in Periode 2 und wie hoch sind dessen Produktionskosten?

Produktionsmengen:
Kosten:

Zu Frage 4. Welche Produktionsmengen stehen dem Zweitziehenden in Periode 2 zur Verfügung wenn der Erstziehende sich in Periode 2 für 70 entscheidet?

Produktionsmengen

E Record Sheet

Spielernummer (Platznummer):

Geschlecht:

Alter:

Studiengang:

Semester:

Tragen Sie in dieser Spalte Ihre Produktionsmengen ein. Die anderen Spalten werden von uns ausgefüllt!

		Sie		**Ihr Gegner**	
		Menge	Auszahlung	Menge	Auszahlung
Spiel 1	Periode 1				
	Periode 2				
Spiel 2	Periode 1				
	Periode 2				
Spiel 3	Periode 1				
	Periode 2				
Spiel 4	Periode 1				
	Periode 2				
Spiel 5	Periode 1				
	Periode 2				
Spiel 6	Periode 1				
	Periode 2				
Spiel 7	Periode 1				
	Periode 2				
Spiel 8	Periode 1				
	Periode 2				
Spiel 9	Periode 1				
	Periode 2				
Spiel 10	Periode 1				
	Periode 2				

Teilen Sie uns bitte kurz mit, was Grundlage ihrer Entscheidung in Periode 1 und in Periode 2 war.
Periode 1:
Periode 2:

Figure 39: Average payoffs per player in the Cournot game.

F Experimenter's Record Sheet

	Spieler	Gegner		Spieler 1 Menge	Gegner Menge		Spieler	Gegner		Spieler 2 Menge	Gegner Menge
Spiel 1	1	11	periode 1			Spiel 1	2	12	periode 1		
			periode 2						periode 2		
Spiel 2	1	12	periode 1			Spiel 2	2	13	periode 1		
			periode 2						periode 2		
Spiel 3	1	13	periode 1			Spiel 3	2	14	periode 1		
			periode 2						periode 2		
Spiel 4	1	14	periode 1			Spiel 4	2	15	periode 1		
			periode 2						periode 2		
Spiel 5	1	15	periode 1			Spiel 5	2	16	periode 1		
			periode 2						periode 2		
Spiel 6	1	16	periode 1			Spiel 6	2	17	periode 1		
			periode 2						periode 2		
Spiel 7	1	17	periode 1			Spiel 7	2	18	periode 1		
			periode 2						periode 2		
Spiel 8	1	18	periode 1			Spiel 8	2	19	periode 1		
			periode 2						periode 2		
Spiel 9	1	19	periode 1			Spiel 9	2	20	periode 1		
			periode 2						periode 2		
Spiel 10	1	20	periode 1			Spiel 10	2	11	periode 1		
			periode 2						periode 2		

Figure 40: Example of experimenter's record sheet

G Payoff Table Period 1 (Cournot Game)

Die Produktionsmengen Ihres Gegners

Periode 1	30							
	Gewinn		Investition		Auszahlung		Kosten in Periode 2	
Ihre Produktionsmengen	Sie	Ihr Gegner	Sie	Ihr Gegner	Sie	Ihr Gegner	Sie	Ihr Gegner
30	**1.80**	1.80	**0.00**	0.00	**1.80**	1.80	**40.00**	40.00
40	**2.00**	1.50	**0.25**	0.00	**1.75**	1.50	**30.00**	40.00
50	**2.00**	1.20	**0.40**	0.00	**1.60**	1.20	**24.00**	40.00
60	**1.80**	0.90	**0.45**	0.00	**1.35**	0.90	**20.00**	40.00

Periode 1	40							
	Gewinn		Investition		Auszahlung		Kosten in Periode 2	
Ihre Produktionsmengen	Sie	Ihr Gegner	Sie	Ihr Gegner	Sie	Ihr Gegner	Sie	Ihr Gegner
30	**1.50**	2.00	**0.00**	0.25	**1.50**	1.75	**40.00**	30.00
40	**1.60**	1.60	**0.00**	0.00	**1.60**	1.60	**40.00**	40.00
50	**1.50**	1.20	**0.15**	0.00	**1.35**	1.20	**32.00**	40.00
60	**1.20**	0.80	**0.20**	0.00	**1.00**	0.80	**26.67**	40.00

Periode 1	50							
	Gewinn		Investition		Auszahlung		Kosten in Periode 2	
Ihre Produktionsmengen	Sie	Ihr Gegner	Sie	Ihr Gegner	Sie	Ihr Gegner	Sie	Ihr Gegner
30	**1.20**	2.00	**0.00**	0.40	**1.20**	1.60	**40.00**	24.00
40	**1.20**	1.50	**0.00**	0.15	**1.20**	1.35	**40.00**	32.00
50	**1.00**	1.00	**0.00**	0.00	**1.00**	1.00	**40.00**	40.00
60	**0.60**	0.50	**0.05**	0.00	**0.55**	0.50	**33.33**	40.00

Periode 1	60							
	Gewinn		Investition		Auszahlung		Kosten in Periode 2	
Ihre Produktionsmengen	Sie	Ihr Gegner	Sie	Ihr Gegner	Sie	Ihr Gegner	Sie	Ihr Gegner
30	**0.90**	1.80	**0.00**	0.45	**0.90**	1.35	**40.00**	20.00
40	**0.80**	1.20	**0.00**	0.20	**0.80**	1.00	**40.00**	26.67
50	**0.50**	0.60	**0.00**	0.05	**0.50**	0.55	**40.00**	33.33
60	**0.00**	0.00	**0.00**	0.00	**0.00**	0.00	**40.00**	40.00

Figure 41: Payoff Table Cournot game.

H Math Details on the Experimental Model

H.1 Cournot

The first step here is to derive the standard Cournot results, which will show best responses as a one shot game.

$$\max_{y_i} \pi_i = P(Y)y_i - C(y_i) \tag{276}$$

substituting the above information and deriving best reply functions:

$$\max_{y_i} \pi_i = (160 - y_i - y_{-i})\, y_i - 40y_i \tag{277}$$

the first oder condition is:

$$\frac{\partial \pi_i}{\partial y_i} = 120 - 2y_i - y_{-i} = 0 \tag{278}$$

Due to symmetry both firms share the same optimal reply function:

$$R_i : y_i(y_{-i}) = 60 - \frac{1}{2}y_{-i} \tag{279}$$

If both firms play their optimal replies, the market brings about the following outcome:

$$y_i^* = y_{-i}^* = 40 \tag{280}$$

$$\pi_i^* = \pi_{-i}^* = 1600 \tag{281}$$

In order to achieve maximal investment in period one, to lower cost in period two by the maximal amount, a firm will have to outperform the other by the greatest difference in profits possible, thus, it will maximize relative profits in period one.

H.2 Walras

A relative profit maximizer will produce that quantity that will achieve the greatest distance in terms of profit between itself and it's competition:

$$\max_{y_i}(\pi_i - \pi_{-i}) = \max_{y_i} \pi_i^R, \text{ where R stands for relative} \tag{282}$$

substituting the above information and deriving best reply functions:

$$\max_{y_i} \pi_i^R = (160 - y_i - y_{-i})\, y_i - 40y_i - [(160 - y_i - y_{-i})\, y_{-i} - 40y_{-i}] \quad (283)$$

the first oder condition is:

$$\frac{\partial \pi_i^R}{\partial y_i} = 120 - 2y_i = 0 \quad (284)$$

If both firms play their optimal replies, the market brings about the following outcome:

$$y_i^* = y_{-i}^* = 60 \quad (285)$$

$$P^*(Y) = 40 \quad (286)$$

$$\pi_i^* = \pi_{-i}^* = 0 \quad (287)$$

this is equivalent to perfect competition, and hence, the Walrasian outcome. A quicker way to derive this result, due to symmetry, is simply equating marginal cost and market price:

$$MC(y_i) = \frac{\partial C(y_i)}{\partial y_i} = 40 = 160 - Y = P(Y) \quad (288)$$

One can easily see that $Y = 120$ and, due to symmetry, both firms have equal share in market output, i.e. $y_i = \frac{1}{2}Y = 60$.

Thus far, I have derived strategies (Walrasian and Cournot) under a simultaneous move process. I will now continue and derive quantities under a sequential move model.

H.3 Stackelberg

I assume firm i is the first mover (leader) and firm -i, subsequently, the second mover (follower). The model is solved through backward induction and starts by finding the optimal reply function of the follower:

$$\max_{y_{-i}} \pi_{-i} = P(Y)y_{-i} - C(y_{-i}) \quad (289)$$

substituting the above information and deriving the optimal reply function:

$$\max_{y_{-i}} \pi_{-i} = (160 - y_i - y_{-i})\, y_{-i} - 40y_{-i} \quad (290)$$

the first oder condition is

$$\frac{\partial \pi_{-i}}{\partial y_{-i}} = 120 - 2y_{-i} - y_i = 0 \tag{291}$$

The follower's optimal reply function is obviously the same as the one derived under simultaneous Cournot (see above):

$$R_{-i} : y_{-i}(y_i) = 60 - \frac{1}{2} y_i \tag{292}$$

As the leader knows what the followers optimal reply is (assuming perfect information), she will maximize her profits by substituting the follower's optimal reply function directly into her profit function:

$$\max_{y_i} \pi_i = (160 - y_i - y_{-i}(y_i))\, y_i - 40 y_i \tag{293}$$

$$\max_{y_i} \pi_i = \left[160 - y_i - \left(60 - \frac{1}{2} y_i\right)\right] y_i - 40 y_i \tag{294}$$

$$\frac{\partial \pi_i}{\partial y_i} = 60 - y_i = 0 \tag{295}$$

The leader in optimum will choose :

$$y_i^* = 60 \tag{296}$$

The followers quantity can easily be derived by substituting the leaders optimal quantity into her reaction function:

$$R_{-i} : y_{-i}(y_i^*) = 60 - \frac{1}{2} y_i^* \tag{297}$$

$$R_{-i} : y_{-i}(60) = 60 - \frac{1}{2} 60 \tag{298}$$

Thus, the follower in optimum will choose :

$$y_{-i}^* = 30 \tag{299}$$

The leader's profit in this Stackelberg model is:

$$\pi_i^* = 1800 \tag{300}$$

While the follower's profit is:

$$\pi_{-i}^* = 900 \tag{301}$$

Solving the sequential moves model for maximum possible investment will again rely on maximization in relative terms.

H.4 Stackelberg in Relative Terms

The analysis, just like before, follows the backward induction process and thus, starts by finding the optimal reply of the follower:

$$\max_{y_{-i}} \pi^R_{-i} = (160 - y_i - y_{-i})\, y_{-i} - 40y_{-i} - [(160 - y_i - y_{-i})\, y_i - 40y_i] \quad (302)$$

the first oder condition is:

$$\frac{\partial \pi^R_{-i}}{\partial y_{-i}} = 120 - 2y_{-i} = 0 \quad (303)$$

The follower's optimal reply function is, no surprise here, the same as the one derived under simultaneous relative profit maximization (see above) and independent of the leaders quantity choice:

$$y^*_{-i} = 60 \quad (304)$$

Thus, the leaders best strategy (in terms of relative performance), under consideration of the followers optimal quantity choice (again assuming perfect information), is derived by applying the followers optimal reply function directly into the leaders profit function.

$$\max_{y_i} \pi^R_i = \left(160 - y_i - y^*_{-i}\right) y_i - 40y_i - \left[\left(160 - y_i - y^*_{-i}\right) y^*_{-i} - 40y^*_{-i}\right] \quad (305)$$

It should come as no surprise that the follower's optimal quantity is also 60, as her quantity decision in this symmetric model is independent of the followers output decision, and vice versa.

$$\frac{\partial \pi^R_i}{\partial y_i} = 120 - 2y_i = 0 \quad (306)$$

Hence:

$$y^*_i = 60 \quad (307)$$

Again, this is the outcome under perfect competition leading to:

$$\pi^*_i = \pi^*_{-i} = 0 \quad (308)$$

H.5 Cournot Quantities in the Stackelberg Model

If the Stackelberg leader chooses 40, the Stackelberg follower's absolute profit maximizing best reply is:

$$\max_{y_i} \pi_i = [160 - y_i - 40]\, y_i - 40 y_i \tag{309}$$

$$\frac{\partial \pi_i}{\partial y_i} = 80 - 2y_i = 0 \tag{310}$$

The Stackelberg follower in optimum will choose:

$$y_i^* = 40 \tag{311}$$

which is the Cournot quantity. If the Stackelberg leader chooses 40, the Stackelberg follower's relative profit maximizing quantity is:

$$\max_{y_i} \pi_i^R = (160 - y_i - 40)\, y_i - 40 y_i - [(160 - y_i - 40)\, 40 - 40\,(40)] \tag{312}$$

$$\frac{\partial \pi_i}{\partial y_i} = 120 - 2y_i = 0 \tag{313}$$

The Stackelberg follower in optimum will choose:

$$y_i^* = 60 \tag{314}$$

which is the Walrasian quantity of the Cournot game.

All that is left, is to complete the strategy options for the Cournot quantity branch of the sequential moves game tree.

1. Period 1: (40,60) Period 2: (60,?)
The follower's relative profit maximizing quantity:

$$\max_{y_{-i}} \pi_{-i}^R = (160 - y_i - y_{-i})\, y_{-i} - 26\frac{2}{3} y_{-i} - [(160 - y_i - y_{-i})\, y_i - 40 y_i] \tag{315}$$

$$\frac{\partial \pi_{-i}^R}{\partial y_{-i}} = 133\frac{1}{3} - 2y_{-i} = 0 \tag{316}$$

$$y_{-i}^* = 66\frac{2}{3} \tag{317}$$

The leaders relative profit maximizing quantity is:

$$\max_{y_i} \pi_i^R = \left(160 - y_i - 66\frac{2}{3}\right) y_i - 40y_i - \left[\left(160 - y_i - 66\frac{2}{3}\right) y_i - 26\frac{2}{3}66\frac{2}{3}\right] \tag{318}$$

$$\frac{\partial \pi_i^R}{\partial y_i} = 120 - 2y_i = 0 \tag{319}$$

$$y_i^* = 60 \tag{320}$$

Aggregation over two periods yields:

$$\Pi_i = \pi_{i,period1} + \pi_{i,period2} = 800 - 400 = 400 \tag{321}$$

analogously for the other firm:

$$\Pi_{-i} = \pi_{-i,period1} + \pi_{-i,period2} = 1200 + 444\frac{4}{9} = 1644\frac{4}{9} \tag{322}$$

2. Period 1: (40,60) Period 2: (60,?)
What is the follower's optimal absolute reaction to the leader's relative optimal choice?

$$\max_{y_{-i}} \pi_{-i} = (160 - y_i - y_{-i})\, y_{-i} - 26\frac{2}{3} y_{-i} \tag{323}$$

$$\frac{\partial \pi_{-i}}{\partial y_{-i}} = 133\frac{1}{3} - 2y_{-i} - y_i = 0 \tag{324}$$

$$R_{-i} : y_{-i}(60) = 66\frac{2}{3} - \frac{1}{2}60 \tag{325}$$

$$y_{-i}^* = 36\frac{2}{3} \tag{326}$$

Aggregation over two periods yields:

$$\Pi_i = \pi_{i,period1} + \pi_{i,period2} = 800 + 1400 = 2200 \tag{327}$$

analogously for the other firm:

$$\Pi_{-i} = \pi_{-i,period1} + \pi_{-i,period2} = 1200 + 1344\frac{4}{9} = 2544\frac{4}{9} \tag{328}$$

3. Period 1: (40,60) Period 2: (?,$66\frac{2}{3}$)
What strategy does the absolute profit maximizing leader choose?

The follower's reaction function:

$$R_{-i}: y_{-i}(y_i) = 66\frac{2}{3} - \frac{1}{2}y_i \tag{329}$$

The leader's profit function:

$$\max_{y_i} \pi_i = \left[160 - y_i - \left(66\frac{2}{3} - \frac{1}{2}y_i\right)\right] y_i - 40y_i \tag{330}$$

$$\frac{\partial \pi_i}{\partial y_i} = 53\frac{1}{3} - y_i = 0 \tag{331}$$

$$y_i^* = 53\frac{1}{3} \tag{332}$$

Aggregation over two periods yields:

$$\Pi_i = \pi_{i,period1} + \pi_{i,period2} = 800 + 0 = 800 \tag{333}$$

analogously for the other firm:

$$\Pi_{-i} = \pi_{-i,period1} + \pi_{-i,period2} = 1200 + 888\frac{8}{9} = 2088\frac{8}{9} \tag{334}$$

4. Period 1: (40,60) Period 2: ($53\frac{1}{3}$,?)
What is the follower's optimal absolute profit maximizing strategy given the leader also chooses an absolute profit maximizing quantity?

The follower's reaction function:

$$R_{-i}: y_{-i}(53\frac{1}{3}) = 66\frac{2}{3} - \frac{1}{2}53\frac{1}{3} \tag{335}$$

$$y_{-i}^* = 40 \tag{336}$$

Aggregation over two periods yields:

$$\Pi_i = \pi_{i,period1} + \pi_{i,period2} = 800 + 1422\frac{2}{9} = 2222\frac{2}{9} \tag{337}$$

analogously for the other firm:

$$\Pi_{-i} = \pi_{-i,period1} + \pi_{-i,period2} = 1200 + 1600 = 2800 \tag{338}$$

I Individual Behavior Cournot Game

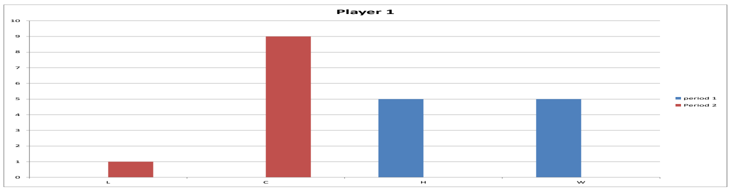

Figure 42: Bar chart of player one's quantity choices

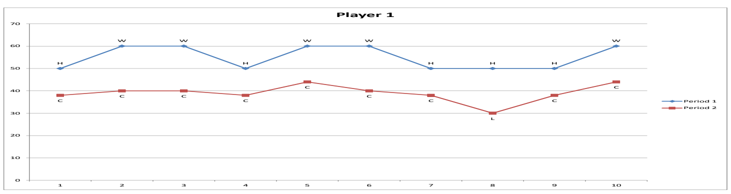

Figure 43: Time series for all 10 games of quantity choices of player one

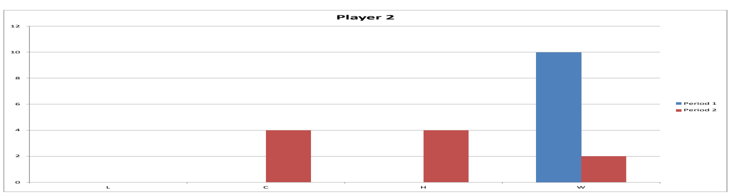

Figure 44: Bar chart of player two's quantity choices

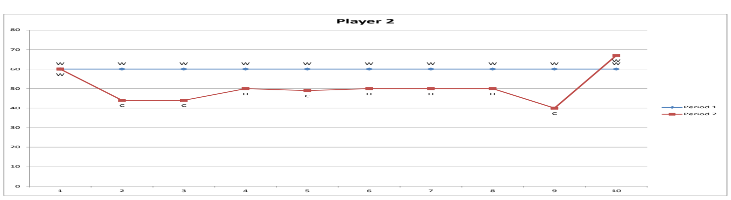

Figure 45: Time series for all 10 games of quantity choices of player two

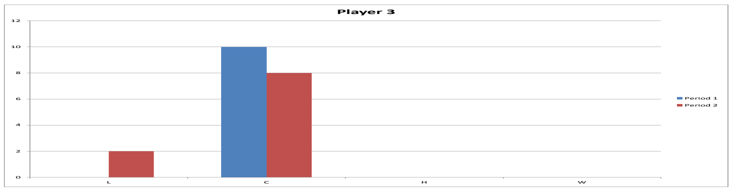

Figure 46: Bar chart of player three's quantity choices

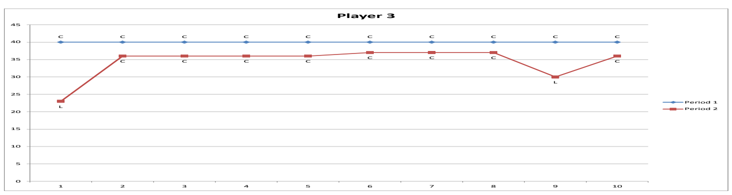

Figure 47: Time series for all 10 games of quantity choices of player three

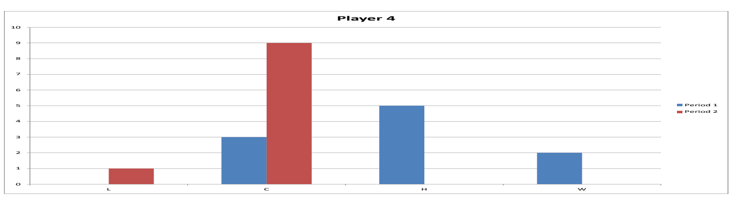

Figure 48: Bar chart of player four's quantity choices

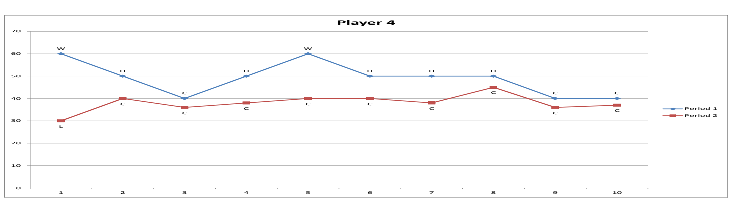

Figure 49: Time series for all 10 games of quantity choices of player four

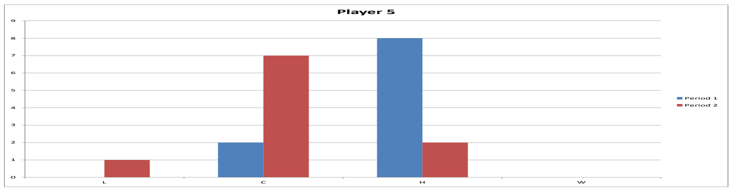

Figure 50: Bar chart of player five's quantity choices

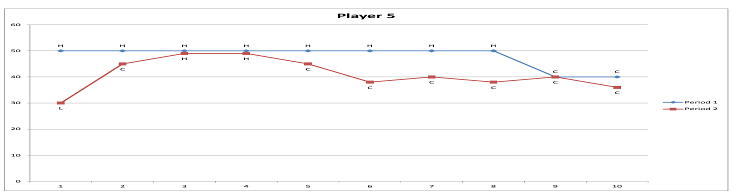

Figure 51: Time series for all 10 games of quantity choices of player five

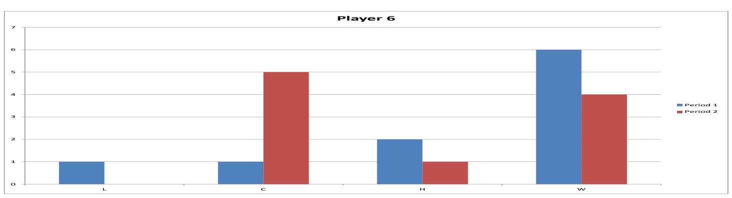

Figure 52: Bar chart of player six's quantity choices

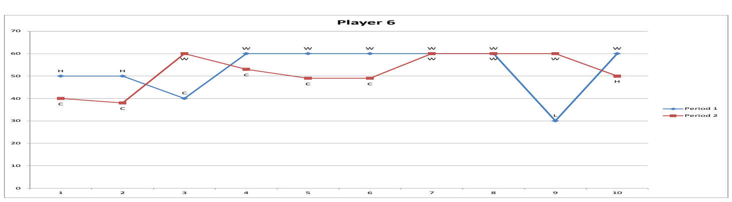

Figure 53: Time series for all 10 games of quantity choices of player six

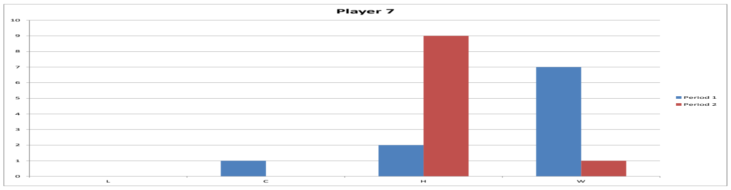

Figure 54: Bar chart of player seven's quantity choices

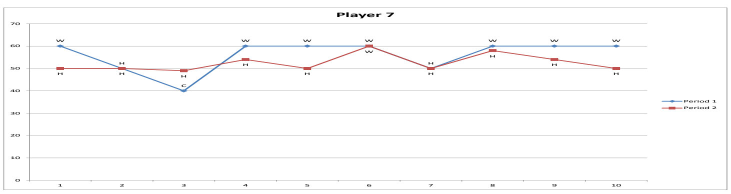

Figure 55: Time series for all 10 games of quantity choices of player seven

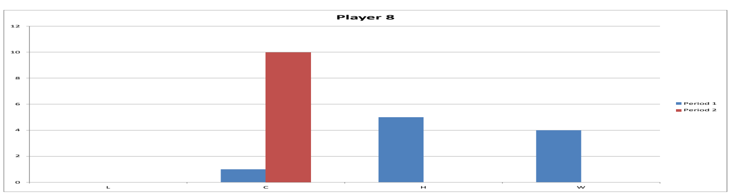

Figure 56: Bar chart of player eight's quantity choices

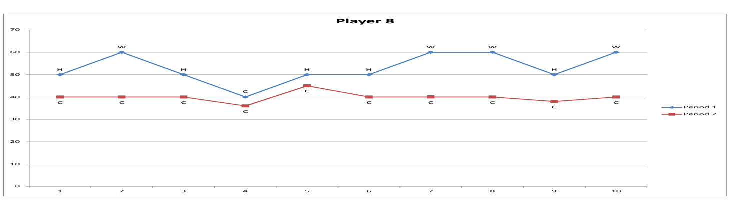

Figure 57: Time series for all 10 games of quantity choices of player eight

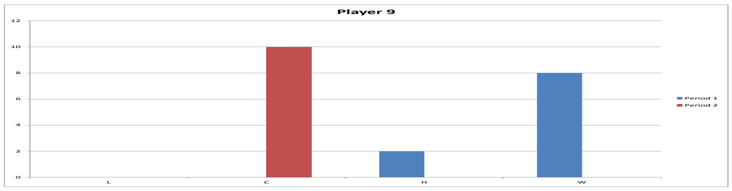

Figure 58: Bar chart of player nine's quantity choices

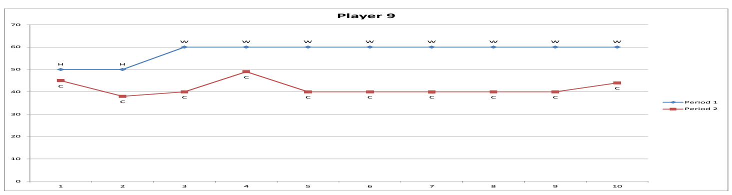

Figure 59: Time series for all 10 games of quantity choices of player nine

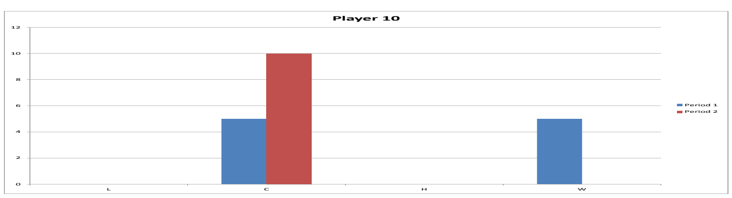

Figure 60: Bar chart of player ten's quantity choices

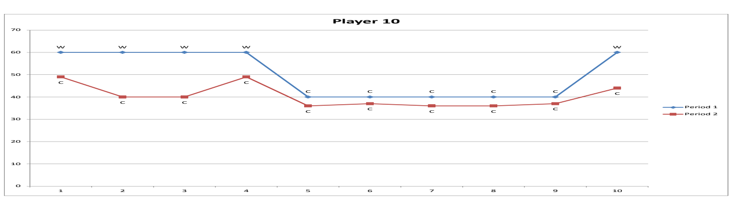

Figure 61: Time series for all 10 games of quantity choices of player ten

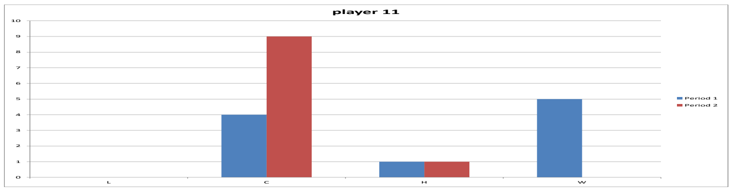

Figure 62: Bar chart of player eleven's quantity choices

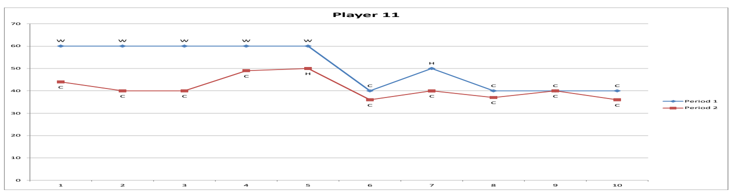

Figure 63: Time series for all 10 games of quantity choices of player eleven

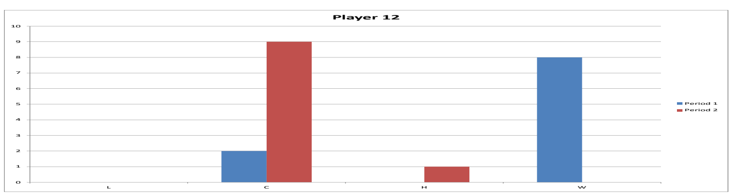

Figure 64: Bar chart of player 12's quantity choices

Figure 65: Time series for all 10 games of quantity choices of player 12

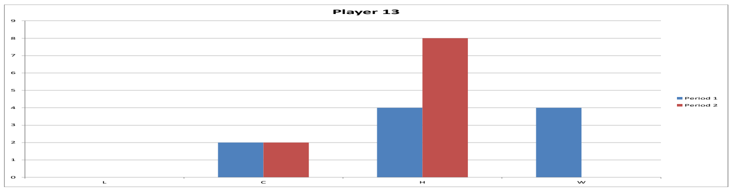

Figure 66: Bar chart of player 13's quantity choices

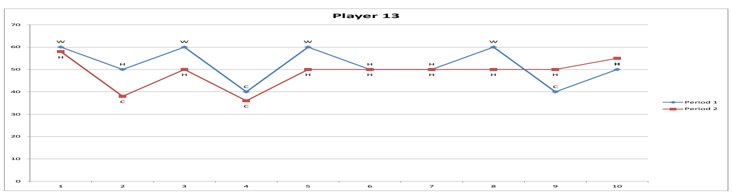

Figure 67: Time series for all 10 games of quantity choices of player 13

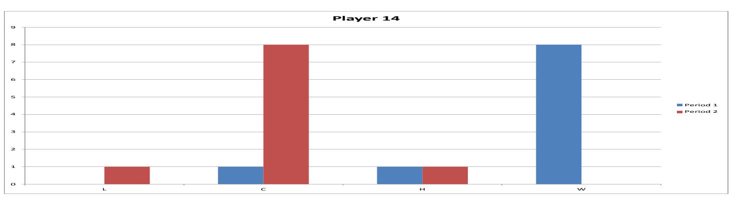

Figure 68: Bar chart of player 14's quantity choices

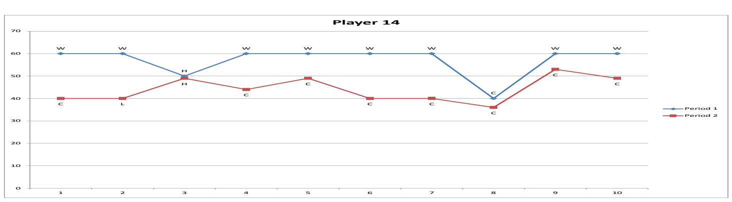

Figure 69: Time series for all 10 games of quantity choices of player 14

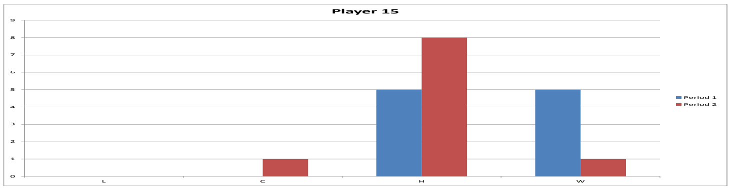

Figure 70: Bar chart of player 15's quantity choices

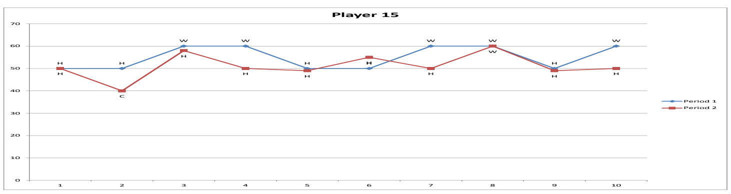

Figure 71: Time series for all 10 games of quantity choices of player 15

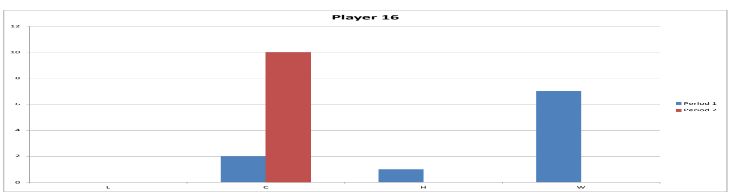

Figure 72: Bar chart of player 16's quantity choices

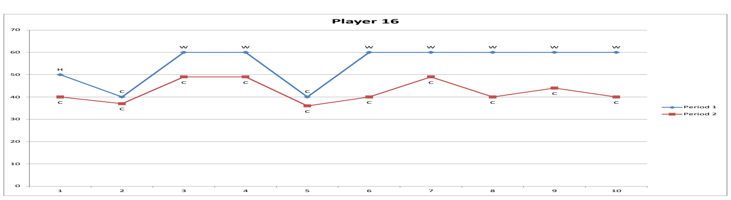

Figure 73: Time series for all 10 games of quantity choices of player 16

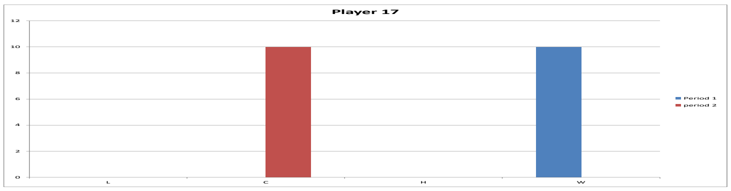

Figure 74: Bar chart of player 17's quantity choices

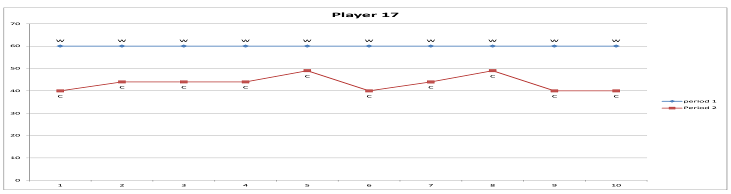

Figure 75: Time series for all 10 games of quantity choices of player 17

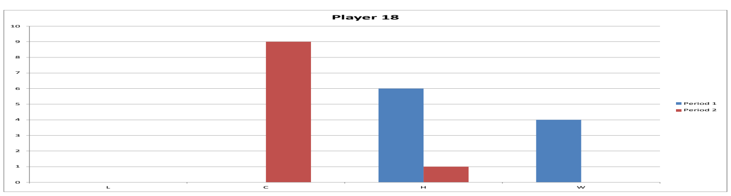

Figure 76: Bar chart of player 18's quantity choices

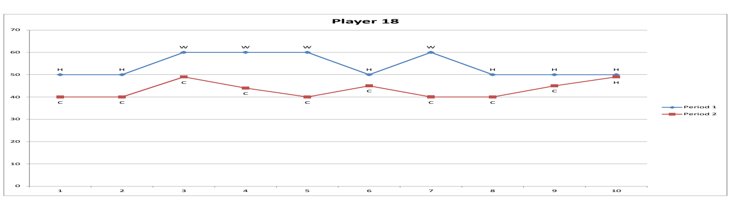

Figure 77: Time series for all 10 games of quantity choices of player 18

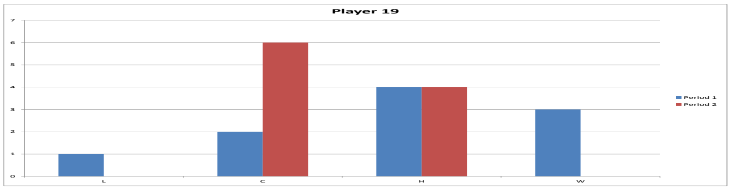

Figure 78: Bar chart of player 19's quantity choices

Figure 79: Time series for all 10 games of quantity choices of player 19

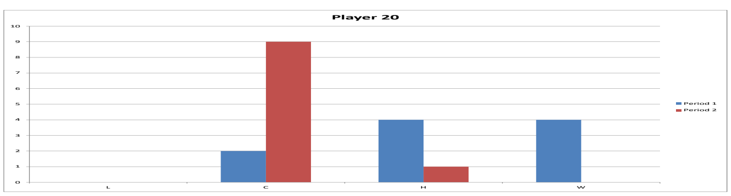

Figure 80: Bar chart of player 20's quantity choices

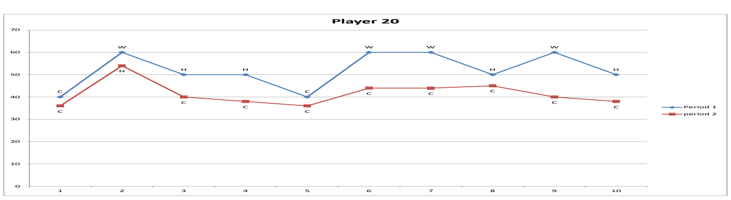

Figure 81: Time series for all 10 games of quantity choices of player 20

J Individual Behavior Stackelberg Game

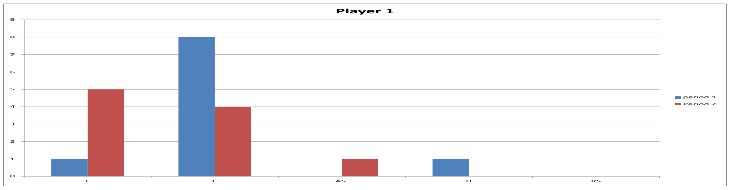

Figure 82: Bar chart of player one's quantity choices (Stackelberg Game)

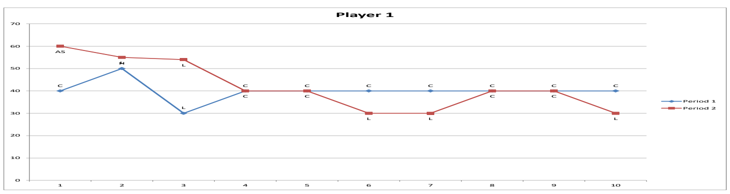

Figure 83: Time series for all 10 games of quantity choices of player one (Stackelberg Game)

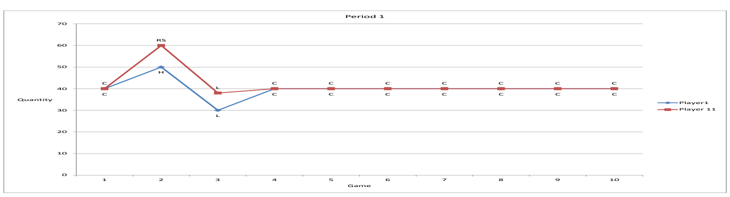

Figure 84: Strategies Player 1 and 11 Period 1 (Stackelberg Game)

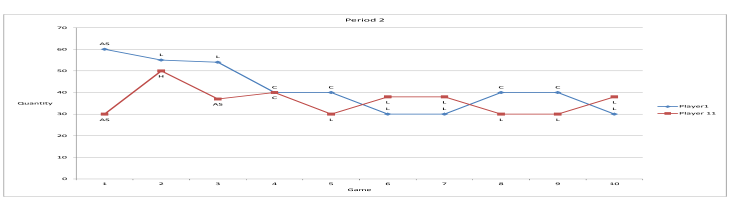

Figure 85: Strategies Player 1 and 11 Period 2 (Stackelberg Game)

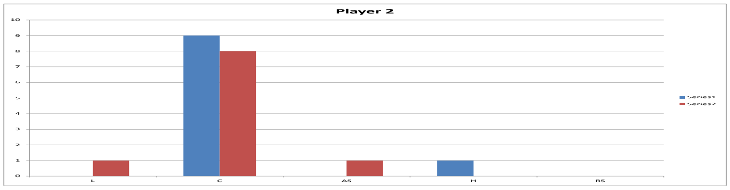

Figure 86: Bar chart of player two's quantity choices (Stackelberg Game)

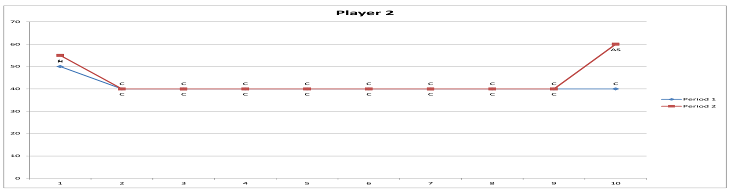

Figure 87: Time series for all 10 games of quantity choices of player two (Stackelberg Game)

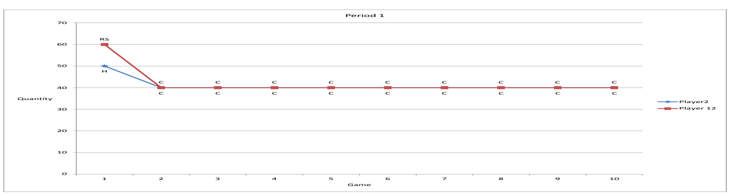

Figure 88: Strategies Player 2 and 12 Period 1 (Stackelberg Game)

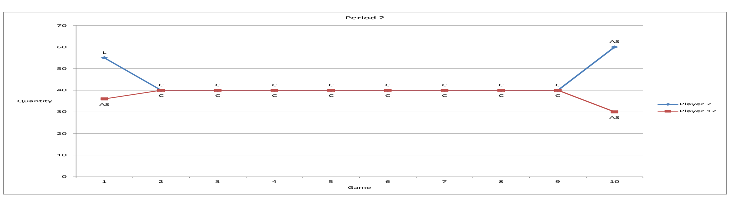

Figure 89: Strategies Player 2 and 12 Period 2 (Stackelberg Game)

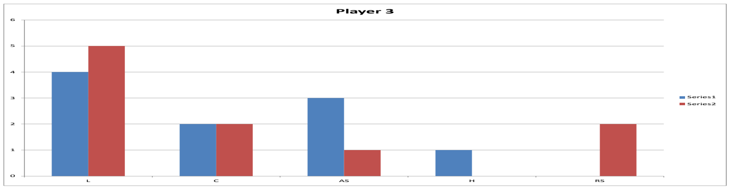

Figure 90: Bar chart of player three's quantity choices (Stackelberg Game)

Figure 91: Time series for all 10 games of quantity choices of player three (Stackelberg Game)

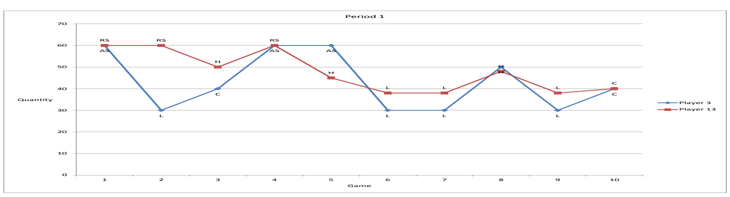

Figure 92: Strategies Player 3 and 13 Period 1 (Stackelberg Game)

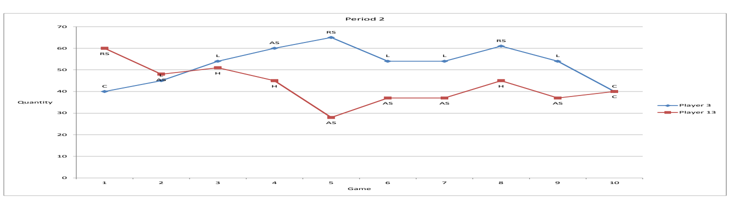

Figure 93: Strategies Player 3 and 13 Period 2 (Stackelberg Game)

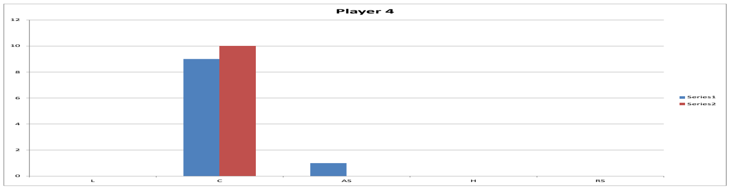

Figure 94: Bar chart of player four's quantity choices (Stackelberg Game)

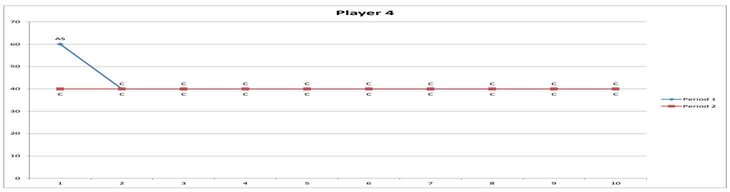

Figure 95: Time series for all 10 games of quantity choices of player four (Stackelberg Game)

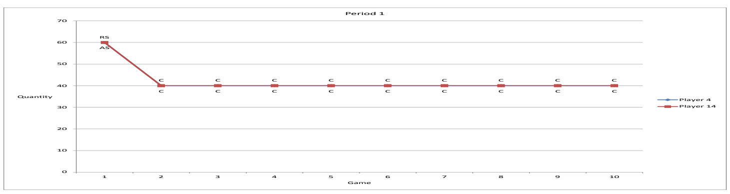

Figure 96: Strategies Player 4 and 14 Period 1 (Stackelberg Game)

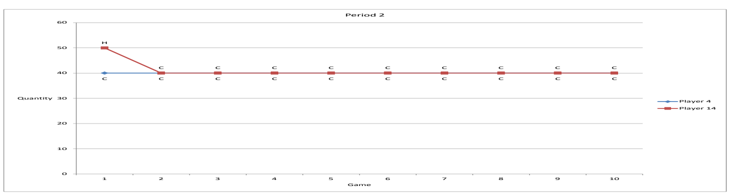

Figure 97: Strategies Player 4 and 14 Period 2 (Stackelberg Game)

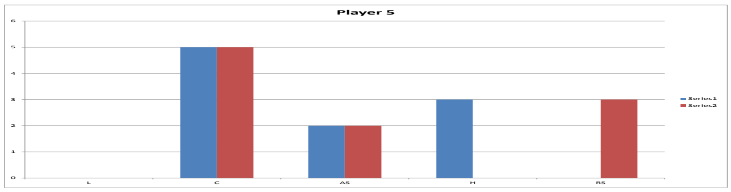

Figure 98: Bar chart of player five's quantity choices (Stackelberg Game)

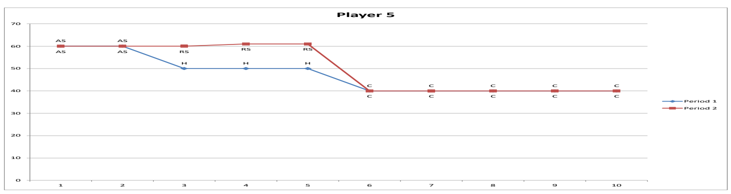

Figure 99: Time series for all 10 games of quantity choices of player five (Stackelberg Game)

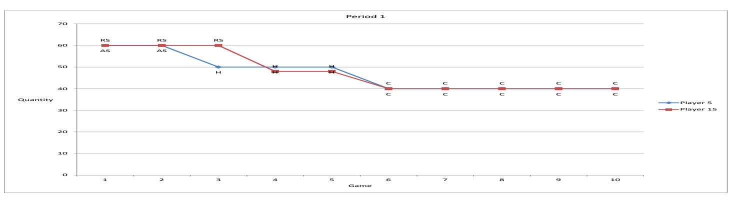

Figure 100: Strategies Player 5 and 15 Period 1 (Stackelberg Game)

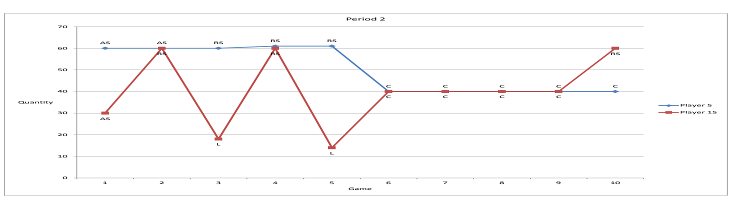

Figure 101: Strategies Player 5 and 15 Period 2 (Stackelberg Game)

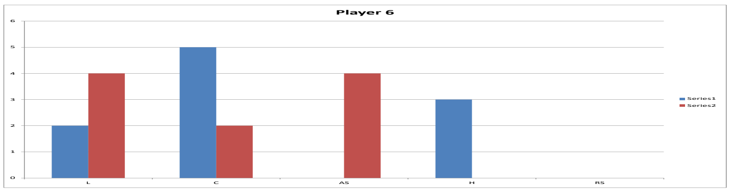

Figure 102: Bar chart of player six's quantity choices (Stackelberg Game)

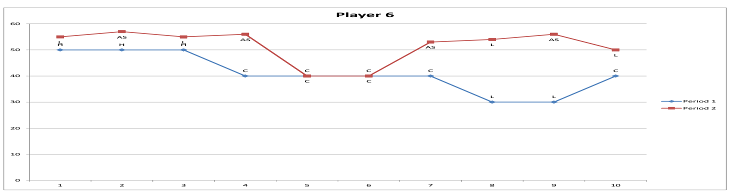

Figure 103: Time series for all 10 games of quantity choices of player six (Stackelberg Game)

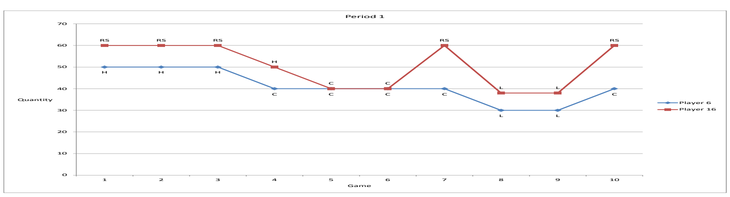

Figure 104: Strategies Player 6 and 16 Period 1 (Stackelberg Game)

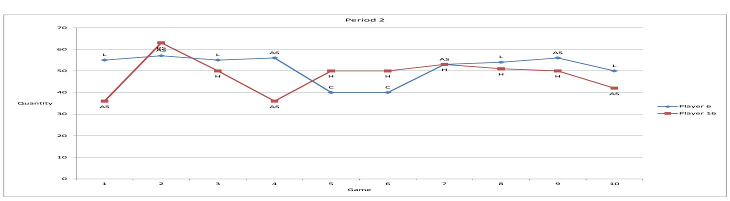

Figure 105: Strategies Player 6 and 16 Period 2 (Stackelberg Game)

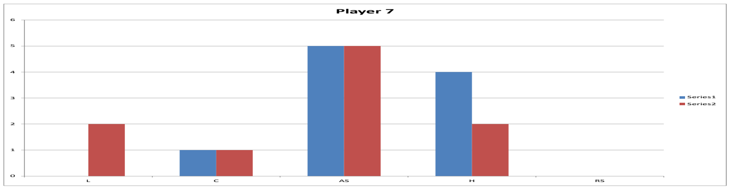

Figure 106: Bar chart of player seven's quantity choices (Stackelberg Game)

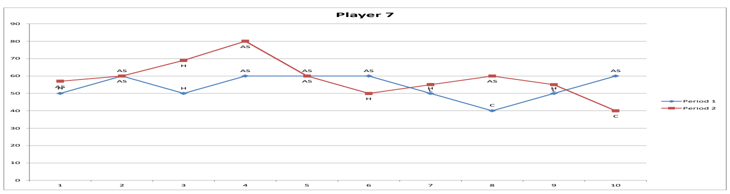

Figure 107: Time series for all 10 games of quantity choices of player seven (Stackelberg Game)

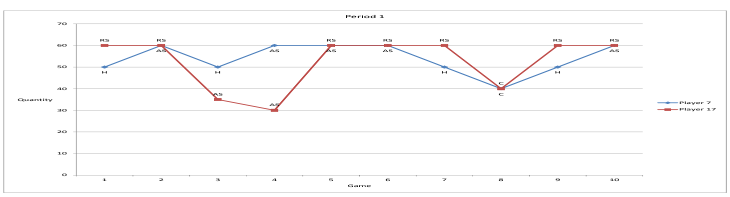

Figure 108: Strategies Player 7 and 17 Period 1 (Stackelberg Game)

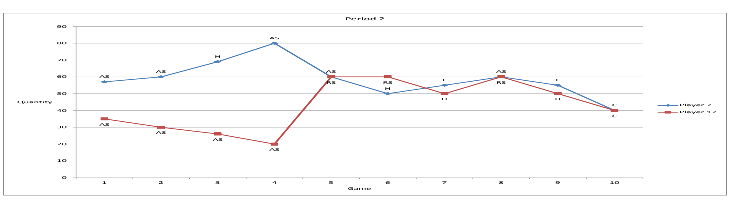

Figure 109: Strategies Player 7 and 17 Period 2 (Stackelberg Game)

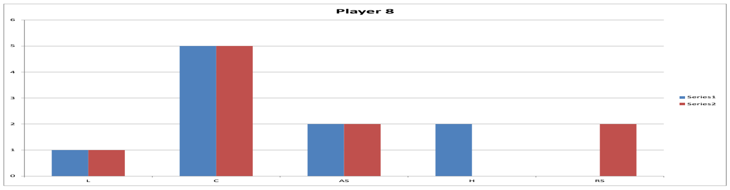

Figure 110: Bar chart of player eight's quantity choices (Stackelberg Game)

Figure 111: Time series for all 10 games of quantity choices of player eight (Stackelberg Game)

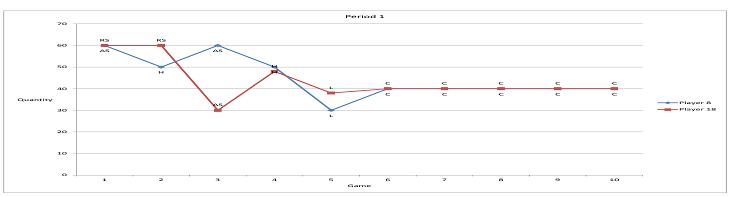

Figure 112: Strategies Player 8 and 18 Period 1 (Stackelberg Game)

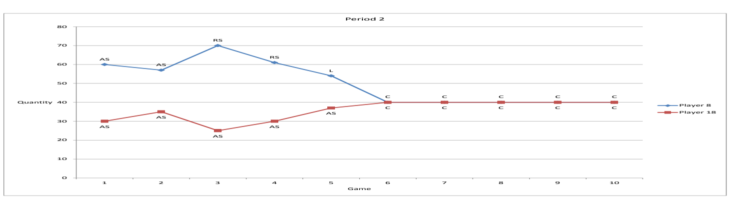

Figure 113: Strategies Player 8 and 18 Period 2 (Stackelberg Game)

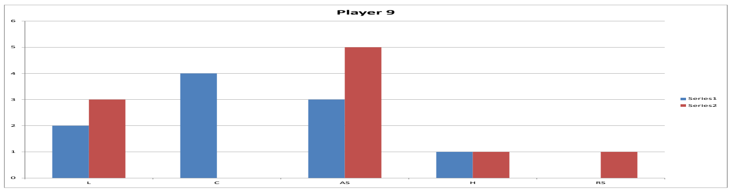

Figure 114: Bar chart of player nine's quantity choices (Stackelberg Game)

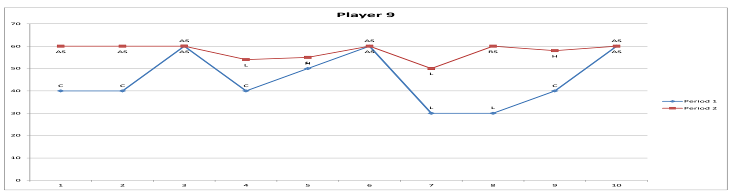

Figure 115: Time series for all 10 games of quantity choices of player nine (Stackelberg Game)

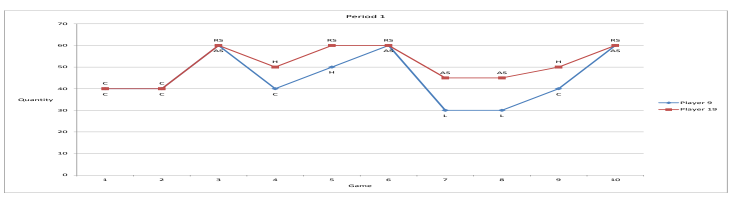

Figure 116: Strategies Player 9 and 19 Period 1 (Stackelberg Game)

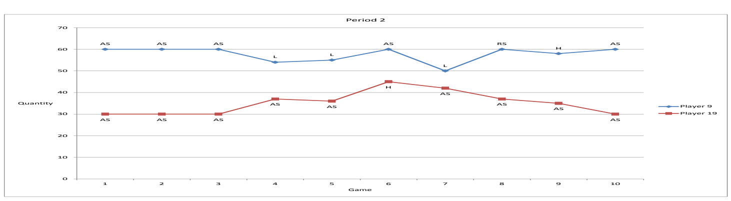

Figure 117: Strategies Player 9 and 19 Period 2 (Stackelberg Game)

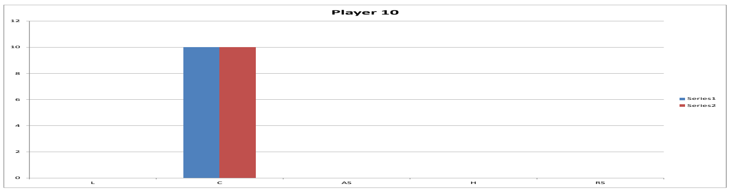

Figure 118: Bar chart of player ten's quantity choices (Stackelberg Game)

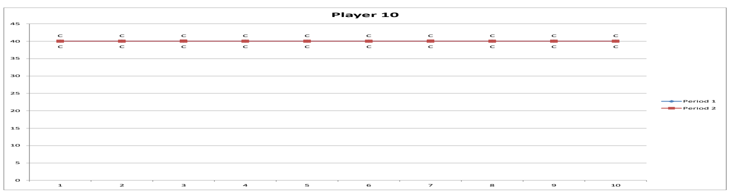

Figure 119: Time series for all 10 games of quantity choices of player ten (Stackelberg Game)

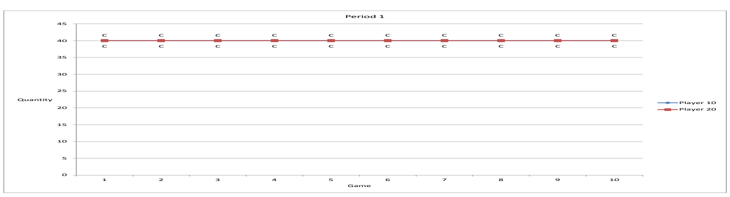

Figure 120: Strategies Player 10 and 20 Period 1 (Stackelberg Game)

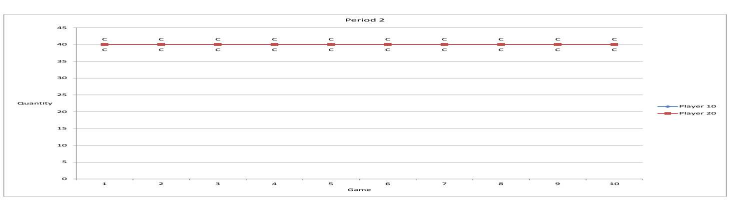

Figure 121: Strategies Player 10 and 20 Period 2 (Stackelberg Game)

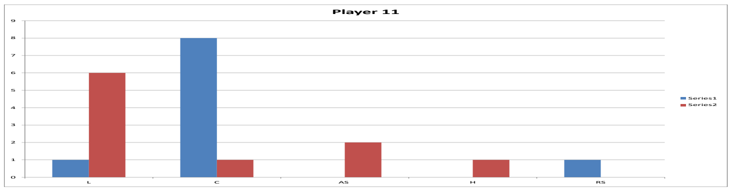

Figure 122: Bar chart of player eleven's quantity choices (Stackelberg Game)

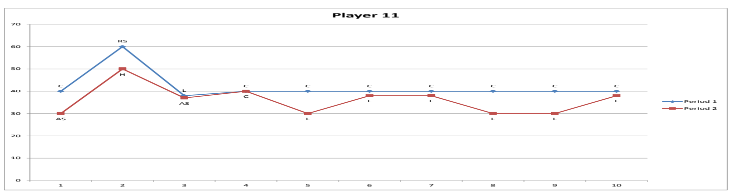

Figure 123: Time series for all 10 games of quantity choices of player eleven (Stackelberg Game)

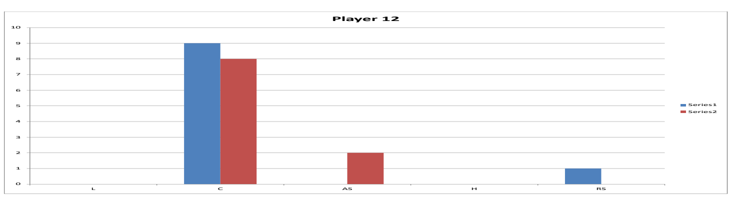

Figure 124: Bar chart of player 12's quantity choices (Stackelberg Game)

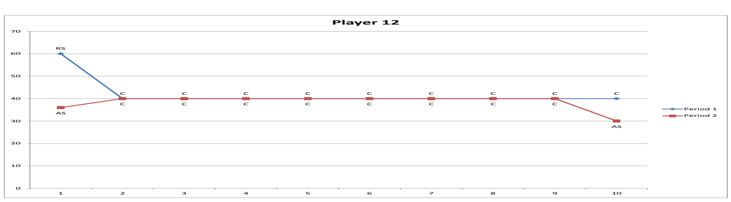

Figure 125: Time series for all 10 games of quantity choices of player 12 (Stackelberg Game)

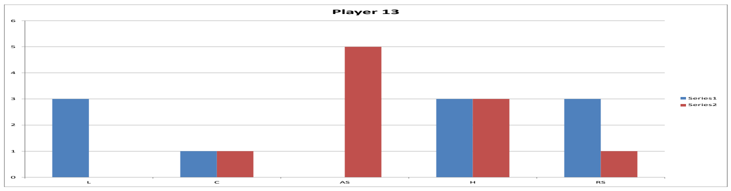

Figure 126: Bar chart of player 13's quantity choices (Stackelberg Game)

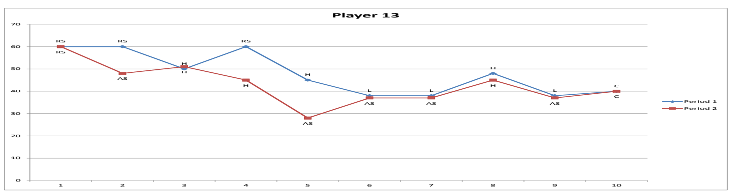

Figure 127: Time series for all 10 games of quantity choices of player 13 (Stackelberg Game)

Figure 128: Bar chart of player 14's quantity choices (Stackelberg Game)

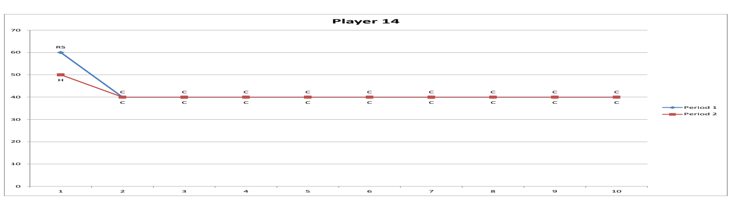

Figure 129: Time series for all 10 games of quantity choices of player 14 (Stackelberg Game)

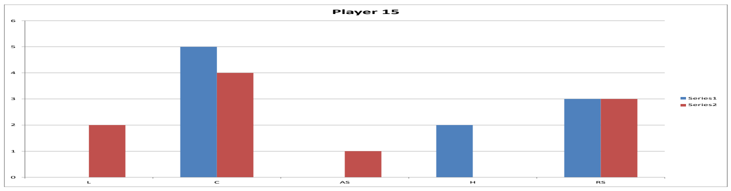

Figure 130: Bar chart of player 15's quantity choices (Stackelberg Game)

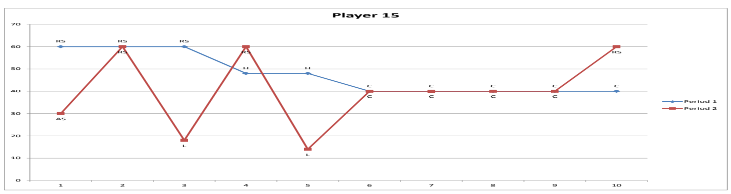

Figure 131: Time series for all 10 games of quantity choices of player 15 (Stackelberg Game)

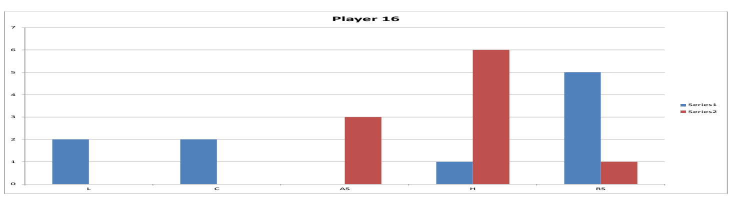

Figure 132: Bar chart of player 16's quantity choices (Stackelberg Game)

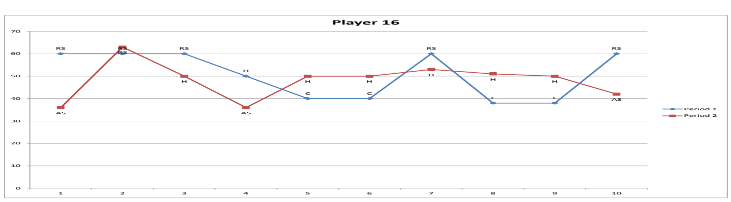

Figure 133: Time series for all 10 games of quantity choices of player 16 (Stackelberg Game)

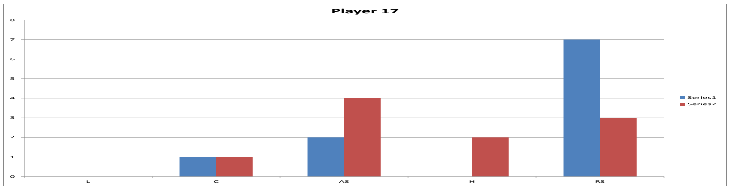

Figure 134: Bar chart of player 17's quantity choices (Stackelberg Game)

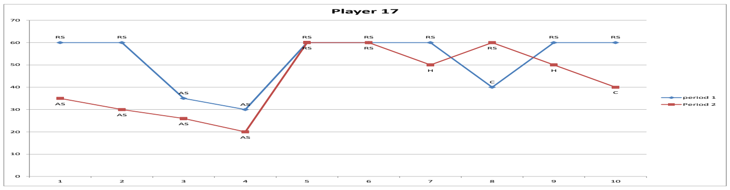

Figure 135: Time series for all 10 games of quantity choices of player 17 (Stackelberg Game)

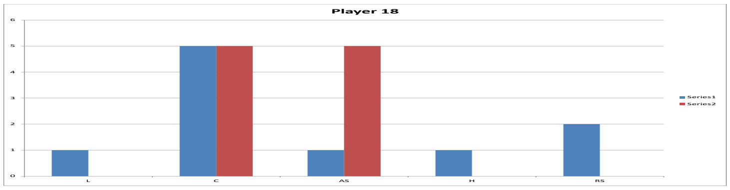

Figure 136: Bar chart of player 18's quantity choices (Stackelberg Game)

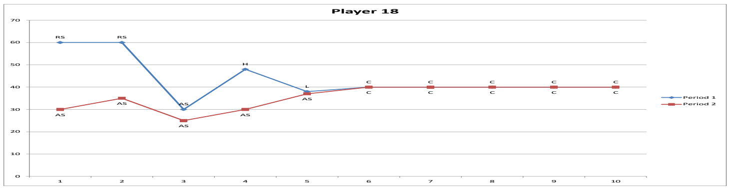

Figure 137: Time series for all 10 games of quantity choices of player 18 (Stackelberg Game)

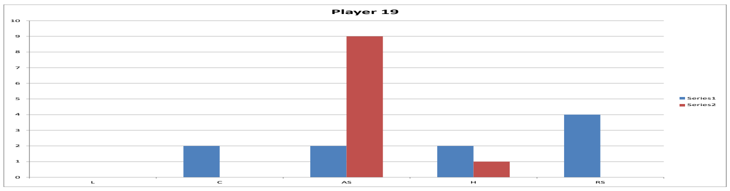

Figure 138: Bar chart of player 19's quantity choices (Stackelberg Game)

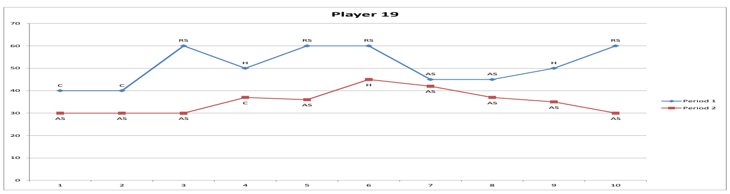

Figure 139: Time series for all 10 games of quantity choices of player 19 (Stackelberg Game)

Figure 140: Bar chart of player 20's quantity choices (Stackelberg Game)

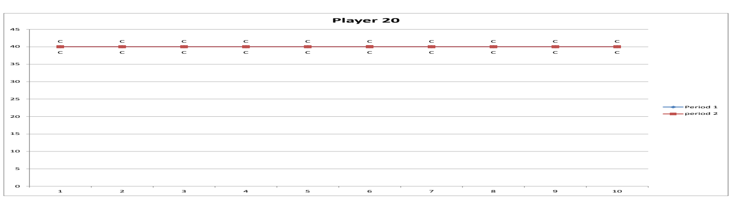

Figure 141: Time series for all 10 games of quantity choices of player 20 (Stackelberg Game)

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