Revision and Cooperation: Evidence from Cournot Duopoly Experiments

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Abstract

This paper presents experimental evidence concerned with behavior in Cournot duopolies where players indulge in a form of pre-play communication termed as revision phase before playing the “one-shot” game. During this revision phase individuals announce their tentative quantities that are publicly observed and revisions are costless. The payoffs are determined only by the quantities selected at the end in a real time revision game while in a Poisson revision game, opportunities to revise arrive according to a synchronous Poisson process and the tentative quantity corresponding to the last revision opportunity are implemented. Contrasting results emerge. While real time revision of quantities results in choices that are more competitive than the static Cournot-Nash, significantly lower quantities are implemented in the Poisson revision games. This shows that partial cooperation can be sustained even when individuals interact only once.

The dynamics of revisions gives rise to the following two observations. First, while a real time revision game is characterized only by late upward quantity adjustments, the Poisson revision games are characterized primarily by initial downward adjustments and sometimes also by the late upward revisions. Second, the quantity adjustments during the initial period of the revision phase show that individuals imitate their opponent’s desired quantity choices, whereas, behavior towards the end of the revision phase can be explained by the best response to the competitor’s desired output.

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Keywords: Cournot duopoly, real time revision, Poisson revision, imitation, best response

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Can cooperation be sustained when individuals interact only once? This paper addresses this question by experimentally implementing Cournot duopoly games with two players where they play this game only once at a pre-specified time but they are involved in a pre-play communication phase. During this phase, they announce their tentative quantities that they desire to produce at the end of the phase and these announcements are observed by both the players. Two types of pre-play communication are implemented. In the first type, the payoffs for the players are determined only by the choices selected at the end of the communication phase. This is known as the real time revision game. The second type of communication is known as the Poisson revision game and works as follows. Although individuals 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 tentative quantities selected at the last revision opportunity.

The act of revising actions before the play of the underlying “one-shot” game is prevalent in many areas. 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. As emphasized in Calcagno and Lovo (2010), revision of actions is a phenomenon that is practiced in some of the financial markets 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 pre-opening 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. Other examples would include situations where communication and implementation occur at different times possibly due to some delays. The Poisson revision game implemented in this study is a stylized representation of these types of situations. It models these inefficiencies or imperfections in implementing the intended choices. At the other extreme, real time revision games implement intended actions without any imperfection.

The real time revision phase is in fact related to a cheap-talk period. However, it is different in at least one respect: no external language of communication is used during the revision phase. Players are allowed to signal only through their intended or desired choice of actions, they are not allowed to send any message or participate in any other explicit form of communication. For the Poisson revision games, although the revisions are costless and there is no exogenous cost of revising quantities, players face exogenous uncertainty about the effectiveness of the revision. Choices are now binding with some exogenous probability.

There are at least two reasons to use the Cournot game for the present study. First, the unique equilibrium outcome (Cournot-Nash) is inefficient as there exist other action profiles that has higher joint profits than under the choice of Nash equilibrium actions. One can think of producing outputs that are closer to the individual collusive output (the total industry output where joint profits are maximized divided by 2) and lower than the Cournot-Nash as being “more cooperative”. Thus, there is
a tension between what is efficient for the industry (for both firms) and what is individually best given that the other firm chooses the cooperative action. So, similar to the Prisoners’ dilemma cooperation can be studied using a Cournot duopoly game between two individuals. Second, announcing plans and revision of these subsequent plans is perhaps most applicable to the production industry where firms are competing in quantity and announce plans about future production. Although production is made at the end, there are many factors that influence the final quantity of output produced. Demand and cost uncertainty, information about competitors’ planned production, capacity constraints and other reasons might make the final choice of production totally different from the initial plans.

This paper uses laboratory methods to analyze the impact of different forms or technology of revisions on the quantities implemented and hence, on the incidence of collusion. In the laboratory, one can not only observe and control key variables including the informational feedback available to the players, but also replicate a given scenario multiple times and make causal inferences. The primary contribution of the present paper is to show that partial cooperation can be achieved in situations where individuals interact only once. This cooperation is achieved through revision process of players’ actions before the “one-shot” game is played at a certain pre-determined time. However, the technology of revisions is vital in determining whether or not individuals are able to take actions that are more “cooperative” than others. While real time revision does not help in achieving cooperation, situations where players’ revisions have exogenous positive probability of being the final implemented actions (the Poisson revision games) are more conducive to cooperation.

The basic results of this study are the following. When individuals play the Cournot duopoly game with real time revision but without observing the rival firm’s revisions then play converges to the Cournot-Nash outcome. Quantity choices are even more competitive in the presence of a real time revision phase with perfect monitoring of rival’s revisions. In contrast, when revision plans are mutually observable and revision opportunities arrive according to a Poisson process then significantly lower quantities are selected than the choices implemented under the real time revision games.

The remainder of the paper is organized as follows. Section I provides an overview of the related literature. The model, treatments, and hypotheses are presented in Section II. Section III lays out the laboratory methods and procedures. The results are discussed in Section IV. The last section V concludes.

Appendix A reproduces the instructions to subjects and appendix B shows the profit sheets that were handed out to the participants. The user interface and screen display are provided in Appendix C.

I Related Literature

There have been numerous experiments conducted on Cournot duopolies and the basic conclusion seems to be that while a random matching scheme results in play converging to the Cournot-Nash equilibrium, incidence of collusion arises in repeated Cournot settings with fixed pair of participants. See Fouraker and Siegel (1963), Holt (1985) and Huck, Muller and Normann (2001). These studies
however do not allow any form of communication among the individuals. 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. Duffy and Feltovich (2002) report that non-binding pre-play communication enhances efficiency in one-shot prisoners’ dilemma games with random matching of participants. Non-binding pre-play communication has been shown to facilitate collusive play in spatial competition (Brown-Kruse et al (1993)), price competition in differentiated products framework (Friedman (1967)) and quantity competition in a Cournot duopoly framework (Daughety and Forsythe (1987a, 1987b), Waichman, Requate and Siang (2011)).

There are only a few studies that focus on the effects of real time revision and most of them are related to public goods provision. Dorsey (1992) studies the effects of allowing real time revision of voluntary contributions for the provision of a public good. He analyzes two rules, one where individuals can only increase their contribution over time (commitment) and another where they can both revise upwards and downwards. Cooperation increases significantly only for the case in which revisions are limited to increases and a provision point exist.[1] Similar results are reported in Goren, Kurzban and Rapoport (2003, 2004), Duffy, Ochs and Vesterlund (2007). Kurzban, McCabe, Smith and Wilson (2001) also implement a real time version of the VCM and show that the commitment mechanism is effective in sustaining cooperation over time when players have access to complete information about others’ contributions but fails to increase public good provision in the case where individuals only observe the highest contribution.

Deck and Nikiforakis (2012) study the effect of real time revision on coordination and find that real time revision coupled with perfect observability of other players’ actions at each moment in time almost always lead a group of individuals to coordinate at the payoff-dominant equilibrium in a minimum-effort game. However, this is no longer true when there is imperfect monitoring of others’ actions. So, real time revision is effective only when monitoring is perfect.

Some other relevant studies have explicitly focused on the dynamics of revision in production plans analyzing data from the U.S. motor vehicle industry. Using a panel data set spanning the years 1965-1995, Doyle and Snyder (1999) report that upward revisions cause competitors to revise plans upward and increase production, thus showing that production plan announcements have information content. Caruana and Einav (2008) develop a dynamic model of quantity competition where firms continuously revise their production targets and incur revision costs whenever they do so. Then, using data on monthly production targets of few firms from the auto manufacturing industry they analyze the dynamics of revision in plans and show that quantity targets follow a hump-shaped pattern. However, the focus of these studies are totally different from the current research. While Doyle and Snyder are interested in the information sharing among firms having demand uncertainty, Caruana and Einav fit their model based on switching costs to explain the dynamic pattern of adjustments.

[1]The linear voluntary contribution mechanism is analogous to a Prisoners’ Dilemma with n players and m strategies. The provision-point mechanism is similar to the voluntary contribution mechanism with an added attribute that the public good is not provided unless a certain level of cooperation is reached.
II Model, Treatments and Hypotheses

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, \( q_i \in [0,50] \) in increments of 0.1. They face a linear inverse demand:

\[
P(Q) = max\{50 - Q, 0\}, \quad Q = q_1 + q_2,
\]

while the cost function for each firm is given by

\[
C_i(q_i) = 2q_i, \quad i = 1, 2.
\]

In this static model where firms decide simultaneously, the Nash equilibrium play implies \( q_{iCNE} = 16, i = 1, 2 \) 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 \( q_{iJPM} = 12, i = 1, 2 \). The perfectly competitive Walrasian output is \( q_{iPCW} = 24, i = 1, 2 \) where price equals the marginal cost. An overview of the relevant benchmarks concerning quantities, market price, market profits, consumers’ surplus and total welfare is provided in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Cournot-Nash</th>
<th>Joint Profit Maximization</th>
<th>Perfect Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual Quantity</td>
<td>16</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Market Quantity</td>
<td>32</td>
<td>24</td>
<td>48</td>
</tr>
<tr>
<td>Market Price</td>
<td>18</td>
<td>26</td>
<td>2</td>
</tr>
<tr>
<td>Market Profits</td>
<td>512</td>
<td>576</td>
<td>0</td>
</tr>
<tr>
<td>Consumers’ Surplus</td>
<td>512</td>
<td>288</td>
<td>1152</td>
</tr>
<tr>
<td>Total Welfare</td>
<td>1024</td>
<td>864</td>
<td>1152</td>
</tr>
</tbody>
</table>

Table 1: Static Benchmarks

Behavior in this basic Cournot setting is investigated in treatments that differ in the technology used to implement the revisions of quantity choices by the firms. These different revision environments are listed below.

A. The Cournot Game with Real Time Revision and No Monitoring (Baseline)

In this Baseline treatment, the Cournot game is played at time \( T \). However, firms could adjust their quantity choices in real time from \( t = 0 \) to \( t = T \). The output choice that is actually implemented is the one that corresponds to time \( t = T \). But, the firms are unable to monitor their competitor’s choices and adjustments over time. Only at the very end a firm gets to observe the implemented choice of the other firm. Thus, this scenario is equivalent to the static Cournot game and there is an unique
Nash equilibrium prediction of $q_{i}^{CNE} = 16, i = 1, 2$ at time $T$. This gives rise to the first hypothesis as follows.

**Hypothesis 1.** *Individual quantities are equal to the Cournot-Nash output of 16 in the baseline treatment.*

**B. The Cournot Game with Real Time Revision and Perfect Monitoring (Real Time)**

In this treatment, firms can not only adjust their quantity choices in real time till 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 an unique Nash equilibrium prediction of $q_{i}^{CNE} = 16, i = 1, 2$ at time $T$ regardless of the dynamics of revisions during $t \in [0, T)$. This leads to the following hypothesis.

**Hypothesis 2.** *Individual quantities are same under the real time revision game with monitoring and without monitoring (baseline).*

**C. The Cournot Game with Poisson Revision and Perfect Monitoring (Poisson)**

Firms submit their intended quantity choices at every time $t$ in this treatment 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 revision plans at each $t$.

The revision phase $[0, T)$ is now different from a “cheap talk” period because revisions are now binding with some exogenous probability and the dynamics of revisions play a role now in this treatment. Kamada and Kandori (2011) analyze these games and call them “Poisson revision games” and identify symmetric revision game equilibrium that uses the “trigger strategy”. This equilibrium 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 has 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 which achieves (ex ante) the highest payoffs in these class of equilibria. Certain assumptions need to be fulfilled in order to apply this equilibrium concept. These assumptions are as follows. First, a pure symmetric Nash equilibrium exists and is different from the best symmetric action profile. Second, the payoff function for each player is twice continuously differentiable. Third, there is an unique best response for each possible action. Next, at the best reply, the first and second order conditions are satisfied. Fifth, the payoff function is strictly increasing (decreasing) if an action is lower (higher) than the best symmetric action. Lastly, the gains from deviation is strictly decreas-
ing (increasing) if an action is lower (higher) than the unique Nash action. The Cournot duopoly game satisfies all these assumptions and hence, an optimal trigger strategy equilibrium exists and is essentially unique.

Kamada and Kandori characterize paths \( q_{T-\tau}(t), \tau \in (-\infty, T) \) that are continuous in \( t \) and lies in \([12, 16]\), i.e., it never prescribes a quantity that is lower than the individual collusive outcome of 12 and higher than the Nash equilibrium output of 16. Denote the individual collusive output by \( q^m \). For \( \tau \leq 0 \), the path always prescribes the play of the Cournot-Nash output of 16 throughout the revision phase. Provided \( \tau > 0 \), \( q_{T-\tau}(t) \) starts at \( q^m \) and remains there till \( t_\lambda(q^m) - (T - \tau) \), where \( t_\lambda(q^m) \) is the first time the prescribed path deviates from the collusive output of 12 when \( \tau = T \). It follows a differential equation for \( t \in (t_\lambda(q^m) - (T - \tau), \tau) \) and hits the Cournot-Nash output of 16 at time \( t = \tau \). Among these paths \( q_{T-\tau}(t) \), the one that reaches the Cournot Nash output level only at the end, i.e., which prescribes the play of 16 at time \( t = T \) and \( q(t) \neq 16, t \neq T \) has the highest payoff as it stays at \( q^m \) for a longer period of time. This is achieved for \( \tau = T \) and is termed as the optimal trigger strategy equilibrium.

Given a long enough horizon for the revision phase, players act as follows in the optimal symmetric trigger strategy equilibrium. They 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 time \( t_\lambda(q^m) \). After this time, they choose the optimal path given by \( q(t) \) whenever a revision opportunity arrive. The closer is the revision opportunity to the end of the revision phase, the closer is the revised quantity 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.

At worst, the trigger strategy equilibria predicts the play of Cournot-Nash throughout the revision phase. And for values of \( \tau \in (0, T] \), the path stays in the collusive output level for a finite period of time and also takes values in \((12, 16)\). Thus, these equilibria predict lower levels of output to be chosen (in expectation) and hence, the following hypothesis is obtained.

**Hypothesis 3.** Individual quantities are lower and incidence of collusion is higher under the game with a Poisson revision phase than with a real time revision phase without monitoring (baseline).

Since, individuals start out at lower quantities and move towards the static Nash output level over the course of the revision phase under these symmetric trigger strategy equilibria, one can obtain the hypothesis regarding the dynamics of revisions as follows.

**Hypothesis 4.** Quantities are revised upwards over time in the games with Poisson revision phase.

The optimal trigger strategy equilibrium path can be calculated as follows. First, the expected payoff from cooperation at time \( t \), supposing that the other player follows the trigger strategy equilibrium, is given by:

\[
V_C(t) = (48 - 2q(t))q(t)e^{-\lambda(T-t)} + \int_{t}^{T}(48 - 2q(s))q(s)\lambda e^{-\lambda(T-s)} ds
\]

\(^2\)They assume continuous action spaces. In the experiments, subjects could choose any quantity in \([0, 50]\) with increments of 0.1, which is “close to being continuous”. 

7
The probability that the current quantity \( q(t) \) will be implemented at the end of the game is \( e^{-\lambda(T-t)} \).

The first term represents the payoff when there is no opportunity of revision in the future. The second term can be explained as follows. With probability density \( \lambda \) a revision opportunity arrives at time \( s \), and with probability \( e^{-\lambda(T-s)} \) this is the last revision opportunity. If that happens then \( q(s) \) will be implemented and the realized payoff equals \((48 - 2q(s))q(s)\).

And the expected payoff from deviation is maximized by deviating to the best response to the competitor’s current quantity, which is \( 24 - \frac{q(t)}{2} \). Also, once there is a deviation, then both players choose the Nash equilibrium output. Thus, the expected payoff from deviation is given by:

\[
V_D(t) = (48 - (24 + \frac{q(t)}{2})(24 - \frac{q(t)}{2})e^{-\lambda(T-t)} + (48 - 2 \frac{48}{3})(16)(1 - e^{-\lambda(T-t)})
\]

\[
= (24 - \frac{q(t)}{2})^2 e^{-\lambda(T-t)} + 256(1 - e^{-\lambda(T-t)})
\]

Note that \( V_C(T) = V_D(T) \) if \( q(T) = 16 \), and the sufficient condition for sustaining cooperation is:

\[ V'_C(t) \geq V'_D(t) \quad \forall \ t \]

Solving the above inequality and using the fact that at the optimal equilibrium, equality holds in the above expression, the following differential equation is obtained:

\[
\frac{d q}{dt} = \frac{\lambda}{18}(q - 80)
\]

Finally, solving the above differential equation, the optimal trigger strategy equilibrium is characterized by the following:

\[
q^m = 12 \quad \text{if} \quad t \in [0, \frac{18}{\lambda} \text{ln}(\frac{17}{16})]
\]

\[
16(5 - 4e^{\frac{\lambda}{18}(T-t)}) \quad \text{if} \quad t \in (\frac{18}{\lambda} \text{ln}(\frac{17}{16}), T]
\]

The optimal symmetric trigger strategy equilibrium induces a probability distribution of quantities over the individual collusive output of 12, the Nash output of 16 and quantities in \([12, 16]\). An interesting feature of this equilibrium is that the probability distribution of the quantities implemented at time \( T \) is independent of the Poisson arrival rate \( \lambda \) provided the time horizon is long enough. This follows from the fact that any revision game with an arrival rate of \( \lambda \) and a time horizon \( T \) can be rewritten as a new model by changing the time scale in such a way that one unit of time in that game would correspond to \( \lambda \) units in the new model. Under the new time scale, the model is identical to the revision game with arrival rate 1 and time horizon \( \lambda T \). And, the first time the optimal path starts deviating from the collusive output, \( t_1(q^m) \) equals \( \lambda t_\lambda(q^m) \leq \lambda T \) given that \( t_\lambda(q^m) \leq T \) in the new model. Thus, the probability distribution of quantities implemented at the end of the revision phase is unchanged if the game starts at \( t_1(q^m) \) and ends at \( \lambda T \). Hence, the probability distribution

\[^3\text{For a detailed analysis, see Kamada and Kandori (2011).}\]
of quantities at time \( t = T \) under any arrival rate \( \lambda \) such that \( t_\lambda(q^m) \leq T \) is equal to the distribution under arrival rate 1 and time horizon \( (\lambda T - t_1(q^m)) \). This leads to the last hypothesis as follows.

**Hypothesis 5.** *Individual quantities are similar and incidence of collusion is same under the games with Poisson revision technology with low and high arrival rates. Thus, the arrival rate does not make a difference.*

### III Methods and Procedures

The experiments reported here were all 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. A total of six sessions were run, using a total of 72 subjects. No subject participated in more than one session. A total of four treatments were generated, each with a revision phase of 120 seconds. As the previous section listed, there were two treatments with real time revision of quantities, one without monitoring (baseline) and the other with monitoring. There were two treatments with Poisson revision phase, one with a low arrival rate (0.02 per second) and the other with a high arrival rate of revision opportunities (0.04 per second). Table 2 summarizes the characteristics of each session.

<table>
<thead>
<tr>
<th>Date</th>
<th>Session</th>
<th>Subjects</th>
<th>Treatment</th>
<th>Matches</th>
<th>Games</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/23/12</td>
<td>1</td>
<td>12</td>
<td>Real Time with Monitoring</td>
<td>11</td>
<td>66</td>
</tr>
<tr>
<td>05/31/12</td>
<td>2</td>
<td>12</td>
<td>Real Time with Monitoring</td>
<td>11</td>
<td>66</td>
</tr>
<tr>
<td>06/05/12</td>
<td>3</td>
<td>12</td>
<td>Baseline</td>
<td>11</td>
<td>66</td>
</tr>
<tr>
<td>06/11/12</td>
<td>4</td>
<td>12</td>
<td>Baseline</td>
<td>11</td>
<td>66</td>
</tr>
<tr>
<td>07/09/12</td>
<td>5</td>
<td>12</td>
<td>Poisson High</td>
<td>11</td>
<td>66</td>
</tr>
<tr>
<td>07/16/12</td>
<td>6</td>
<td>12</td>
<td>Poisson Low</td>
<td>11</td>
<td>66</td>
</tr>
</tbody>
</table>

Exchange Rate : US$ 1 was worth 150 points earned in the experiment.
Subjects \((n)\) : Number of subjects in a session.
Matches \((m)\) : Number of dynamic games played per subject.
Games : Total number of dynamic games played (summing across all subjects). As a game is played among two persons, there are \( \frac{m \times n}{2} \) dyadic games in total.

Table 2: Treatments and Sessions

On arrival, instructions\(^4\) were read aloud. Subjects interacted anonymously with each other through computer terminals. There was no possibility of any kind of communication between the subjects, except as instructed in the instructions. All sessions consisted of eleven matches and lasted between 45 and 50 minutes. Subjects’ average earnings were US$19. Each subject also earned an

\(^4\)A copy of the instructions is given in appendix A.
additional US$5 show-up fee.

In the instructions (see Appendix A) 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 match, both have to decide what quantity to produce. They were also informed that every match they would be matched to a new participant from the room and thus, they would not be matched with the same person ever again.

Participants were provided with a profit sheet (see Appendix B) and a profit calculator (see Appendix C). 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 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 matches. This USD equivalent was determined by using an exchange rate from 150:1.

Subjects were informed that every match they would get 120 seconds to decide the quantities they wish to produce. At the beginning of this “120 seconds” period they were asked to enter an initial tentative quantity. For the real time revision with monitoring and the Poisson revision treatments they were able to observe the other seller’s tentative quantity as well as the tentative profits at any point in time\(^5\). For the real time revision with monitoring individuals 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 match. And for the Poisson revision treatments the final quantity choice for a match was given by the tentative quantity corresponding to the last time an event happened before the revision phase ended. For each pair of participants, the occurrence of this event was decided using a random draw of an integer from an uniform distribution over \([1, 50]\)\(^6\). If the draw was 1, then an event occurred. 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.

IV Results

The results are reported in this section. Subsection A collects the results from comparison of the selected quantities as well as the incidence of collusion in the different treatments. The aggregate (average) dynamics and market level behavior over time are discussed in the next subsection B. The final subsection C discusses in greater detail about the characteristics of quantity adjustment over time.

\(^5\)Appendix C discusses in detail about the user interface and screen display.

\(^6\)This was for the Poisson Low treatment. For the Poisson High treatment, an integer was drawn from an uniform distribution over \([1, 25]\).
A. Comparison of Quantities and Incidence of Collusion

The essential summary statistics at an aggregate level is provided in Table 3 for all the four treatments. More detailed information is given in Tables 4 and 5. There is an interesting pattern in the quantities selected over matches in the four treatments, as shown in Figure 1. There is a significant upward trend in the quantities selected over matches in the real time revision treatments. While average individual quantity is below 15 at the start of the experiment, it reaches 16 during the later stages in the baseline treatment. In the real time revision treatments with monitoring, the average quantity is close to 15 in match 1 but higher than 17 in the matches 9-11. In contrast, higher quantities are chosen during the initial matches whereas there is a considerable decline over the course of the experiment in the Poisson revision treatments.

<table>
<thead>
<tr>
<th></th>
<th>Cournot-Nash</th>
<th>Baseline</th>
<th>Real Time</th>
<th>Poisson High</th>
<th>Poisson Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual Quantity</td>
<td>16</td>
<td>15.7 (15.9)</td>
<td>16.4 (17.0)</td>
<td>15.6 (14.5)</td>
<td>14.8 (14.1)</td>
</tr>
<tr>
<td>Market Quantity</td>
<td>32</td>
<td>31.4 (31.9)</td>
<td>32.9 (33.9)</td>
<td>31.2 (29.0)</td>
<td>29.7 (28.3)</td>
</tr>
<tr>
<td>Market Price</td>
<td>18</td>
<td>18.6 (18.1)</td>
<td>17.2 (16.1)</td>
<td>18.9 (21.0)</td>
<td>20.5 (21.7)</td>
</tr>
<tr>
<td>Market Profits</td>
<td>512</td>
<td>514.2 (510.6)</td>
<td>476.0 (458.4)</td>
<td>481.2 (532.5)</td>
<td>517.1 (544.1)</td>
</tr>
<tr>
<td>Consumers' Surplus</td>
<td>512</td>
<td>495.8 (509.6)</td>
<td>550.4 (584.9)</td>
<td>506.5 (430.9)</td>
<td>449.3 (406.5)</td>
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<tr>
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<td>1024</td>
<td>1010.1 (1020.2)</td>
<td>1026.4 (1043.2)</td>
<td>987.7 (963.3)</td>
<td>966.3 (950.5)</td>
</tr>
</tbody>
</table>

Table 3: Aggregate Data (Averages). Data from matches 7-10 in parentheses.

It is usual in these experiments implementing the Cournot model (Fouraker and Siegel (1963), Holt (1985) and Huck, Muller and Normann (2001)) to work with the data from the later half of the experiment when subjects have gathered a lot of experience. Also, the last match is not considered in the data analysis due to possible end game effects. Unless otherwise mentioned, only the data for matches 7 through 10 is used in the analysis in this study.

The quantities selected in the baseline treatment are close to 16 which is the Cournot-Nash equilibrium. The median and mode are exactly equal to 16 in matches 7-10. This observation is familiar and is consistent with the other experimental studies which report that under random matching, play converges to the Cournot Nash equilibrium. In contrast, markets are more competitive under real time revision with monitoring. Comparing the average market quantity shows that there is a highly significant difference between the two treatments, with p-value < 0.01 from a two-sided Mann-Whitney-U test.

Also, comparing the market quantities among the Poisson-High and the baseline as well as among Poisson-Low and baseline treatment reveal that the Poisson revision treatments result in lower aggre-

7Using the average quantities of each market as the unit of observation is preferred to the other option of using the average of individual quantities as the former gives independent observations on each unit.
gate quantities (p-value < 0.01 in Poisson-Low and < 0.05 in Poisson-High, Mann-Whitney-U tests). Finally, although the average quantity chosen under the Poisson Low treatment is slightly lower than the quantities chosen under the Poisson High treatments, the difference is not statistically significant. In fact, the market quantities are statistically similar among the Poisson-High and Poisson-Low treatments (p-value > 0.1, Mann-Whitney-U test).

In matches 7-10, the collusive market outcome of 24 is chosen in 33% of the markets in Poisson revision treatments and in 2 out of 48 markets under the real time revision with monitoring treatments. Whereas, none of the pairs achieve the fully collusive outcome in the baseline treatment. Also note that the modal individual quantity chosen in the matches 7-10 is 16 (Cournot-Nash) in the baseline treatment, 18 in the real time revision with monitoring and 12 (collusive individual outcome) in the Poisson revision treatments.

Comparing the average market profits realized in the four treatments, Table 3 shows that the markets under baseline treatment attains almost 89% of the collusive profits in matches 7-10 similar to what the Cournot-Nash quantities attain. However, only 79% of the collusive profits are realized in the real time revision treatments with monitoring. On the other hand, the markets in the Poisson revision treatments attain 92-94% of the collusive profits.

Thus, the results from the above discussion can be summarized as follows.
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<tr>
<th>Match</th>
<th>Baseline Mean</th>
<th>Baseline SD</th>
<th>Real Time Mean</th>
<th>Real Time SD</th>
<th>Poisson High Mean</th>
<th>Poisson High SD</th>
<th>Poisson Low Mean</th>
<th>Poisson Low SD</th>
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<tr>
<td>1</td>
<td>14.87</td>
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<td>15.31</td>
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<td>15.92</td>
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Table 4: Mean and Standard Deviation of Individual Quantity Implemented by Matches

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<tr>
<th>Match</th>
<th>Baseline Median</th>
<th>Baseline Mode</th>
<th>Real Time Median</th>
<th>Real Time Mode</th>
<th>Poisson High Median</th>
<th>Poisson High Mode</th>
<th>Poisson Low Median</th>
<th>Poisson Low Mode</th>
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<td>15</td>
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<td>16</td>
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<td>14</td>
<td>12</td>
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</table>

Table 5: Median and Mode of Individual Quantity Implemented by Matches
Result 1. Average individual quantity is equal to the Cournot-Nash output of 16 in the baseline treatment. This supports Hypothesis 1.

Result 2. The real time revision treatment with monitoring results in higher individual and market quantities than the treatment without monitoring (baseline). This rejects Hypothesis 2.

Result 3. Individual and market quantities are significantly lower under the Poisson revision games than the baseline treatment. This supports Hypothesis 3.

Result 4. Statistically indistinguishable quantities are chosen under the Poisson High and Poisson Low treatments. This supports Hypothesis 5.

B. Dynamics

Aggregate Dynamics

The distribution for the initial tentative quantity selected and the final quantity implemented for a match is given in Table 6. Focusing on matches 7-10, one can immediately infer that the average quantity in the baseline treatment is fairly stable over the entire revision phase. Almost 70% of the quantities chosen are in the range [16, 18) right from the beginning. This is also displayed in panel (a) of Figure 2. The p-value from a pairwise Wilcoxon rank sum test is > 0.1 showing no difference in the initial and final quantity choices. In contrast, the p-value for the same test in the real time revision treatment with monitoring is less than 0.001. In fact, around 64% of the observations for initial tentative quantity are near the individual collusive quantity of 12, whereas, only 12% of the final quantities are close to 12. More than 60% of the final observations are in [16, 19). This happens primarily because of the ‘last second’ increase in the tentative quantities, as shown in Figure 2(b).

The average tentative quantity starts just below 15 and then increases to 16 while declining further to below 15 over time and then finally there is a sharp increase to around 17 towards the end of the revision phase.

In the Poisson High treatment, average tentative quantities start at above 18 but declines drastically during the initial period and reaches around 14 while again increasing towards 16 over time. See Figure 2(c). Comparing the initial tentative quantities and the final implemented quantities in this treatment, Table 6 shows that around 56% of the initial observations are above 18 whereas only 13% of the implemented quantities are above 18. Also, 38% of the observations are near the collusive output of 12 for the final implemented quantities. These clearly show substantial difference in the distribution of initial tentative and final implemented quantities. The behavior of average tentative quantity over the revision phase is less volatile in the Poisson Low treatment (see Figure 2(d)). Although the average quantities implemented are statistically indistinguishable in the high and low treatments, the dynamics is more ‘flat’ in the Poisson Low treatment. Unlike the Poisson High treatment, there is no indication of tentative quantity increasing towards the Cournot-Nash at the end of the revision phase. Thus, the dynamics exhibited in the Poisson revision treatments show that unlike the paths under the symmetric trigger strategy equilibria, quantities first start high and then decline over time and sometimes move upwards. Thus, the following result is obtained.
<table>
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<tr>
<th>Qty</th>
<th>Initial (01.04)</th>
<th>Final (01.04)</th>
<th>Initial (01.04)</th>
<th>Final (01.04)</th>
<th>Initial (01.04)</th>
<th>Final (01.04)</th>
<th>Initial (01.04)</th>
<th>Final (01.04)</th>
<th>Initial (01.04)</th>
<th>Final (01.04)</th>
<th>Initial (01.04)</th>
<th>Final (01.04)</th>
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<tr>
<td>0.00 - 12</td>
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<td>0.27 (05.21)</td>
<td>0.27 (05.21)</td>
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<td>0.30 (00.00)</td>
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<td>12.00 - 20</td>
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<td>0.76 (01.04)</td>
<td>0.76 (01.04)</td>
<td>0.76 (01.04)</td>
<td>0.76 (01.04)</td>
<td>0.76 (01.04)</td>
<td>0.76 (01.04)</td>
<td>0.76 (01.04)</td>
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<td>0.27 (05.21)</td>
<td>0.27 (05.21)</td>
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<td>0.50 (01.04)</td>
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<td>0.50 (01.04)</td>
</tr>
</tbody>
</table>

Table 6: Initial and Final (Implemented) Quantity Distribution. Data from matches 7-10 in parentheses.
Result 5. There is no significant upward trend in the quantity revisions over time in the Poisson revision treatments. This rejects Hypothesis 4.

Market Level Dynamics

The tentative quantities selected by a pair of participants is very stable over time in the baseline treatment. This is quite obvious as there is no information feedback and hence there is no opportunity to react to the competitor’s plans. However, interesting dynamic patterns are exhibited in the real time revision treatments with monitoring. Figure 3 collects some of these patterns. The most common behavior is displayed in panels (a) and (b) which shows that both the firms select the collusive quantity of 12 for a long time but as the revision phase comes to an end either one or both of them switch to a higher quantity. This ‘last second’ defection towards the best response of 18 explains the sharp increase in average tentative quantity as in Figure 2(b). Another type of behavior is documented in panel (c) of Figure 3. Both firms start at the collusive quantity then one of them switches to a higher quantity followed by the other firm. Revisions in quantities are positively correlated and the ‘last second’ defection is also present.

818 is a best response to the competitor’s choice of 12.
Situations where one firm starts out with a high quantity and the other with a low quantity are shown in panels (d) and (e). While panel (d) shows that over time firms’ quantities are revised downwards and are positively correlated, panel (e) shows that only one of the firms (which started out low) is trying to signal the other firm that it is willing to lower quantities provided it’s partner does so. Ultimately, they end up producing somewhere in between the quantities they initially intended to produce.

Finally, Stackelberg leadership emerges endogenously in a few cases. The quantity for the leader is 24 and the follower is 12. As the panels (h) and (i) show one of the firms always selects a tentative quantity of 24 throughout the revision phase and it’s competitor finally ‘gives in’ and selects a quantity of 12 or close to 12. However, when none of the firms ‘give in’, as in panel (g), then both firms produce very high quantities and earn very less profits. Yet another situation is depicted in panel (f) wherein both the firms keep on selecting the high quantity of 25 (near the Stackelberg leader quantity) but just when only a few seconds remain for the revision phase to end both of them switch to lower quantities.

Next, the dynamics is remarkably different in the Poisson revision treatments. Figure 4 displays some typical patterns of play in these treatments. Panels (a)-(c) show the situations where both the firms start out with high tentative quantities. While sometimes they revise quantities downwards in small multiple steps as in (b), in other cases they do so in fewer steps (as in (c)). Panels (d)-(i)
C. Revisions - Best Response versus Imitation

How often do individuals revise their quantities? Do they revise upwards or downwards? Do they best respond to competitor’s desired output choices or try to match them (imitation)? Are these behavior different depending on the time left for the revision phase to end? The answers to these questions for all treatments are provided in this section.

To keep the analysis simple, this section uses only a part of the available data. The initial response to competitor’s tentative quantity at time \( t = 0 \) is taken as the first changed quantity if \( t < 10 \) or the tentative quantity at \( t = 10 \) which equals quantity at \( t = 0 \) if there is no change. The subsequent data from the revision phase is taken at 10 seconds duration, i.e., observations at the following times are

Figure 4: Pattern of Behavior in a Market in Poisson Revision
taken for analysis in this section. Then it is divided into three sub-phases: the first one consists of data from 10-60 (first half), the second from 70-110 (second half) and the last one is final observation at time 120.

Table 7 gives the percentage of times there is no revision in tentative quantity and also percent of upward and downward output adjustments for the different sub-phases of the entire revision period. As there is no informational feedback in the baseline treatment, the focus of this section is only on the real time revision with monitoring and Poisson revision treatments. As is clear from Table 7, there are very few adjustments in tentative quantity until the final sub-phase of the revision period in the treatment with real time revision phase. And, in the final phase, the quantities selected at time $t = 120$ are higher than those selected at $t = 110$ in more than 50% of the observations. Subjects wait till the last few seconds before revising and when they do revise, bulk of them adjust quantities upwards. In contrast, in the Poisson revision treatments, it is the initial sub-phase (that is initial 10 seconds of the entire revision phase) where majority of the revisions occur. Also, most of the revisions are downward adjustment in quantities. And, finally there is a significant upward trend in quantity adjustment, especially in Poisson High treatment. Thus, an important difference in the revision behavior is documented which can be summarized as follows.

**Result 6.** While a real time revision game is characterized only by late upward quantity adjustments, the Poisson revision games are characterized primarily by initial downward adjustments and sometimes also by the late upward revisions.

When there is a change in quantity, this revision in the tentative output can be explained better by one of the following two obvious behaviors. The first one is 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 $t - 1$. And 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 is estimated:

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

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 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 Table 8. First, focus on the real time revision treatment with monitoring. While imitation significantly explains behavior in initial and subsequent phases, in the final phase it is the best-response to competitor’s choice that characterizes behavior. Similar behavior is exhibited in the Poisson Low treatment. However, in the Poisson High treatment, best-response behavior is significant throughout and explains output adjustments much better than imitation. But, one observation that is consistent across all the treatments is that towards the end of the revision phase

---

9Dividing the data at 5 seconds intervals gives same qualitative results.

10The standard errors are clustered at the subject level.
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<tr>
<th></th>
<th>Real Time with Monitoring</th>
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<td>Upward</td>
<td>Downward</td>
<td>No</td>
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<td>32.29</td>
<td>57.29</td>
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Table 7: Incidence of Revisions subdivided by Time in the Revision Phase (in percentages)
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<th>Poisson Low</th>
</tr>
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</tr>
<tr>
<td><strong>First Half</strong></td>
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<td>0.65***</td>
</tr>
<tr>
<td><strong>Second Half</strong></td>
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<td>0.10</td>
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<tr>
<td><strong>Final</strong></td>
<td>1.15**</td>
<td>0.73***</td>
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Table 8: OLS Estimation of Individual Revision Behavior. *, **, *** denote significance at the 10%, 5%, and 1% levels.
behavior is fairly captured by best response dynamics. The above discussion can be summarized as follows.

**Result 7.** While individuals imitate their competitor’s choices in the beginning, they tend to best respond towards the end of the revision phase.

V Conclusion

Using laboratory techniques, this paper investigated the effect of different forms of pre-play revisions in two person Cournot games on the choice of quantities. It showed that with real time revision of quantities but without any informational feedback on competitor’s revisions, quantity choices converge to the Cournot-Nash equilibrium. When perfect information is available concerning the competitor’s intended quantity along with real time revisions then final output choices are significantly more competitive than the Cournot-Nash output. This shows that more information is detrimental to the firms (when they could revise their quantities in real time) as their average profits are now less than the situation without any information. In contrast, in coordination games with real time revision, information is an essential factor in enhancing efficiency. The reason is straightforward. In coordination games, there is a profile of actions that is Pareto efficient where none of the players have any unilateral incentive to deviate, that is, there is a profile which constitutes a Nash equilibrium and is also the most efficient. The problem with coordination games is that there are other equilibria that are Pareto inferior. However, with perfect information players can completely get rid of the uncertainty about the other players’ actions. Whereas, in the current study, the Cournot game has an unique Nash equilibrium which is not efficient. More information does not help in achieving the efficient profile of actions, rather it serves as a tool to deceive other players.

On a more general level, this paper showed that even though individuals interact only once in the sense that the payoffs are determined only by the one-time play of the game, a significant amount of cooperation could be sustained. This is achieved through the introduction of a Poisson revision phase where opportunities to revise quantities arrive according to a Poisson process and the payoffs are determined by the quantities chosen at the last revision opportunity before the end of the revision phase.

The overall dynamics of revisions in the real time revision games and Poisson revision games has some interesting differences. While quantities are fairly stable in the games with real time revision phase with “last second defections” to higher quantities, there is a drastic downward adjustment of outputs in the initial phases of the Poisson revision period and a modest upward trend in desired quantities during the last few seconds of the revision phase. However, there is one similarity in individual behavior across treatments with different forms of revisions. While the quantity adjustments during the initial period of the revision phase show that individuals imitate their opponent’s desired quantity choices, behavior towards the end of the revision phase can be explained by the best response to the competitor’s desired output.

There are few interesting directions to pursue in future research. First, one could explore markets
with asymmetric firms where one firm is a “big” firm (possibly because of cost advantage) and another is a “small” firm. Do we see endogenous Stackelberg leadership emerging over the course of the revision phase? Second, it would be interesting to investigate whether market quantities are significantly lower under the Poisson revision games than the real time revision games when there are more than two firms in the market (triopoly/oligopoly). Does increasing the number of competitors result in choices that are more competitive? Third, the focus of this study was on situations where revision opportunities are synchronous, yet it is very likely that different players may get these opportunities at different points in time (asynchronous). It would be worthwhile to see if quantity choices are significantly different. Fourth, an important characteristic of the revision games implemented in this paper was perfect observability of competitor’s intended choices at every point in time. Relaxing this assumption might affect the competitiveness of the market. For example, allowing participants to observe only the choices at last received opportunity is likely to induce different dynamics of behavior depending on the initial choices.

References


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:

\[
\text{Profit} = \text{Revenue} - \text{Cost} = (P - 2) \times (\text{quantity produced by you})
\]

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’ treatments.] 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 with Monitoring’ treatments.] 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 ‘Poisson Revision’ treatments.] 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 [1,50]. If the integer drawn is 1, then an “event” occurs. This means that every second the probability that an “event” happens is 0.02 (as every integer is equally likely to be drawn). So on an average, an “event” takes place every 50 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 11th 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

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11For the Poisson High treatment, the following was presented: 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.
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.
C User Interface

Figures C1-C3 show the user interface. At the beginning of any match each subject had to choose 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 match started in real time. In the baseline treatment, a subject only observed her own tentative quantity, as shown in Figure C1. Notice that 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 match.

![Figure C1: Subject Screen for Baseline Treatment](image)

Figure C1 displays the interface for the treatments with real time revision with monitoring. Here a participant got to see her own tentative quantity, the tentative quantity chosen by her competitor and the tentative profits. The screen was updated whenever either of the two matched participants decided to change their respective quantities. The final output choice for a match was given by the last entry on the screen at the end of the revision phase.

The screen display for the treatments with a Poisson Revision phase is given in Figure C3. Now 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 match. Specifically, the final
choices and profits for a match were given by the tentative quantities and profits corresponding to the last “starred” entry on the screen.
Figure C3: Subject Screen for Poisson Revision