Action revision, information and collusion in an experimental duopoly market

Nilanjan Roy

City University of Hong Kong

23 February 2017

Action Revision, Information and Collusion in an Experimental Duopoly Market *

Nilanjan Roy†

February 23, 2017

Abstract

We report on an experiment designed to study a dynamic model of quantity competition where firms continuously revise their production targets prior to the play of the "one-shot" game. We investigate how the observability of rival firm's plans and the technology for implementation of revised actions affect market competitiveness. Under a real-time revision game where payoffs are determined only by the quantities prepared at the end, play converges to the Cournot-Nash output when rival's plans are unobservable. If plans cannot be hidden from competitors, choices are even more competitive than the static Nash equilibrium, thereby showing a negative value of information with lower profits. With stochastic revision, where opportunities to revise arrive according to a Poisson process and the quantities selected at the last opportunity are implemented, collusion is much frequent. This shows, more generally, that cooperation can be observed even when individuals interact only once.

JEL Classification Numbers: C72, C92, D22, D43, D83, L13

Keywords: Cournot duopoly, real-time revision, stochastic revision, experiment, information, imitation, best response.

---

*I gratefully acknowledge the financial support from City University of Hong Kong and the Gordon and Betty Moore Foundation. I am thankful to Thomas Palfrey for the generous support for running the experiments at the Social Science Experimental Laboratory (SSEL), California Institute of Technology, USA and Chris Crabbe for developing the experimental software. The paper benefited from discussions during presentations at several conferences and seminars. Peter Bossaerts, Federico Echenique, Yuichiro Kamada, Michihiro Kandori, Stefano Lovo and Thomas Palfrey provided valuable suggestions.

†Department of Economics and Finance, College of Business, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon Tong, Hong Kong

1 Introduction

Strategic interactions are typically modeled using simultaneous one-shot games in economics. Even though the interaction might happen only once and payoffs are realized through a one-time play of the game, the actions chosen by the players are normally the result of a long preparation process. Static one-shot models fail to capture this underlying (and often complex) dynamics that are generally present in the process of deliberation before players finally "settle" for an action choice. In this paper, we analyze a dynamic model of quantity competition, where firms can continuously adjust their production targets during a revision phase that precedes the one-time play of the game.

Announcing plans and revision of production targets happens in the production industry where firms compete in quantity.[1] Although production is made at the end, there are several factors that might influence the final quantity of output produced. Demand and cost uncertainty, information about competitor's planned production, capacity constraints and other reasons might make the final choice of production different from the initial plans. We use a laboratory experiment to analyze the impact of introducing action revision on the final quantities implemented and on market competitiveness in a Cournot duopoly. In the laboratory, one can not only observe and control key variables, including the information feedback available to players, but also replicate a given scenario multiple times and make causal inferences. We study two types of games that differ in the technology of implementation of revised actions:

- Real Time Revision- Firms continuously announce quantities that they desire to produce. Player payoffs are determined only by the choices selected at the end of the revision phase.

- Stochastic Revision- Although firms post their desired quantities in real time, opportunities to revise choices arrive according to a synchronous Poisson process and players' payoffs are given by the desired quantities selected at the last revision opportunity.

The stochastic revision game provides a stylized representation of situations where communication and implementation occur at different times, possibly due to delays. It models the inefficiencies or imperfections in implementing the intended choices. On the other hand, real time revision game implements intended actions without any imperfection. Stochastic

[1]It is very common to announce plans for the production of cars few months ahead of actual production in the US motor vehicle and aircraft industries. The trade journal *Ward's Automotive Reports* publishes the firm's announcements of their plans for monthly U.S. production of cars as early as six months before actual production and these plans could be continuously revised until the end of the target month.

revision games are theoretically introduced in Kamada and Kandori (2015) where the authors show that the addition of the revision phase can widen the set of achievable payoffs as compared to the static game without any such pre-play phase. Calcagno et al. (2014) demonstrate that the revision phase can narrow down the set of achievable payoffs in games of coordination. Doyle and Snyder (1999) study the role of revision phase as information sharing tool using panel data from the U.S. automobile industry. In a quantity setting game, Caruana and Einav (2008) develop a theoretical model of real time revision in quantity choices with convex adjustment costs.[2]

Revision of actions is a phenomenon that is practiced in some of the financial markets as well, such as Nasdaq and Euronext. Prior to opening of the market, participants are allowed to submit orders which can be continuously withdrawn and changed until the opening time. During the entire preopening phase, these orders and resulting prices are publicly posted but only the orders that are still posted at the opening time are binding and are executed. Traders do not always manage to withdraw and submit new orders simultaneously due to technological and other reasons. While these preopening mechanisms are theoretically studied in Vives (1995) and Calcagno and Lovo (2010), empirical investigations are documented in Biais et al. (1999) and Cao et al. (2000). Biais et al. (2014) experimentally analyze how to design preopening mechanisms that facilitate coordination on high equilibrium liquidity and gains from trade.

By varying the assumption on the ability to observe rival's plans, we are also able to answer whether market competitiveness is different with observable plans than when rivals plans are hidden. Is information valuable in raising firms' profits? Previous literature has explored the value of information as well as the incentives to share information in oligopolistic markets. See Fried (1984), Sakai (1985), Gal-Or (1985, 1987, 1988), Raith (1996), Einy et al. (2002), Myatt and Wallace (2015) for theoretical models in this field. Information here typically refers to the knowledge about the underlying demand or cost parameter. Some studies have investigated the impact of asymmetries in information and cost in experimental duopolies (Mason et al. (1992), Mason and Phillips (1997), Fonseca et al. (2005)). In the context of learning in Cournot oligopoly, Huck et al. (1999) study experimental markets where they vary information about demand and cost conditions as well as about the quantities and profits of other firms across decision rounds. In contrast to the above papers, information in our model refers to the observability of rival's prepared actions or production targets during

[2]As our focus is on the role of revision technology on the market competitiveness, we abstract away from any explicit costs of quantity adjustment. Revisions are, however, costly in the stochastic revision game as choices are binding with some probability. Commitment is introduced in our model by the choice of the revision technology.

the revision phase.

Although related to cheap-talk, the real time revision phase differs considerably from the former in that no external language of communication is used during the revision phase. Players are allowed to signal their intentions or desired choice of actions, but they cannot send any message or participate in any other explicit form of communication. For the stochastic revision games, although the revisions are costless and there is no explicit cost of revising quantities, players face exogenous uncertainty about the effectiveness of the revision. Choices are now binding with some exogenous probability.

Real time revision mechanism has been investigated experimentally in the context of public good provision (Dorsey (1992), Goren et al. (2003, 2004), Duffy et al. (2007), Kurzban et al. (2001)) and coordination in a minimum-effort game (Deck and Nikiforakis (2012)). In contrast, we study the effect of both real time revision and stochastic revision in a quantity-setting game. We are unaware of any paper that analyzes stochastic revision in the laboratory.

The Cournot duopoly game can be used to study cooperation between two individuals, similar to the prisoner's dilemma game.[3] There is a tension between what is efficient for the industry and what is individually best given that the other firm chooses the cooperative action. This allows us to interpret our research question more generally as follows: in the absence of explicit communication, can cooperation be observed when individuals interact only once?[4]

There have been numerous experiments conducted on Cournot duopolies and the basic conclusion is that while a random matching scheme results in play converging to the Cournot-Nash equilibrium, some degree of collusion often arises in repeated Cournot settings with a fixed pair of participants (Fouraker and Siegel (1963), Holt (1985), Huck et al. (2001), Huck et al. (2004)).[5] These studies however generally do not allow communication between the players.

Balliet (2010) provides a meta-analysis of communication and cooperation in social dilemmas and concludes that there is a large positive effect of communication on cooperation in these situations. Non-binding pre-play communication (or cheap talk) has been shown to facilitate collusive play in oligopoly markets, mostly in repeated settings ((Friedman (1967), Daughety and Forsythe (1987a, 1987b), Brown-Kruse et al. (1993), Fonseca and Normann

[3]The unique equilibrium outcome is inefficient in the Cournot game as there exist other action profiles that have higher joint profits than under the choice of Nash equilibrium actions.

[4]The interaction among players occurs only once in the sense that the payoffs are determined by the one-time play of the game among the players.

[5]For an overview of papers employing laboratory experiments to study oligopoly markets, see Potters and Suetens (2013).

(2012), Cooper and Kuhn (2014), Waichman et al. (2014)).[6] As opposed to cheap talk, we study the role of intention signaling in oligopoly markets in real time as players prepare their actions in one-shot games.

2 Markets, Treatments, and Theoretical Predictions

The experiment uses the Cournot duopoly model of quantity competition. There are two firms, firm 1 and firm 2, producing and selling a homogeneous product in a market. Each firm's decision is to choose an output level, $q_i \in [0, 50]$. They face a linear inverse demand:

$$P(Q) = max\{50 - Q, 0\}, \quad Q = q_1 + q_2, \tag{1}$$

while the cost function for each firm is given by

$$C_i(q_i) = 2q_i, \quad i = 1, 2. \tag{2}$$

In this static model where firms decide simultaneously, the Nash equilibrium play implies $q_i^{CNE} = 16, i = 1, 2$ and the joint profit maximization implies an aggregate market quantity of $Q^{JPM} = 24$. On a symmetric Cournot market, the symmetric joint profit maximizing output is $q_i^{JPM} = 12, i = 1, 2$. The perfectly competitive Walrasian output is $q_i^{PCW} = 24, i = 1, 2$ where price equals the marginal cost. With perfect collusion, market price is 18. On the other hand, at the Nash equilibrium, price is 26. Market profit equals 512 under perfectly collusive play and 576 if firms choose the Cournot-Nash quantity.

A standard measure of collusion consists in measuring the extent to which firms manage to increase their profits above the Nash equilibrium profits and come closer to cartel profits (Holt (1995), Argenton and Müller (2012)). The collusion index (θ) is defined as follows:

$$\theta = \frac{\pi - \pi^{CNE}}{\pi^{JPM} - \pi^{CNE}},$$

where π stands for the market profits actually achieved, π^{CNE} is the market profit at the Nash equilibrium, and π^{JPM} stands for the maximum possible market profits.[7]

A planning phase is added to the static model described above where firms can revise their production targets. Three markets are considered that differ in the assumption regarding the observability of rival's revised plans and the type of technology used to implement the

[6] Few studies have shown positive effect of cheap talk on cooperation in social dilemmas under one-shot setting with random rematching of participants. See Duffy and Feltovich (2002) and Palfrey et al. (2015).

[7] $\theta = 1$ at the perfectly collusive individual output of 12 and $\theta = 0$ if both firms choose 16 each.

revisions of quantity choices by the firms.

Baseline Market: Hidden Plans

In this baseline market, the Cournot game is played at time T. However, firms could adjust their quantity choices in a costless manner in real time from $t = 0$ to $t = T$. The output choice that is actually implemented is the one that corresponds to time $t = T$ (perfect implementation), but, the firms are unable to observe their competitor's choices and adjustments over time. Only at the very end does a firm get to observe the implemented choice of the other firm. With hidden plans, there is no informational feedback during the planning phase. Thus, this scenario is strategically equivalent to the static simultaneous-move Cournot game. The static game is implemented in this manner instead of the usual one-shot version to make every aspect comparable to the other markets, except for the observability of competitor's choices. In this game, similar to the one-shot game, there is an unique Nash equilibrium of $q_i^* = 16, i = 1, 2$ at time T. This gives rise to the first hypothesis as follows.

Hypothesis 1. *The collusion index equals zero in the baseline market.*

Real Time Revision Market

In this market, firms can not only adjust their quantity choices in real time until time reaches T but also observe the output revisions of their competitor in real time. Again the output choices corresponding to time $t = T$ are implemented. Since the choices at any time $t < T$ are not binding, the entire phase $[0, T)$ constitutes a "cheap talk" period where the language of communication is the intended quantity that a firm wishes to produce at time T. There is still a unique Nash equilibrium prediction of $q_i^* = 16, i = 1, 2$ at time T regardless of the dynamics of revisions during $t \in [0, T)$. This is because at time T there is no future and the unique mutual best response is at the quantity level of 16. This leads to the following hypothesis.

Hypothesis 2. *The extent of collusion is the same between baseline and real time revision markets.*

Stochastic Revision Market

Firms submit their intended quantity choices "continuously" in this market and a synchronous stochastic process determines which quantity choices are implemented at time T. Specifically, there is a Poisson process with an arrival rate $\lambda > 0$ defined over the time interval $[0, T)$ and the intended choices corresponding to the last time the process takes place are implemented at time T. Both the firms observe all the past events including the "continuous" revision plans. Thus, while there is perfect observability of rival's prepared plans, the implementation of adjusted choices is imperfect, unlike the *real time revision* market.

The revision phase $[0, T)$ is now different from a "cheap talk" period because revisions are now binding with some exogenous probability. In this game of stochastic revision, Kamada and Kandori (2015) identify symmetric equilibria that use trigger strategies.[8] Each of these equilibria prescribes an action path $q(t)$ which implies that when a revision opportunity arrives at time t, players are supposed to choose the quantity $q(t)$, given that there have been no deviations in the past. If any player deviates and does not choose $q(t)$, then in the future players choose the Nash equilibrium quantity of the Cournot game, whenever a revision opportunity arrives. They identify the optimal symmetric trigger strategy equilibrium that achieves (ex ante) the highest payoffs in this class of equilibrium.

Kamada and Kandori (2015) characterize action paths that are continuous in time and lie in $[12, 16]$, i.e., it never prescribes a quantity that is lower than the individual collusive outcome of $q^m = \frac{24}{2} = 12$ and higher than the Nash equilibrium output of 16. At the beginning of the revision phase, players start with quantities lower than the static Nash equilibrium output of 16 and remains there till a cut-off time. From the cut-off time onward, players start adjusting their quantities upwards.

While there are multiple trigger strategy equilibria in this game, at the optimal symmetric trigger strategy equilibrium, players start with the best symmetric action which is the individual collusive output of 12. They do not revise their quantity plans (even if revision opportunities arrive) till a cut-off time. After this time, they choose the optimal path given by $q(t)$ whenever a revision opportunity arrives. The closer the revision opportunity is to the end of the revision phase, the closer the revised quantity is to the Nash equilibrium output of 16. When the revision phase is over and the game ends, the quantities chosen at the last revision opportunity are implemented.[9]

As the quantities implemented are determined by the last time the Poisson process takes place and not by the choices prepared at the end of the revision phase, these equilibria generally predict lower levels of output to be chosen (in expectation) than the Cournot-Nash equilibrium and hence, the following hypothesis is obtained.

Hypothesis 3. *The extent of collusion is higher in the stochastic revision market than*

[8] Kamada and Kandori (2015) analyze a general class of games that satisfy a set of conditions. The Cournot duopoly game that is studied here satisfies all these conditions. Kamada and Kandori (2015) assume continuous action spaces. In the experiments, subjects could choose any quantity in $[0, 50]$ with increments of 0.1, which is "almost" continuous.

[9] For calculation of the optimal trigger strategy equilibrium path using differential equation and other details, see Kamada and Kandori (2015).

either baseline or real time revision markets.

The characteristics of the three markets are summarized in Table 1.

Market	Rival's Plans	Revision Implementation
Baseline	Hidden	Perfect
Real Time Revision	Observable	Perfect
Stochastic Revision	Observable	Imperfect

Table 1: Market Characteristics

3 Methods and Procedures

The experiments were conducted at the Social Science Experimental Laboratory (SSEL), California Institute of Technology (Caltech) using the Multistage software package. Subjects were recruited from a pool of volunteer subjects, maintained by the SSEL. Eight sessions were run, using a total of 96 subjects. No subject participated in more than one session. A total of three treatments were generated, each with a revision phase of 120 seconds: *baseline* (two sessions), *real time revision* (two sessions), and *stochastic revision* (four sessions).[10]

On arrival, instructions were read aloud.[11] Subjects interacted anonymously with each other through computer terminals. There was no possibility of any kind of communication between the subjects, except as explained in the instructions. Each session had exactly 12 participants and it lasted between 45 and 50 minutes. Average earnings were US$19. Each subject also received an additional US$5 show-up fee.

In the instructions subjects were told that they were to act as a seller which, together with another seller, produces the same product in a market and that, in each round, both have to decide what quantity to produce. They were also informed that every round they would be matched to a new participant from the room and thus, they would not be matched with the same person ever again. This was done to eliminate the reputation and super-game effects which might occur with repeated play. Each session consisted of eleven rounds.

Participants were provided with a profit sheet and a profit calculator. The profit sheet showed the profits a seller would earn for every possible combination of integer choices (from 0 to 30) by her and the other seller. For integer numbers above 30 or non-integer numbers, they had to use the profit calculator provided on their screens. Each seller could choose an output

[10]In two sessions, the arrival rate of revision opportunities was equal to 0.04 per second while in the other two sessions, this rate was 0.02 per second.

[11]A copy of the instructions is provided in the Appendix.

level from the set $\{0, 0.1, 0.2, ..., 49.8, 49.9, 50\}$ and the payoffs were generated according to the demand and cost functions given in equations (1) and (2). The payoffs were measured in a fictitious currency unit called points and subjects were told that at the end of the experiment they would be paid the US Dollars equivalent of the sum of points earned by them across all rounds. This USD equivalent was determined by using an exchange rate from 150:1.

Subjects were informed that every round they would have 120 seconds to decide the quantity to be produced. At the beginning of this "120 seconds" round they were asked to enter an initial tentative quantity from $\{0, 0.1, 0.2, ..., 49.8, 49.9, 50\}$. Once all the participants in the room made an initial choice, the round started in real time. In the *baseline* treatment, a subject only observed her own tentative quantity. Whenever there was a change in the tentative quantity made by the subject, the screen was updated along with the time at which the change took place. At the end of the revision phase each subject observed not only her tentative quantity but also the quantity of the other seller as well as the profits earned for that round.

In the *real time revision* treatment, a participant gets to see her own tentative quantity, the tentative quantity chosen by her competitor as well as the tentative profits. The screen was updated whenever either of the two matched participants decided to change their respective quantities. Subjects were also told that the word "tentative" reflects the fact that if there were no more changes then the last entry shows the final quantity choice and the amount of profits earned by them for that round.

In the *stochastic revision* treatment, the screen was updated for two separate reasons. First, there was an update if any of the two matched participants changed their respective tentative quantities. This was shown as an "unstarred" entry on the screen. The second type of update was shown with a "starred" entry and it marked the occurrence of an "event" that was responsible for the final quantity choices in a round. Specifically, the final choices and profits for a round were given by the tentative quantities and profits corresponding to the last "starred" entry on the screen. For each pair of participants, the occurrence of this event was decided using a random draw of an integer from an uniform distribution. Thus, the inter-arrival time between the occurrence of this event follows a geometric distribution which is an approximation to the exponential distribution in continuous time.

The user interface or screen display for each treatment is provided in Appendix C.

4 Experimental Results

Comparison of Quantities and Extent of Collusion

The essential statistics is summarized in Tables 2 and 3. Table 2 shows, for each round, the average individual quantities implemented for each treatment. The number of instances where a market achieved the perfectly collusive output of 24 for each treatment is shown in Table 3, which also provides the median collusion index across treatments.

The average quantities selected in the baseline treatment converge to 16, which is the Cournot-Nash equilibrium. The median and mode are exactly equal to 16 in most of the rounds. Over all rounds, only one out of the 132 markets achieve perfect collusion (see Table 3). The median collusion index is zero when considering the last five rounds and all rounds together. Analyzing each round separately, we find that the collusion index cannot be statistically distinguished from zero. The p-values from a two-sided Mann-Whitney U test are > 0.1 for each round.[12] Thus, supporting the first hypothesis, we have the following result.

Result 1. *The average quantity equals the Cournot-Nash output and collusion index is zero in the baseline market.*

In contrast, markets are more competitive under real time revision than under *baseline* treatment. The modal individual quantity chosen is 18 in nine of the eleven rounds and median choice is 18 in the last five rounds (see Table 2). In fact, 18 is the best-response to the rival's choice of 12. While a total of 7 markets achieve perfect collusion, the median collusion index is negative when considering the last five rounds. Table 4 presents the results from round-by-round two-sided Mann-Whitney U test of equality of collusion index between treatments. A comparison of the market collusion index for each round separately is preferred as observations are independent.[13] The difference between *baseline* and *real time revision* starts becoming significant in the latter half of the experiment when subjects have gathered a lot of experience.

Thus, rejecting Hypothesis 2, we have the following result.

Result 2. *The real time revision market results in higher individual quantity and lower collusion index than baseline market.*

Table 2 shows that the modal individual quantity chosen in the majority of the rounds in the *stochastic* market is 12, the symmetric joint profit maximizing output. The median and mean choices decline over rounds as subjects gather more experience. This is in contrast

[12] The p-values are: 0.17, 0.17, 0.3, 0.17, 0.97, 0.31, 0.75, 0.5, 0.75, 0.98, 0.75 for rounds 1-11 respectively.

[13] We use this method of statistical test as individual quantities or average (across rounds) market observations based on pairs are not independent variables.

	Baseline			*Real Time Revision*			*Stochastic Revision*		
Round	Mean (SE)	Median	Mode	Mean (SE)	Median	Mode	Mean (SE)	Median	Mode
1	14.9 (0.6)	15	12	15.3 (0.8)	15	12	16.7 (0.7)	16	16
2	15.6 (0.5)	16	15	15.8 (1.0)	16	18	15.5 (0.5)	15	15
3	15.6 (0.5)	16	16	15.5 (0.7)	15	12	15.9 (0.6)	15.5	12
4	15.4 (0.3)	16	16	16.6 (0.7)	18	18	15.5 (0.6)	15	12
5	15.7 (0.3)	16	16	16.2 (0.6)	16.5	18	15.5 (0.5)	15	12
6	15.5 (0.4)	15.8	15	15.9 (0.6)	16	18	16.3 (1.0)	15	12
7	15.9 (0.3)	16	16	16.9 (0.6)	17.8	18	15.2 (0.4)	15.1	12
8	16.1 (0.2)	16	16	16.7 (0.7)	17	18	14.9 (0.4)	15	12
9	15.9 (0.3)	16	16	17.1 (0.5)	17.5	18	14.6 (0.5)	13.5	12
10	15.8 (0.3)	16	16	17.1 (0.6)	18	18	14.5 (0.8)	12.1	12
11	16.0 (0.2)	16	15	17.5 (0.5)	18	18	14.9 (0.8)	12.8	12
1-6	15.5 (0.4)	16	16	15.9 (0.6)	16	18	15.9 (0.3)	15	12
7-11	15.9 (0.1)	16	16	17.1 (0.3)	18	18	14.8 (0.3)	14	12

Table 2: Mean (standard errors), median and mode of individual quantity implemented by rounds in each treatment. Each round has 24 observations for *Baseline* and *Real Time Revision* each, and 48 observations for *Stochastic Revision*.

	Perfect Collusion			Median Collusion Index (θ)		
Rounds	*Baseline*	*Real Time*	*Stochastic*	*Baseline*	*Real Time*	*Stochastic*
1-6	$\frac{1}{72}$	$\frac{5}{72}$	$\frac{26}{144}$	0.18	0.23	0.23
7-11	$\frac{0}{60}$	$\frac{2}{60}$	$\frac{37}{120}$	0.00	-0.49	0.44
All	$\frac{1}{132}$	$\frac{7}{132}$	$\frac{63}{264}$	0.02	-0.13	0.44

Table 3: Instances of perfect collusion and median collusion index across treatments.

Round	*Real Time* vs. *Baseline*	*Stochastic* vs. *Baseline*	*Stochastic* vs. *Real Time*
1	0.64	0.13	0.27
2	0.75	0.83	0.62
3	0.75	0.88	0.91
4	0.22	0.82	0.34
5	0.52	0.56	0.21
6	0.73	0.55	0.43
7	0.05	0.45	0.04
8	0.80	0.05	0.09
9	0.02	0.05	0.00
10	0.13	0.01	0.00
11	0.02	0.04	0.00

Table 4: P-values from round-by-round two-sided Mann-Whitney U test of equality of collusion index between treatments.

to both the *baseline* and *real time revision* markets. Out of 264 markets in the *stochastic revision* treatment, 63 attain the perfectly collusive output with the median collusion index being significantly positive. The p-values from difference in collusion index across treatments (*Stochastic* vs. *Baseline* and *Stochastic* vs. *Real Time Revision*) are significant in the latter half. Hence, supporting the third hypothesis, the following result is obtained.

Result 3. *The stochastic revision market results in lower individual quantity and higher collusion index than either baseline or real time revision market.*

Dynamics of Quantity Adjustment

Tables 5 and 6 provides the frequency distribution of the initial, implemented and final individual quantities across rounds for each of the three treatments. The implemented and final quantities coincide for *baseline* and *real time revision* markets. The mean, median and modal individual quantity over the revision phase of 120 seconds is depicted in Figure 1. With no information feedback on rival's revised production targets, play is fairly stable over the revision phase in *baseline* market.[14]

In the *real time revision* market, an overwhelming number of initial quantities is around the individually collusive output of 12, however, only few of the final quantities are near 12. From initial to final, the instances of output near 12 drops from 88 to 42 out of 144 in rounds 1-6 and even more drastically, from 76 to 14 out of 120. Figure 1 shows that the median as well as mode stays at low values (lower than the static Nash output) for most of the revision phase. At the very end, just before the revision phase ends, there is a jump in the modal tentative quantity to 18 (and median rises to 18 in the last five rounds as well). A round-by-round Wilcoxon signed-rank test shows that final tentative quantities are significantly higher than the initial prepared ones.[15] In our model, an output of 18 is the best response to rival's choice of 12. This suggests that subjects revise their production target at the very end of the revision phase after indicating an intention to produce the collusive output of 12. When they revise, subjects tend to adjust the quantity upwards as they best respond to rival's currently prepared choice of 12.[16]

The overall dynamics follow a non-monotonic pattern in the *stochastic revision* market. Quantity choices start high, with median being around 15. As the revision phase progresses, quantity is adjusted downwards, especially in the last five rounds. The tentative quantity

[14]A round-by-round Wilcoxon signed-rank test of equality of initial and final quantities reveals that the number of pairs with no ties is not large enough, especially in the last five rounds.

[15]P-values from two-sided test are 0.063, 0.056, 0.075, 0.010, 0.024 in rounds 7-11 (last five rounds) respectively.

[16]Further statistical validation of best response behavior is provided at the end of this section.

stabilizes for a while before rising upwards towards the static Nash output of 16 as the revision phase approaches it's end. Unlike the *real time revision* market, the quantity choices implemented for the round are determined by the last time the opportunity to revise arrived. This feature most likely implements an quantity that is lower than the static Nash of 16. The modal choice of 12 reveals that several choices of 12 are also implemented in the *stochastic revision* market. This explains the high collusion index observed in these markets in comparison to the other two treatments. A round-by-round Wilcoxon signed-rank test shows that while there is no difference between initial and final tentative quantities, implemented quantities are significantly lower than initially prepared ones.[17]

The median and modal choices in the *stochastic revision* market also imply that several participants in fact behaved similar to the trigger strategy equilibrium path identified in the theoretical model of Kamada and Kandori (2015). Players start with quantities that are lower than the static Nash equilibrium of 16 and they remain there till a cut-off time. After the cut-off time, players adjust their quantities upwards, approaching static Nash as the revision phase comes to an end.

Examining pair level data, we also observed that there were only a handful of instances of endogenous Stackelberg leadership. This is in line with previous studies that find hardly any evidence for such behavior in related oligopoly markets (Huck et al. (2002), Fonseca et al. (2005)).

Table 7 gives the percentage of times for which there is no revision in tentative quantity as well as the percent of upward and downward output adjustments for initial and final revision in the *real time revision* and *stochastic revision* markets.[18] Initial revision is given by the first response to competitor's tentative quantity at time $t = 0$ and is calculated as the first changed quantity if $t < 10$, or the tentative quantity at $t = 10$ which equals the quantity at $t = 0$ if there is no change. Final revision is calculated as the last changed quantity if $t > 110$, or the tentative quantity at $t = 110$ if there is no change in the last ten seconds.

During the initial ten seconds, not much activity takes place in the *real time revision* market, with no change in quantity in more than 80% of the instances. There is a tendency to adjust quantity downwards in a significant number of cases in the *stochastic revision* market (around 28% of the observations). In terms of final revision, play is far more stable in *stochastic revision* market than *real time revision* market. In the last five rounds, subjects do

[17] P-values from two-sided test of equality of initial and final quantities are 0.27, 0.4, 0.681, 0.646, 0.478 in rounds 7-11 (last five rounds) respectively. On the other hand, in eight of the eleven rounds, the difference between initial and implemented quantities are statistically significant. The p-values from two-sided test are 0.555, 0.036, 0.029, 0.08, 0.078, 0.052, 0.069, 0.067, 0.114, 0.045, 0.174 in rounds 1-11 respectively.

[18] Given that there is no information feedback about rival's quantity adjustments in the *baseline* market, we focus on the other two markets here.

	Baseline		*Real Time Revision*		*Stochastic Revision*		
Qty.	Initial	Final	Initial	Final	Initial	Implemented	Final
$[0, 11]$	3	1	2	2	9	3	2
$(11, 13]$	31	25	88	42	91	78	64
$(13, 15]$	34	37	5	21	51	66	62
$(15, 17]$	58	63	7	17	36	85	95
$(17, 19]$	13	15	3	48	21	24	37
$(19, 50]$	5	3	39	14	80	34	28
nobs.	144	144	144	144	288	288	288
Median	15.5	16	12	16	15	15	16

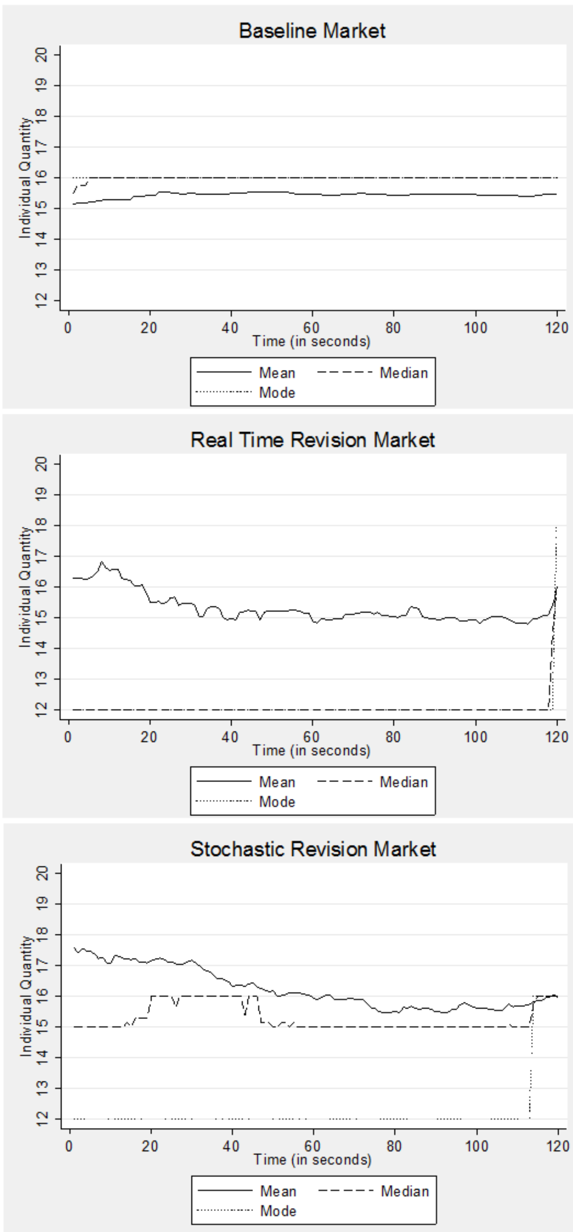
nobs.: Number of observations.

Table 5: Frequency distribution of initial, implemented and final individual quantity- Rounds 1-6.

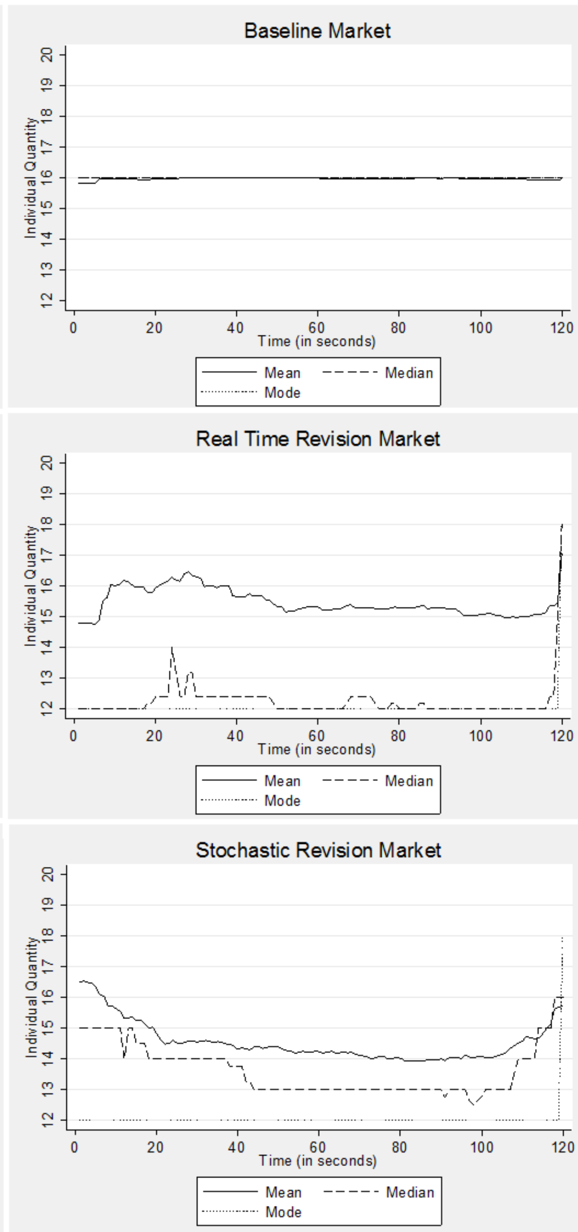
	Baseline		*Real Time Revision*		*Stochastic Revision*		
Qty.	Initial	Final	Initial	Final	Initial	Implemented	Final
$[0, 11]$	1	0	1	0	4	0	0
$(11, 13]$	7	7	76	14	91	114	62
$(13, 15]$	19	21	6	12	33	33	37
$(15, 17]$	82	82	13	32	19	48	71
$(17, 19]$	11	10	2	48	50	32	55
$(19, 50]$	0	0	22	14	43	13	15
nobs.	120	120	120	120	240	240	240
Median	16	16	12	18	15	14	16

nobs.: Number of observations.

Table 6: Frequency distribution of initial, implemented and final individual quantity- Rounds 7-11.



(a) Rounds 1-6



(b) Rounds 7-11

Figure 1: Individual quantity over the revision phase within a round- mean, median and mode.

	Real Time Revision					*Stochastic Revision*			
Rounds	↓	No	↑	*nobs.*		↓	No	↑	*nobs.*
					Initial Revision				
1-6	4.86	86.11	9.03	144		13.19	77.08	9.73	288
7-11	5.00	82.50	12.50	120		27.09	57.08	15.83	240
					Final Revision				
1-6	13.89	45.14	40.97	144		8.68	73.96	17.36	288
7-11	10.83	35.00	54.17	120		9.17	59.58	31.25	240

↓: Downward adjustment of tentative quantity.
No: No change in tentative quantity.
↑: Upward adjustment of tentative quantity.

Table 7: Incidence of initial and final revisions (in percentages).

not change their tentative quantity in 60% of the cases under *stochastic revision* as opposed to 35% under *real time revision* market. Individuals adjust their quantities upwards in more than 50% of the instances during the last five rounds in *real time revision* market. Although it is less severe, upward revision is still a phenomenon that is observed in *stochastic revision* market as well.

Thus, summarizing the dynamics of quantity adjustment across markets, we have the following result.

Result 4. *Prepared quantities are fairly stable in the baseline market. Real time revision markets are characterized by drastic upward adjustment in quantity at the very end of the revision phase. In stochastic revision markets, quantities start high, with downward adjustment in the course of the revision phase, and approach the static best response of 16 as revision phase nears the end.*

The adjustment in quantity during the revision phase can be explained using one of the following two behaviors. The first one is the best-response behavior where an individual adjusts her quantity towards the level that is a best response to her competitor's selected desired quantity at time $t-1$. The second type of behavior is imitation in which case a subject tries to "match" the output level of her competitor at time $t-1$. Accordingly, the following model of the adjustment process is estimated[19]:

$$q_i^t - q_i^{t-1} = \beta_0 + \beta_1(r_i^{t-1} - q_i^{t-1}) + \beta_2(q_j^{t-1} - q_i^{t-1}),$$

where q_i^t is the tentative quantity posted by subject i at time t, r_i^{t-1} is the subject i's best

[19]The standard errors are clustered at the subject level.

	Real Time Revision				*Stochastic Revision*			
Rounds	β_0	β_1	β_2	*nobs.*	β_0	β_1	β_2	*nobs.*
1-6	2.41	0.07	0.97***	20	-0.17	0.59***	0.51***	66
	(1.81)	(0.29)	(0.29)		(0.94)	(0.13)	(0.07)	
7-11	1.35	0.03	1.15***	21	0.35	0.54***	0.39***	103
	(1.24)	(0.46)	(0.18)		(0.55)	(0.08)	(0.08)	
All	2.16**	-0.04	1.06***	41	0.21	0.58***	0.42***	169
	(1.00)	(0.19)	(0.16)		(0.53)	(0.08)	(0.07)	

nobs.: Number of observations with change in tentative quantity.

Table 8: OLS estimation of initial revision behavior (clustered standard errors in parentheses). *, **, *** denote significance at the 10%, 5% and 1% levels.

response to the competitor's tentative quantity at time $t-1$ and q_j^{t-1} denotes the tentative quantity of the competitor at time $t-1$. An individual who strictly plays a myopic best response (imitation) will have $\beta_1 = 1 (\beta_2 = 1)$.

The estimation results are displayed in Tables 8 and 9, for initial and final revisions, respectively. In *real time revision* market, imitation significantly explains behavior for the initial quantity adjustment. On the other hand, both β_1 and β_2 are highly significant in *stochastic revision* market, showing heterogeneous behavior- use of both imitation and best-response. Table 9 reveals that it is best response behavior that primarily explains the final quantity adjustment during the end of the revision phase. The above discussion leads to the final result as follows.

Result 5. *While imitation predominantly explains the initial adjustments in quantity during the revision phase, firms tend to best respond towards the end of the revision phase.*

5 Conclusion

Using a laboratory experiment, this study investigated the effect of observing competitor's plans and different forms of pre-play revisions in two-player dynamic game of quantity competition. With real time revision of quantity choices where payoffs are determined by the action choices at the end, play converges to the static Cournot-Nash equilibrium output with hidden plans. With perfect monitoring of competitor's quantity adjustments, final output choices are significantly more competitive than Cournot-Nash output. Choices are closer to the joint profit maximizing choice including several instances of perfect collusion under

	Real Time Revision				*Stochastic Revision*			
Rounds	β_0	β_1	β_2	*nobs.*	β_0	β_1	β_2	*nobs.*
1-6	0.18	0.80***	0.17***	79	1.33**	0.55***	0.15	75
	(0.47)	(0.08)	(0.05)		(0.52)	(0.13)	(0.15)	
7-11	1.19***	0.73***	0.15	78	0.54	0.78***	0.22**	97
	(0.35)	(0.05)	(0.15)		(0.35)	(0.07)	(0.11)	
All	0.67*	0.77***	0.17***	157	1.17***	0.62***	0.18	172
	(0.35)	(0.06)	(0.07)		(0.41)	(0.10)	(0.13)	

nobs.: Number of observations with change in tentative quantity.

Table 9: OLS estimation of final revision behavior (clustered standard errors in parentheses). *, **, *** denote significance at the 10%, 5% and 1% levels.

stochastic revision where rival's plans are observable and implementation of revisions is imperfect.

While real time revision markets are characterized by drastic upward adjustment in quantity at the end of the revision phase, quantities start high and are adjusted downwards as the revision phase progresses in the stochastic revision markets. As the revision phase nears the end, players adjust quantities upward towards the static best response. Given that the payoffs are determined by the quantities chosen at the last opportunity before the end of the revision phase, lower quantities are implemented, thereby fostering collusion.

Our results on *real time revision* markets can be compared with Deck and Nikiforakis (2012). We show that with perfect implementation of revised actions, having more information is detrimental to the firms. This negative value of information runs contrary to the result in Deck and Nikiforakis (2012) who study the minimum effort game in the laboratory. They find that the coordination problem can be resolved by having the players revise their actions in real time and letting them monitor each others' action choices. The difference in our result can be attributed to the strategic character of the two games. In coordination games, there is a profile of actions that is Pareto efficient where none of the players have any unilateral incentive to deviate. Players can completely get rid of the uncertainty about other players' actions with perfect monitoring. In contrast, in our study, the Cournot game has an unique Nash equilibrium which is not efficient and at the most efficient action profile, each player has an unilateral incentive to deviate. With perfect implementation of revisions, more information does not help in achieving the efficient profile of actions, rather it serves as a tool to deceive others.

With stochastic revision, there is a positive value of information. Our findings indicate that in order to achieve higher cooperation among players a game of quantity competition between two firms, we do not need strong restrictions on the institution of revision as presented in Dorsey (1992) and Kurzban et al. (2001). These papers study the provision of public goods in voluntary contribution games and find that provision is higher only when an incremental revision mechanism is used where individuals can only revise their contributions upwards. This enables individuals to make small commitments to the public good while allowing them simultaneously to limit their commitments so that they can control the extent to which they expose themselves to being free ridden. In our *stochastic revision* markets, "commitment" is introduced through the imperfect probabilistic implementation of prepared actions.

More generally, we show that cooperation can be observed even in one-shot games where the static Nash equilibrium predicts no cooperation. In presenting experimental support for the main theoretical result of Kamada and Kandori (2015), our research provides a justification for the widely observed cooperation in the outside world, even when individuals interact only once.

References

[1] Argenton, C. and Müller, W. (2012), "Collusion in experimental Bertrand duopolies with convex costs: the role of cost asymmetry," *International Journal of Industrial Organization*, 30, 508-517.

[2] Balliet, D. (2010), "Communication and cooperation in social dilemmas: a meta-analytic review," *Journal of Conflict Resolution*, 54, 39-57.

[3] Biais, B., Hillion, P. and Spatt, C. (1999), "Price discovery and learning during the preopening period in the Paris Bourse," *Journal of Political Economy*, 107, 1218-1248.

[4] Biais, B., Bisière, C. and Pouget, S. (2014), "Equilibrium discovery and preopening mechanisms in an experimental market," *Management Science*, 60(3), 753-769.

[5] Brown-Kruse, J., Cronshaw, M. B., and Schenk, D. J. (1993), "Theory and experiments on spatial competition," *Economic Inquiry*, 31, 139-165.

[6] Calcagno, R. and Lovo, S. (2010), "Preopening and equilibrium selection," *Tinbergen Institute Discussion Paper 10-023/2*, http://dx.doi.org/10.2139/ssrn.1557137.

[7] Calcagno, R., Kamada, Y., Lovo, S. and Sugaya, T. (2014), “Asynchronicity and coordination in common and opposing interest games,” *Theoretical Economics*, 9, 409-434.

[8] Cao, C., Ghysels, E. and Hatheway, F. (2000), “Price discovery without trading: evidence from the Nasdaq preopening,” *Journal of Finance*, 55, 1339-1365.

[9] Caruana, G. and Einav, L. (2008), “Production targets,” *Rand Journal of Economics*, 39(4), 990-1017.

[10] Cooper, D. J. and Kühn, K.-U. (2014), “Communication, renegotiation, and the scope for collusion,” *American Economic Journal: Microeconomics*, 6(2), 247-278.

[11] Daughety, A. F. and Forsythe, R. (1987a), “The effects of industry-wide price regulation on industrial organization,” *Journal of Law, Economics, and Organization*, 3, 397-434.

[12] Daughety, A. F. and Forsythe, R. (1987b), “Industry-wide regulation and the formation of reputations: a laboratory analysis,” In Bailey, E. E., editor, *Public Regulation: New perspectives on Institutions and Policies*, pages 347-398. MIT press, Cambridge, Massachusetts.

[13] Deck, C. and Nikiforakis, N. (2012), “Perfect and imperfect real-time monitoring in a minimum effort game,” *Experimental Economics*, 15(1), 71-88.

[14] Dorsey, R. E. (1992), “The voluntary contributions mechanism with real time revisions,” *Public Choice*, 73, 261-282.

[15] Doyle, P. and Snyder, C. (1999), “Information sharing and competition in the motor vehicle industry,” *Journal of Political Economy*, 107, 1326-1364.

[16] Duffy, J. and Feltovich, N. (2002), “Do actions speak louder than words? an experimental comparison of observation and cheap talk,” *Games and Economic Behavior*, 39(1), 1-27.

[17] Duffy, J., Ochs, J., and Vesterlund, L. (2007), “Giving little by little: dynamic voluntary contribution games,” *Journal of Public Economics*, 91, 1708-1730.

[18] Einy, E., Moreno, D. and Shitovitz, B. (2002), “Information advantage in Cournot oligopoly,” *Journal of Economic Theory*, 106, 151-160.

[19] Fonseca, M. A., Huck, S. and Normann, H-T. (2005), “Playing Cournot although they shouldn’t: endogenous timing in experimental duopolies with asymmetric costs,” *Economic Theory*, 25, 669-677.

[20] Fonseca, M. A., and Normann, H-T. (2012), "Explicit vs. tacit collusion- the impact of communication in oligopoly experiments," *European Economic Review*, 56, 1759-1772.

[21] Fouraker, L. and Siegel, S. (1963), *Bargaining Behavior*, McGraw-Hill, New York.

[22] Fried, D. (1984), "Incentives for information production and disclosure in duopolistic environment," *The Quarterly Journal of Economics*, 99, 367-381.

[23] Friedman, J. W. (1967), "An experimental study of cooperative duopoly," *Econometrica*, 35, 379-397.

[24] Gal-Or, E. (1985), "Information sharing in oligopoly," *Econometrica*, 53, 329-343.

[25] Gal-Or, E. (1987), "First mover disadvantages with private information," *Review of Economic Studies*, 54, 279-292.

[26] Gal-Or, E. (1988), "The advantages of impreciser information," *Rand Journal of Economics*, 19, 266-275.

[27] Goren, H., Kurzban, R. and Rapoport, A. (2003), "Social loafing vs. social enhancement: public goods provisioning in real-time with irrevocable commitments," *Organizational Behavior and Human Decision Processes*, 90, 277-290.

[28] Goren, H., Kurzban, R. and Rapoport, A. (2004), "Revocable commitments to public goods provision under the real-time protocol of play," *Journal of Behavioral Decision Making*, 17, 17-37.

[29] Holt, C. A. (1985), "An experimental test of the consistent-conjectures hypothesis," *American Economic Review*, 75, 314-325.

[30] Holt, C. A. (1995), "Industrial organization: a survey of laboratory research," in Kagel, J., Roth, A. (Eds.), *Handbook of Experimental Economics*, Princeton University Press, Princeton, pp. 349-443.

[31] Huck, S., Normann, H-T. and Oechssler, J. (1999), "Learning in Cournot oligopoly- an experiment," *The Economic Journal*, 109, C80-C95.

[32] Huck, S., Müller, W. and Normann, H-T. (2001), "Stackelberg beats Cournot: on collusion and efficiency in experimental markets," *The Economic Journal*, 111, 749-765.

[33] Huck, S., Müller, W. and Normann, H-T. (2002), "To commit or not to commit: endogenous timing in experimental duopoly markets," *Games and Economic Behavior*, 38(2), 240-264.

[34] Huck, S., Normann, H-T. and Oechssler, J. (2004), "Two are few and four are many: number effects in experimental oligopolies," *Journal of Economic Behavior and Organization*, 53(4), 435-446.

[35] Kamada, Y. and Kandori, M. (2015), "Revision games," *Working Paper*.

[36] Kurzban, R., McCabe, K., Smith, V. L. and Wilson, B. J. (2001), "Incremental commitment and reciprocity in a real-time public goods game," *Personality and Social Psychology Bulletin*, 27(12), 1662-1673.

[37] Mason, C. F., Phillips, O. R. and Nowell, C. (1992), "Duopoly behavior in asymmetric markets: an experimental evaluation," *The Review of Economics and Statistics*, 74(4), 662-670.

[38] Mason, C. F. and Phillips, O. R. (1997), "Information and cost asymmetry in experimental duopoly markets," *The Review of Economics and Statistics*, 79(2), 290-299.

[39] Myatt, D. P. and Wallace, C. (2015), "Cournot competition and the social value of information," *Journal of Economic Theory*, 158(B), 466-506.

[40] Palfrey, T. R., Rosenthal, H. and Roy, N. (2015), "How cheap talk enhances efficiency in threshold public goods games," *Games and Economic Behavior*, http://dx.doi.org/10.1016/j.geb.2015.10.004.

[41] Potters, J. and Suetens, S. (2013), "Oligopoly experiments in the current millennium," *Journal of Economic Surveys*, 27(3), 439-460.

[42] Raith, M. (1996), "A general model of information sharing in oligopoly," *Journal of Economic Theory*, 71, 260-288.

[43] Sakai, Y. (1985), "The value of information in a simple duopoly model," *Journal of Economic Theory*, 36, 36-54.

[44] Vives, X. (1995), "The speed of information revelation in a financial market mechanism," *Journal of Economic Theory*, 67, 178-204.

[45] Waichman, I., Requate, T., and Siang, C. K. (2014), "Communication in Cournot competition: an experimental study," *Journal of Economic Psychology*, 42, 1-16.

APPENDIX (Not for Publication)

A Instructions to subjects

Thank you for agreeing to participate in this decision-making experiment. During the experiment we require your complete, undistracted attention, and ask that you follow instructions carefully. You should not open other applications on your computer, chat with other students, or engage in other distracting activities, such as using your phone, reading books, etc.

You will be paid for your participation, in cash, at the end of the experiment. Different participants may earn different amounts. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

The entire experiment will take place through computer terminals, and all interactions between you will take place through the computers. It is important that you not talk or in any way try to communicate with other participants during the experiment.

During the instruction period, you will be given a complete description of the experiment and will be shown how to use the computers. If you have any questions during the instruction period, raise your hand and your question will be answered out loud so everyone can hear. If you have any questions after the experiment has begun, raise your hand, and I will come and assist you.

The experiment will consist of 11 matches. In each match, you will be matched with one of the other participants in the room. In each match, both you and the participant you are matched with will make some decisions. Your earnings for that match will depend on both of your decisions, but are completely unaffected by decisions made by any of the other participants in the room.

At the end of the experiment, you will be paid the sum of what you have earned in each of the 11 matches, plus the show-up fee of $ 5. Everyone will be paid in private and you are under no obligation to tell others how much you earned. Your earnings during the experiment are denominated in points. At the end of the experiment you will be paid $1 for every 150 points you have earned.

The Structure of a Match

Every match proceeds as follows. You are matched with another person from the room at the beginning of a match. Both you and the other person are sellers in a market producing and selling the same product. **Your decision is to choose the quantity of the product to be produced and sold in the market. You can choose any number (up to one decimal place) between (and including) 0 and 50.**

It costs 2 points to produce an unit of the product. Thus, if you produce q units, your total cost is $2q$ points.

The total market quantity (Q) is the sum of the quantity chosen by you and the quantity chosen by the other person. The price of the product depends on the total market quantity according to the following rule. Whenever the total market quantity is less than or equal to 50, then the price of the product is 50 minus the total market quantity. However, if the total market quantity exceeds 50, then the price of the product is zero. That is,

$$P = \begin{cases} 50 - Q & Q \leq 50 \\ 0 & Q > 50 \end{cases}$$

Your revenue is given by price times the quantity you produce and costs are 2 times the quantity you produce. And, your profit equals your revenue minus your cost:

Profit = Revenue - Cost = $(P - 2)*$(quantity produced by you)

In order to make an informed decision, each of you has been provided with a profit sheet and your screen contains a profit calculator. The profit sheet shows the profit that you will earn for every possible combination of integer choices (for 0 to 30). Each row in the profit sheet refers to your quantity, and each column refers to the quantity produced by the person you are matched with. For any combination of (integer) quantities chosen by you and the person you are matched with, you find the corresponding cell to find the resulting profits. If you wish to find out the resulting profits when you enter integer numbers above 30 or non-integer numbers for your quantity and other person's quantity, then use the profit calculator. Here you can enter any number up to one decimal place between 0 and 50.

[The following paragraph only in the *Baseline* treatment.] You and the person you are matched with will have 120 seconds to decide your quantities to be produced. At the beginning of a match, each of you should enter an initial tentative quantity. After you enter an initial tentative quantity, you will get to see your tentative quantity on your screen. However, **you will not be able to observe** the tentative quantity chosen by the person you are matched with, your tentative profits and the other person's tentative profits. Once everyone in the room has entered a tentative quantity, the "120 seconds" timer starts. Remaining time will be displayed on top of your screen. At any point, you can change your tentative quantity (during the 120 seconds). Every time you make a change it is updated on your screen. The word *tentative* reflects the fact that if there are no more changes then the last entry shows your final quantity choice for the match. Your final quantity choice for the match is whatever your tentative quantity is at the end of 120 seconds. At the end of the 120 seconds you will get to observe not only your own final quantity choice but also the final quantity choice made by the person you are matched with. Depending on these quantity choices, you will then get to know the profits earned by you and the profits earned by the person you are matched with for the match.

[The following paragraph only in the *Real Time Revision* treatment.] You and the person you are matched with will have 120 seconds to decide your quantities to be produced. At the beginning of a match, each of you should enter an initial tentative quantity. After both of you enter an initial tentative quantity, you will get to see your tentative quantity, the tentative quantity chosen by the person you are matched with, your tentative profits and the other person's tentative profits on both of your screens. Once everyone in the room has entered a tentative quantity, the "120 seconds" timer starts. Remaining time will be displayed on top of your screen. At any point, you can change your tentative quantity (during the 120 seconds). Every time you or the person you are matched with makes a change it is updated on the screen for both of you to see along with the tentative profits. The word *tentative* reflects the fact that if there are no more changes then the last entry shows the final quantity choice and the amount of profits you earn for this match. Your final quantity choice for the match is whatever your tentative quantity is at the end of 120 seconds. Your earnings for this match will be the tentative profits at the end of 120 seconds.

[The following two paragraphs only in the *Stochastic Revision* treatment.] You and the person you are matched with will have 120 seconds to decide your quantities to be produced. At the beginning of a match, each of you should enter an initial tentative quantity. After both of you enter an initial tentative quantity, you will get to see your tentative quantity, the tentative quantity chosen by the person you are matched with, your tentative profits and the other person's tentative profits on both of your screens. Once everyone in the room has entered a tentative quantity, the "120 seconds" timer starts. Remaining time will be displayed on top of your screen. At any point, you can change your tentative quantity (during the 120 seconds). Every time you or the person you are matched with makes a change it is updated on the screen for both of you to see along with the tentative profits.

The word *tentative* suggests that the quantity choice is not the final choice for the match. Your final quantity choice for the match is determined according to the following procedure: After each second, the computer generates a random integer for each pair of matched participants. This integer is drawn from a uniform distribution over [1,25]. If the integer drawn is 1, then an "event" occurs. This means that every second the probability that an "event" happens is 0.04 (as every integer is equally likely to be drawn). So on an average, an "event" takes place every 25 seconds. Of course this is just an average; this random number generation is independent across each second. **Your final quantity choice for the match is given by the tentative quantity corresponding to the last time an "event" happened before the "120 seconds time" ends. Your earnings for this match will be the tentative profits corresponding to the last time an "event" happened before the "120 seconds time" ends.** Also note that if an "event" does not happen in the entire "120 seconds time", then the tentative quantity choices at time 1 (initial choices) will be implemented as the final quantity choices. So, to summarize, whether or not you change your tentative quantity is always in your "hands" but whether its implemented for the match is dependent on the random occurrence of the "event".

After a match is over we will go to the next match. **You will be matched to a new participant from the room. It is very important to note that you will not be matched with the same person ever again.** Every match proceeds according to exactly the same rules as described above. When the 11^{th} match is over, you will be paid the sum of what you have earned in all matches plus the show up fee.

Before we begin with the experiment, it is important that you understand the range of profits that you can earn depending on your quantity choice and the other person's quantity choice. For this reason, you will have two minutes before the start of the experiment to explore different quantity combinations with the profit sheet and the profit calculator. During the actual experiment, you are free to consult both the profit sheet and the profit calculator whenever you wish.

B Profit Sheet

The profit sheets that were handed out to the participants are given in Figures B1 and B2.

You ↓ \ Other →	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33
2	92	90	88	86	84	82	80	78	76	74	72	70	68	66	64
3	135	132	129	126	123	120	117	114	111	108	105	102	99	96	93
4	176	172	168	164	160	156	152	148	144	140	136	132	128	124	120
5	215	210	205	200	195	190	185	180	175	170	165	160	155	150	145
6	252	246	240	234	228	222	216	210	204	198	192	186	180	174	168
7	287	280	273	266	259	252	245	238	231	224	217	210	203	196	189
8	320	312	304	296	288	280	272	264	256	248	240	232	224	216	208
9	351	342	333	324	315	306	297	288	279	270	261	252	243	234	225
10	380	370	360	350	340	330	320	310	300	290	280	270	260	250	240
11	407	396	385	374	363	352	341	330	319	308	297	286	275	264	253
12	432	420	408	396	384	372	360	348	336	324	312	300	288	276	264
13	455	442	429	416	403	390	377	364	351	338	325	312	299	286	273
14	476	462	448	434	420	406	392	378	364	350	336	322	308	294	280
15	495	480	465	450	435	420	405	390	375	360	345	330	315	300	285
16	512	496	480	464	448	432	416	400	384	368	352	336	320	304	288
17	527	510	493	476	459	442	425	408	391	374	357	340	323	306	289
18	540	522	504	486	468	450	432	414	396	378	360	342	324	306	288
19	551	532	513	494	475	456	437	418	399	380	361	342	323	304	285
20	560	540	520	500	480	460	440	420	400	380	360	340	320	300	280
21	567	546	525	504	483	462	441	420	399	378	357	336	315	294	273
22	572	550	528	506	484	462	440	418	396	374	352	330	308	286	264
23	575	552	529	506	483	460	437	414	391	368	345	322	299	276	253
24	576	552	528	504	480	456	432	408	384	360	336	312	288	264	240
25	575	550	525	500	475	450	425	400	375	350	325	300	275	250	225
26	572	546	520	494	468	442	416	390	364	338	312	286	260	234	208
27	567	540	513	486	459	432	405	378	351	324	297	270	243	216	189
28	560	532	504	476	448	420	392	364	336	308	280	252	224	196	168
29	551	522	493	464	435	406	377	348	319	290	261	232	203	174	145
30	540	510	480	450	420	390	360	330	300	270	240	210	180	150	120

Figure B1: Profit Sheet - Page 1

Other →

	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17
2	62	60	58	56	54	52	50	48	46	44	42	40	38	36	34	32
3	90	87	84	81	78	75	72	69	66	63	60	57	54	51	48	45
4	116	112	108	104	100	96	92	88	84	80	76	72	68	64	60	56
5	140	135	130	125	120	115	110	105	100	95	90	85	80	75	70	65
6	162	156	150	144	138	132	126	120	114	108	102	96	90	84	78	72
7	182	175	168	161	154	147	140	133	126	119	112	105	98	91	84	77
8	200	192	184	176	168	160	152	144	136	128	120	112	104	96	88	80
9	216	207	198	189	180	171	162	153	144	135	126	117	108	99	90	81
10	230	220	210	200	190	180	170	160	150	140	130	120	110	100	90	80
11	242	231	220	209	198	187	176	165	154	143	132	121	110	99	88	77
12	252	240	228	216	204	192	180	168	156	144	132	120	108	96	84	72
13	260	247	234	221	208	195	182	169	156	143	130	117	104	91	78	65
14	266	252	238	224	210	196	182	168	154	140	126	112	98	84	70	56
15	270	255	240	225	210	195	180	165	150	135	120	105	90	75	60	45
16	272	256	240	224	208	192	176	160	144	128	112	96	80	64	48	32
17	272	255	238	221	204	187	170	153	136	119	102	85	68	51	34	17
18	270	252	234	216	198	180	162	144	126	108	90	72	54	36	18	0
19	266	247	228	209	190	171	152	133	114	95	76	57	38	19	0	-19
20	260	240	220	200	180	160	140	120	100	80	60	40	20	0	-20	-40
21	252	231	210	189	168	147	126	105	84	63	42	21	0	-21	-42	-42
22	242	220	198	176	154	132	110	88	66	44	22	0	-22	-44	-44	-44
23	230	207	184	161	138	115	92	69	46	23	0	-23	-46	-46	-46	-46
24	216	192	168	144	120	96	72	48	24	0	-24	-48	-48	-48	-48	-48
25	200	175	150	125	100	75	50	25	0	-25	-50	-50	-50	-50	-50	-50
26	182	156	130	104	78	52	26	0	-26	-52	-52	-52	-52	-52	-52	-52
27	162	135	108	81	54	27	0	-27	-54	-54	-54	-54	-54	-54	-54	-54
28	140	112	84	56	28	0	-28	-56	-56	-56	-56	-56	-56	-56	-56	-56
29	116	87	58	29	0	-29	-58	-58	-58	-58	-58	-58	-58	-58	-58	-58
30	90	60	30	0	-30	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60

Figure B2: Profit Sheet - Page 2

C User Interface

The user interface (screen display) for each of the three treatments is provided in Figures C1-C3.

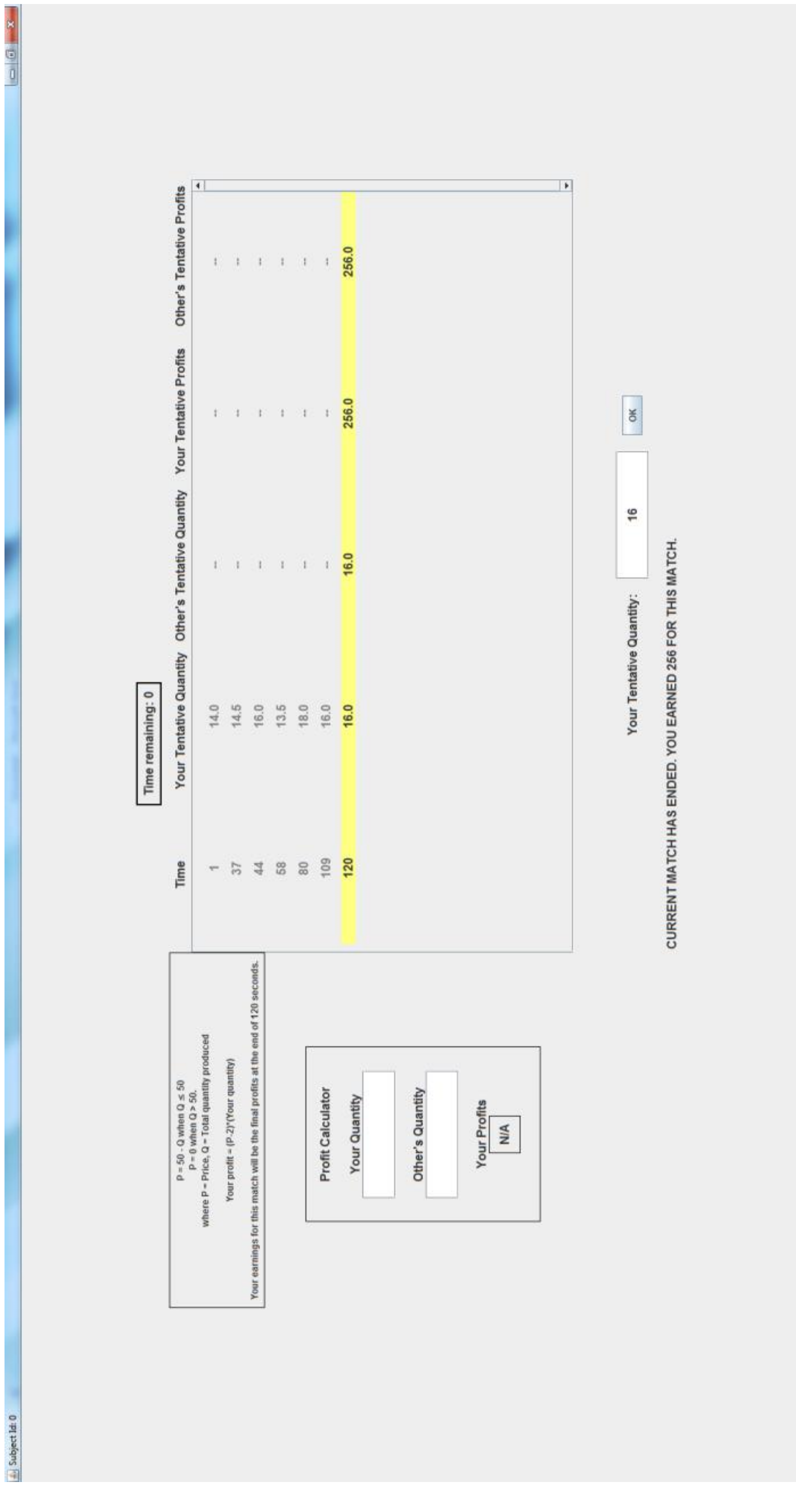


Figure C1: Subject screen for *Baseline* treatment

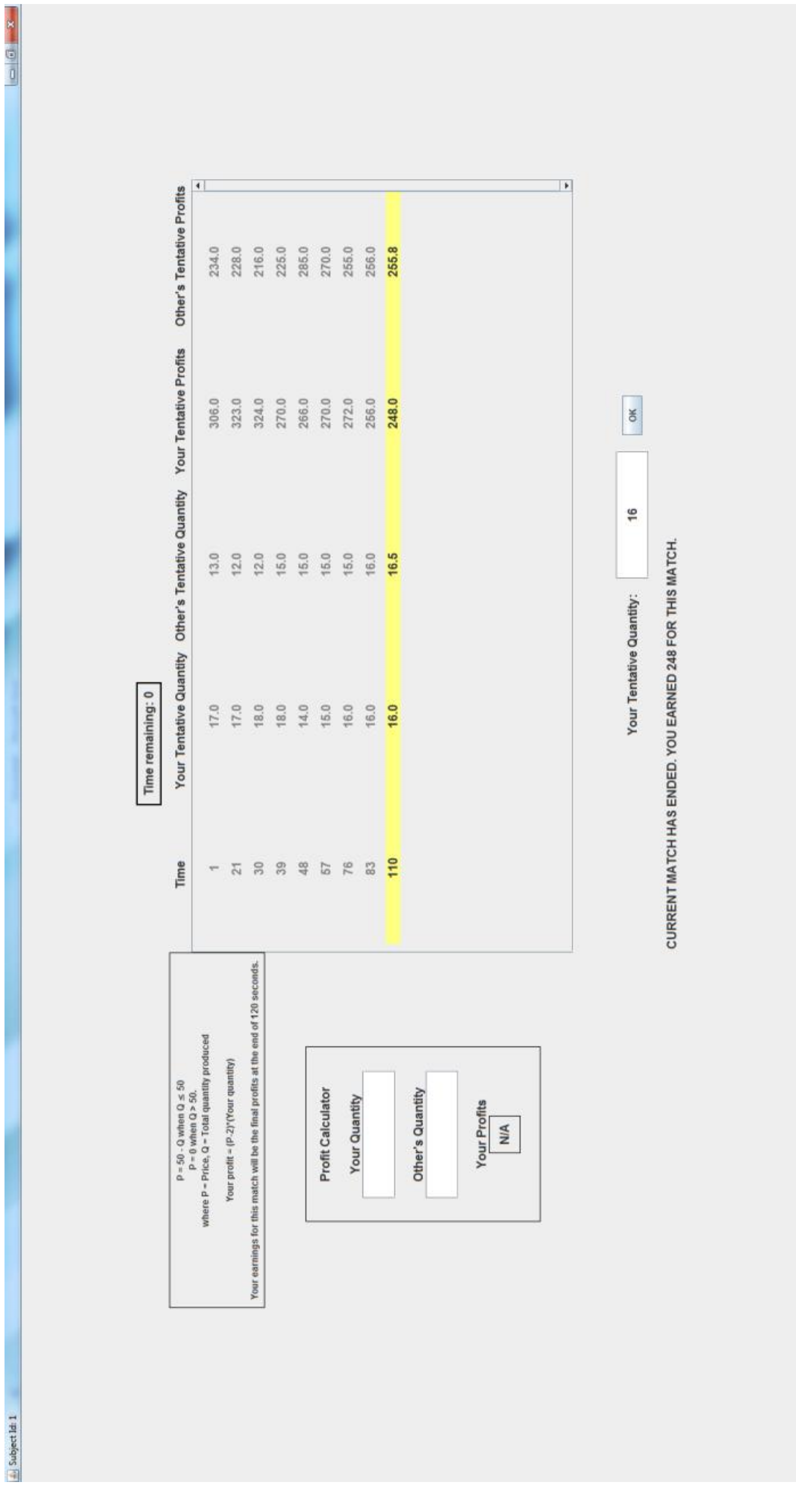


Figure C2: Subject screen for *Real Time Revision* treatment

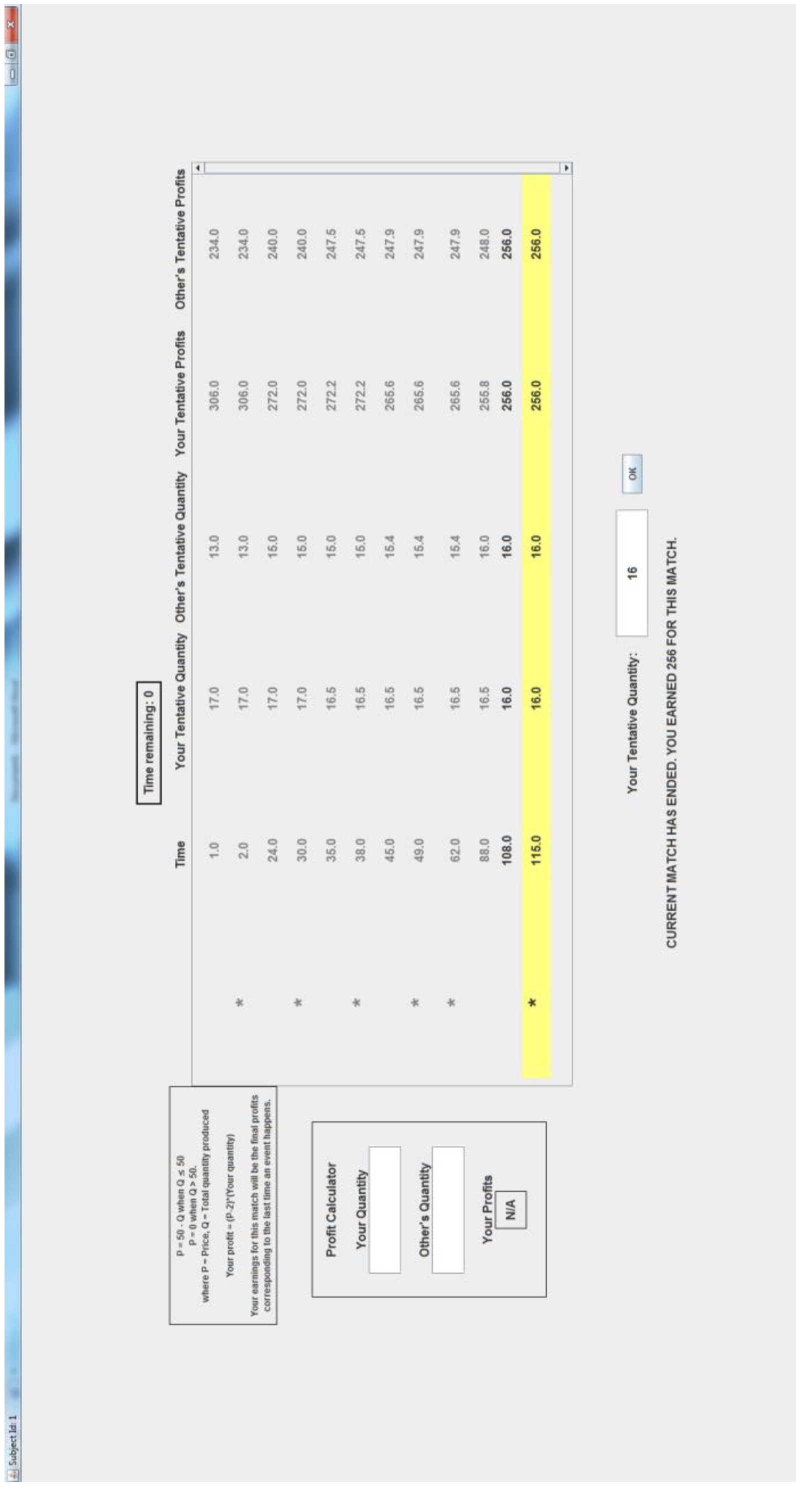


Figure C3: Subject screen for *Stochastic Revision* treatment