A Classroom Experiment on Oligopolies

Robert G. Nelson and Richard O. Beil, Jr.*

Abstract

This experiment demonstrates principles of decision-making in dynamic oligopolies, especially the difficulties in forming and maintaining cartels. As an illustration of firm behavior under imperfect competition, the game distinguishes between procedurally rational choices and substantively rational decisions in the context of collusive, Cournot, and competitive equilibria. The paper discusses results from an actual classroom exercise and suggests some additional variations in institutional details. Instructions for students and a spreadsheet program for producing payoff tables are provided in the appendices.

Key Words: teaching, experimental economics, oligopoly

In his criticism of attempts to describe the behavior of the oligopolist within the framework of profit maximization and substantive rationality, Herbert Simon referred to the theory of imperfect competition as "the permanent and ineradicable scandal of economic theory" (p. 140). He argued that not until attention is directed to the *procedure* of decision-making will the profession come to terms with the realities of behavior in oligopolies. This experiment exposes the student to some of the institutional details of imperfect competition within the framework of procedural rationality--behavior that is simply the outcome of "appropriate deliberation" (Simon, p.131)--and encourages them to explore strategies used by real-world oligopolists. Following a more orthodox approach, results of the experiment can also be organized to supplement understanding of several of the "classical" equilibria: collusive, Cournot, and competitive.

The key assumption that distinguishes the model of perfect competition from models of oligopoly is the degree of interdependence among firms. The model of perfect competition assumes that firms believe they are independent, in the sense that their actions have no effect on the actions of others. In contrast, models of oligopoly assume that firms believe they are interdependent and must take into account the behavior of other firms in their market. Real-world oligopolists are well aware that their actions can trigger strategic counteractions by their rivals. Mathematical models of oligopolistic behavior make specific assumptions about the conjectures firms hold regarding how their rivals will react to changes in prices or outputs. In addition to conventional models of competition and monopoly (including cooperative oligopolies, cartels or joint profit-maximizing industries), these "conjectural variations" models include the Cournot, Bertrand, Edgeworth, and Stackelberg models of oligopoly behavior. This experiment reveals some of the limitations of these models when output decisions are made over several periods.

Classroom games are unique in that learning takes place through the student's own experiences, which in turn reinforces the relevance of related theory and analytical procedures (Tierney). Efforts by our profession to encourage more "discovery-learning" (Ladd) extend at least as

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far back as the 1960's (Babb and Eisgruber; Curtis). For the most part, previous work has been directed toward computer-assisted games that emphasize market complexity, dynamism and realism (Dahlgran). The activities most often described are computerized simulations that are integrated throughout the entire course and that require considerable investment of effort on the part of the instructor(s). For example, the "Packer-Feeder Game" of Koontz et al. is a testimonial to how successful and engaging experiential learning can be, but it required the attentions of four faculty members and one graduate student to coordinate the exercise. Such computer-aided simulations have been developed for a wide variety of agricultural applications including farm management (Eidman et al.), rural bank management (Fisher, Boehlje, and Roush), rural development (Nelson and Doeksen), and commodity futures and options trading (Trapp; Fackler).

The classroom exercise described in this paper comes from the family of experiential learning techniques known as "experimental economics." Advantages of experimental economics games have been addressed by a number of educators including Walker, French and Turner, DeYoung, and Fels. Descriptions of specific experimental games include price discovery mechanisms (French and Turner), Coasian bargaining (Leuthold), monopoly (Nelson and Beil), voting paradoxes (Sulock), public goods (Brock), and oligopolies as Prisoners' Dilemmas (Hemenway, Moore, and Whitney). Experimental games, even those that are computer-assisted (Williams and Walker), are generally more simple and more abstract than computer-assisted simulations. But what experiments give up in complexity may be returned in efficient use of scarce instructional resources, and what they lack in realism may be gained in replicability and "control" so that the effect of a treatment variable is unambiguous.

Experiential learning can greatly improve students' understanding of firm behavior in oligopolistic markets. Although the procedures we describe have been employed in the research literature of experimental economics for at least thirty years, we hope that by carefully detailing the pedagogical aspects of this exercise it will be more widely adopted in the classroom.

Method

Three types of experimental markets have been used to examine behavior in oligopolies: markets with firms that set quantity only, or firms that set price only, or firms that set both price and quantity (Kreps and Scheinkman; Holt, 1985; Feinberg and Sherman). This experiment shows how to construct a quantity-setting market with a small number of participants (two to four "firms").[1] One purpose of the experiment is to demonstrate that it can be surprisingly difficult to form an effective cooperative oligopoly or cartel, even when the number of firms is "small" by conventional standards.

In this experiment the class is broken up into groups of two, three or four participants.[2] Each member of a group is given a participant number and represents one firm in the market. Firms are identical in that they sell the same product to a common group of customers, and have the same cost of production. Markets are not subject to entry by new firms. The product is homogeneous (to obviate considerations of quality differences) and nondescript (to eliminate preconceptions about specific products and markets). Production costs and demand are incorporated in a payoff table (Fouraker and Siegel: Battalio and Phillips). Each student receives a set of instructions, a payoff table, a record sheet and a set of quantity registers. Examples of these materials are provided in the appendices.

For all but the smallest class sizes, the instructor will need to recruit some class members to collect quantity registers and to sum the quantity delivered by the members in each market/group. Motivation to play the game seriously can be increased by rewards of bonus points, participation credit, money, etc.[3] Helpers should be compensated with the average earnings for the class.

After the instructions and other materials have been handed out, the instructor reads the instructions to the class, demonstrates how to fill out the record sheet and the quantity registers, and explains the payoff table. Each student will be playing the role of one producer/firm in the market.

In the first period, each producer writes down on a quantity register some quantity to be delivered to market. The instructor and the helpers collect the quantity registers, group them by market, and sum the output delivered to each market. The output totals for each market are then posted on the blackboard.

After the totals for the period have been posted, students look up their individual earnings on a payoff table, record their earnings from that period on a record sheet, and use the rest of the time to consider what quantity to deliver in the next period. The instructor then opens the next period for deliveries and the process begins again.

This experiment can be conducted in one 50-minute class period. Alternatively, the experiment can be conducted over a number of class periods. In either case, two firms can often achieve the collusive equilibrium, while aggregate outcomes from three and four firms more closely approximate Cournot or competitive equilibria. With more than four firms, and in the absence of facilitating factors, outcomes are almost never collusive. As the number of players in each market increases there is also a tendency for markets to settle into a pattern more slowly (Alger). When multiple class periods are used (and students can find out who else is in their market) collusive outcomes are more common.

The outcomes from two classroom markets are illustrated in the Sample Results section. The payoff table used in that experiment (30 rows by 50 columns) covered four pages; only the second page, which shows a number of the classical equilibria, is reproduced in table 1.[4] Table 1 highlights the collusive and Cournot quantities and profits for three- and four-firm markets, and Cournot and competitive values for a duopoly. The remaining three equilibria are located on other pages of the payoff table given to students (not shown here). Of course, cells on the students' tables were not highlighted.

Since the firms in each industry are identical, they should produce identical quantities in equilibrium if profits are to be shared equally (a symmetric equilibrium). For this reason, the three classical symmetric equilibria lie on a "diagonal" in the payoff table. Thus a quick way to find these points in an identical-firm payoff table is to highlight the relevant profit cells on the diagonal, which in the four-firm case would start with coordinates (1,3), (2,6), (3,9), etc. The largest value among those cells is the collusive outcome at coordinates (6,18) with $78 profit, highlighted in table 1. The Cournot outcome is the cell at which any move up or down the column yields a lower profit. In the four-firm case this occurs at coordinates (10,30) with $50 profit, also shown in table 1. The competitive outcome is the cell that has a zero in it or, in the case of non-integer equilibria, is closest to zero, such as in the four-firm example where the coordinates are (12,36) with $12 profit (not part of table 1).[5]

Sample Results

Figure 1 shows the results of a 90-minute experiment for a four-firm market (Industry A) and a three-firm market (Industry B). This particular experiment was chosen to illustrate the effects of a rule change in the middle of the game. The figure also demonstrates how to present market results graphically; it is not intended to be representative of any sort of "typical" outcomes.

Players in both types of markets operated under the "no talking" rule (mentioned near the end of the instructions) until period 11 when the instructor waived the rule and allowed them to discuss production alternatives and plans. The effect in Industry A was quite dramatic: they formed a cartel and maintained it for the remainder of the experiment. The cartel organizer monitored the output of each member by asking what quantity each had submitted. However, because the instructor would not reveal who had actually delivered what quantities, it was possible for individuals to cheat on the cartel by producing more than their share, although no one in Industry A exploited this opportunity after period 11.[6]

Despite the opportunity to talk after period 10, Industry B did not form any recognizable pattern of output during the experiment, although the average output was closest to the non-cooperative, Cournot prediction. However, figure 1 demonstrates how industry aggregate results may seemingly imply some commonality in behavior, while individual results reveal considerable variation in behavior. The lack of stable equilibrium outcomes (other than the collusive) is a phenomenon that has been noted regularly as far back as Fouraker and Siegel's pioneering work.

Table 1. Partial[a] payoff table with classical equilibria for 2-firm[b], 3-firm[c], and 4-firm[d] oligopolies

		SUM OF OTHERS' CHOICES----------->															
		16	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
N	**1**	16 5	16	15.5	15	14.5	14	13 5	13	12 5	12	11 5	11	10 5	10	9 5	9
U	**2**	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17
M	**3**	46 5	45	43.5	42	40 5	39	37 5	36	34 5	33	31.5	30	28 5	27	25 5	24
B	**4**	60	58	56	54	52	50	48	46	44	42	40	38	36	34	32	30
E	**5**	72 5	70	67.5	65	62.5	60	57 5	55	52.5	50	47.5	45	42.5	40	37 5	35
R	**6**	84	81	**78**	75	72	69	66	63	60	57	54	51	48	45	42	39
	7	94.5	91	87 5	84	80 5	**77**	73.5	70	66 5	63	59 5	56	52 5	49	45.5	42
O	**8**	**104**	100	96	92	88	84	80	76	**72**	68	64	60	56	52	48	44
F	**9**	112 5	108	**103.5**	99	94 5	90	85.5	81	76 5	72	67.5	**63**	58 5	54	49 5	45
	10	120	115	110	105	**100**	95	90	85	80	75	70	65	60	55	**50**	45
U	**11**	126.5	121	115 5	110	104.5	99	**93.5**	88	82.5	77	71 5	66	60 5	55	49.5	44
N	**12**	132	126	120	114	108	102	96	90	**84**	78	72	66	60	54	48	42
I	**13**	136 5	130	123 5	117	110.5	104	97.5	91	84.5	78	**71.5**	65	58.5	52	45.5	39
T	**14**	140	133	126	119	112	105	98	91	84	77	70	63	**56**	49	42	35
S	**15**	142 5	135	127.5	120	112 5	105	97.5	90	82 5	75	67.5	60	52.5	45	**37.5**	30
	16	**144**	136	128	120	112	104	96	88	80	72	64	56	48	40	32	24
Y	**17**	144 5	**136**	127 5	119	110.5	102	93 5	85	76 5	68	59 5	51	42 5	34	25 5	17
O	**18**	144	135	**126**	117	108	99	90	81	72	63	54	45	36	27	18	9
U	**19**	142 5	133	123 5	**114**	104 5	95	85.5	76	66 5	57	47 5	38	28 5	19	9 5	0
	20	140	130	120	110	**100**	90	80	70	60	50	40	30	20	10	0	-10
D	**21**	136 5	126	115 5	105	94 5	**84**	73 5	63	52 5	42	31 5	21	10 5	0	-10 5	-21
E	**22**	132	121	110	99	88	77	**66**	55	44	33	22	11	0	-11	-22	-33
L	**23**	126 5	115	103 5	92	80 5	69	57 5	**46**	34 5	23	11 5	0	-11 5	-23	-34 5	-46
I	**24**	120	108	96	84	72	60	48	36	**24**	12	0	-12	-24	-36	-48	-60
V	**25**	112 5	100	87 5	75	62.5	50	37 5	25	12.5	**0**	-12 5	-25	-37 5	-50	-62 5	-75
E	**26**	104	91	78	65	52	39	26	13	0	-13	-26	-39	-52	-65	-78	-91
R	**27**	94.5	81	67 5	54	40 5	27	13 5	0	-13.5	-27	-40.5	-54	-67 5	-81	-94 5	-108
E	**28**	84	70	56	42	28	14	0	-14	-28	-42	-56	-70	-84	-98	-112	-126
D	**29**	72 5	58	43 5	29	14 5	0	-14 5	-29	-43.5	-58	-72 5	-87	-102	-116	-131	-145
	30	60	45	30	15	0	-15	-30	-45	-60	-75	-90	-105	-120	-135	-150	-165

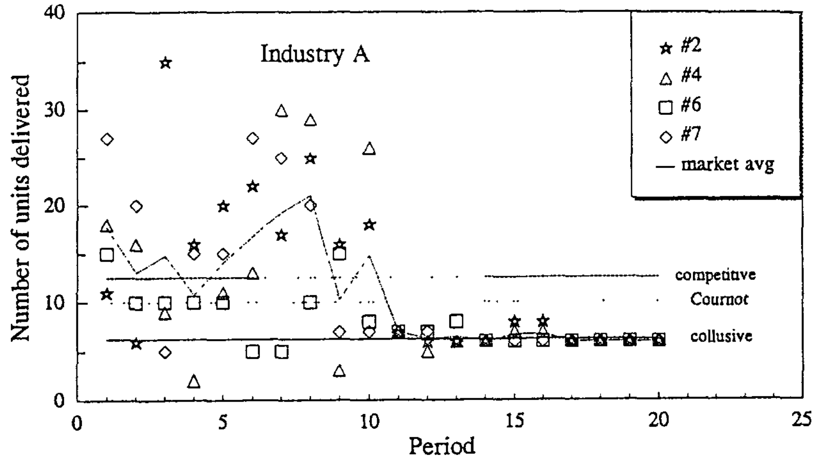
[a] This table shows only the second page of a four-page handout (30 x 50 matrix) given to students. Their version had no highlighted cells.

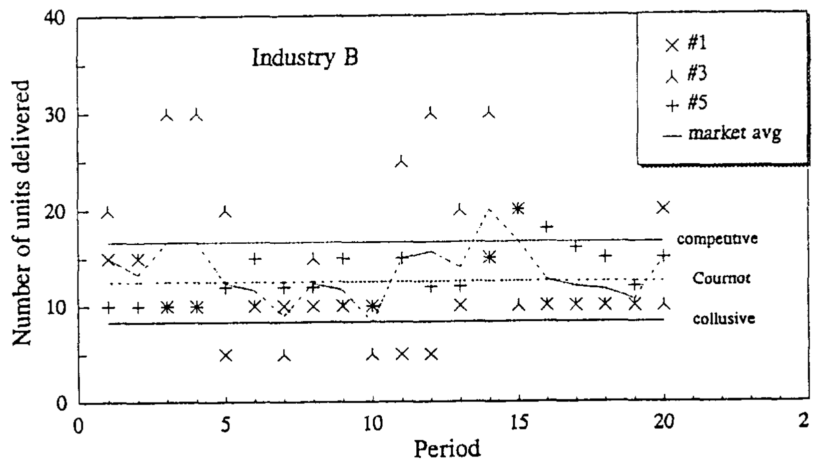
[b] Lower highlighted diagonal is for duopoly; upper boxed cell shows Cournot outcome, lower shows competitive outcome.

[c] Middle highlighted diagonal is for 3-firm oligopoly; upper boxed cell shows collusive outcome, lower shows Cournot outcome.

[d] Upper highlighted diagonal is for 4-firm oligopoly; upper boxed cell shows collusive outcome, lower shows Cournot outcome.

Figure 1. Results from a four-firm market (A) and a three-firm market (B)





Fluctuations *around* the Cournot outcome are evidently far more common than equilibration, as players continuously respond to more or less cooperative quantity signals.[7]

Discussion

Principles and Theory

At the level of introductory principles courses, the experiment illustrates several points of interest. Participants in the four-firm oligopoly learn that it is difficult to collude--even with as few as four firms in a market--when it is unclear who the other firms are and what each one is doing. On the other hand, participants in the duopoly market may be able to attain the collusive outcome simply because it is less ambiguous what the only other producer is doing, a condition that adds greatly to the information content of a quantity signal.

If time permits, it may be instructive to let each student experience both the two-firm and the four-firm situations, so they can appreciate the dynamics of these markets from a comparative viewpoint. As demonstrated in the sample results above, an alternative that facilitates cooperation is to allow the participants to talk to each other in later periods. Either of these variations can serve to illustrate some of the elements necessary to achieve cooperative outcomes.

For a more advanced discussion of theory, the classical equilibrium outcomes have some interesting features. The four-firm oligopoly demonstrates that the collusive outcome is difficult to achieve and maintain. It is an equilibrium that is likely to be unstable in the absence of continuous inputs of organizational energy (Beil). However, once it is achieved this is usually conclusive evidence that all the players are colluding, even when only aggregate data are available.

The competitive outcome (zero, or near-zero profits for all) is usually not stable because all of the participants, even with only their self-interest at heart, can individually do better than that. For example, suppose a duopolist finds himself at the competitive point on table 1 (coordinates (25,25); profit = $0). If he believes that the other player is going to deliver 25 units (or some similarly large quantity) again then he could reduce his deliveries to around 13 units and earn up to $78. Nevertheless, the competitive outcome is still the "efficient" point from a welfare perspective since it maximizes producer-*plus*-consumer surplus.

The Cournot outcome is often dismissed as implausible due to its popular interpretation that each firm believes that in the coming period all the other firms will produce exactly the same amount that they produced in the last period, even in the face of repeated experience to the contrary. Yet, paradoxically, production of the Cournot quantity (40 units, in the four-firm market) turns out to be a relatively common aggregate outcome.

What can aggregate results tell us about a theory that is based on individual behavior? Here the economics experiment is most useful because the analysis does not have to rely only on aggregate data; individual data are also available. Indeed, it is much less common for each firm to deliver exactly the symmetric Cournot quantity, as the individual results show in figure 1. Player-firms are rarely content to deliver the Cournot quantity period after period. Thus, the interpretation of market dynamics is vastly different when four firms deliver 10-10-10-10 than when they deliver 6-6-6-22, even though the aggregate output infers Cournot conjectures in both cases.

In cases where all firms are delivering the Cournot quantity, this is also a symmetric Nash equilibrium. That is, if all firms admit a right to produce an amount equal to every other firm (i.e. some affirmation of the "fairness" of equal market shares in an identical-firm industry) or, using a weaker form of conjectures, they expect the sum of the other three firms' output to stay fixed at 30 units (for whatever reason), then no firm can make itself unilaterally better off by producing more or less than 10 units. In short: if they all get to the Cournot output, they should have a strong motivation to stay there, assuming no changes in conjectures. Even though the *aggregate* Cournot output is the empirical regularity of this experiment (Beil), the *individual* Cournot output may still be useful for illustrating the game theoretic concept of Nash equilibrium (Gibbons), and for demonstrating that "non-cooperation" is distinct from "competition" under the conditions of oligopoly.

Variations

In advanced classes, students can be given the actual cost and market demand functions that generate the payoff tables. Using these functions, students should arrive at the same numbers as used in the payoff table, barring errors in calculation. This would also make it possible to assign different cost functions to different firms, as well as allow for more complicated experiments involving price- and quantity-setting conditions (Friedman). Product differentiation, including quality factors and potential returns to advertising, could be incorporated to add further complexity.

If students are allowed to reveal their identities and talk to one another then collusion is greatly facilitated, but is by no means guaranteed to endure. To achieve a lasting cartel, provisions for monitoring and penalties are usually necessary (Beil). Various agreements such as contractual restrictions or trigger reactions can be explored. Follow-up lectures could include discussions of anti-trust regulations and the legalities of cooperative agreements in national and international contexts.

Another variation that can be accommodated with payoff tables is the Stackelberg leader-follower model. In this design one of the firms is designated as Leader and the other firm(s) as Follower(s). The only difference between the Stackelberg experiment and the one detailed in this paper is in the sequencing of actions: the Leader gets to choose his quantity first, his choice is posted, and then the Followers all submit their quantity offers at the same time. The sum of all quantities delivered is then posted and the participants find their individual payoffs from the table as before. Because of the Leader's first-mover advantage, equilibrium quantities delivered in the Stackelberg game are not symmetric.

Conclusions

Classroom oligopolies readily reproduce much of the richness of small-group interaction that is absent from mathematical treatments of oligopoly theory. Students observe that outcomes are clearly sensitive to such institutional variables as the number of firms, factors that facilitate communication, monitoring of cooperative compliance, and enforcement of penalties for non-cooperation. Single-period "rational" decisions become subordinate to the effectiveness of procedures used to make decisions over many periods.

Considerable efforts are being expended on a number of research fronts to identify an acceptable equilibrium-selection mechanism that uniquely describes and predicts firm behavior under conditions of interdependence. Currently no single theory satisfactorily encompasses the totality of observed behavior.

Prospects for a unified theory being doubtful in the near future, the state of substantively rational theories of imperfect competition is likely to merit Simon's epithet of "scandal" for some time. However, through the medium of classroom experiments our students can at least experience how decisions are made in imperfectly competitive markets and come to appreciate some of the variables that influence outcomes. Just because our theory is insufficient does not mean our students' learning experience need be.

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Appendix 1

FOUR-FIRM OLIGOPOLY
INSTRUCTIONS FOR PARTICIPANTS

In this experiment, you will participate as a producer in a market. Your market has three other producers in it. The experiment will last for a number of periods. You have been given a "participant number" to use in reporting the choices that you make and a "market number" to distinguish what market you are in. You will get one extra point added to your final grade for every $1000 that you earn in this game.

In each period you will choose a quantity to produce and deliver to market (i.e. a number between 0 and 30). After the other producers have also made their choices, the total amount delivered by all the producers in your market will be posted on the blackboard, but you will not be told how much any particular individual delivered.

A payoff table is provided so that you may determine your potential profits. To read your payoff table, look at the number of units that you chose to produce (written down the left hand side of the table) and the sum of the units that the other three participants produced (written across the top of the table).

Your profits for a given period are shown at the intersection of the row you chose and the column showing the sum of the production by the other three producers. For example, suppose you chose to produce 9 units. You don't know what any one of the other producers chose, but you see posted on the blackboard that a total of 36 units were produced by your market. Since you know that you produced 9 of those units, then the sum of the others' choices must be 27 (i.e. 36 minus 9). To find your profits you would locate 9 on the side of the table and 27 along the top of the table and find where the 9^{th} row and the 27^{th} column intersect. At that intersection you would find the number 63, which would be your earnings for that period ($63, or 63/1000 of a point). All the producers in your market have identical production characteristics; that is, they have the same cost curves, the same market demand, and the same payoff table.

At the beginning of each period, each producer in your market will have to make a guess as to what the other producers will do in that period. After you have made your guess about what the others will do, then you can choose the level of output that you think will maximize your earnings.

Understanding how the payoff table works is very important. If you don't understand it when you play the game, your earnings will suffer. Let's take some time now so that you can get more practice with the payoff table.

Example 2: If you think that each of the other producers will choose 6 units, what will you choose? Suppose you choose 7 units. Then you would expect your earnings to be $87.50 for that period, which is the intersection of row 7 and column 18 (since you predicted that the others would choose a total of 18 units, or 6+6+6). But notice that if you choose 16 units, your predicted earnings would be $128.

Example 3: If all four producers were to choose 12 units of output, how much would you would earn? Since your choice was 12 and the sum of the others' choices was 36, then the intersection of row 12 and column 36 shows that your earnings would be $12.

At the beginning of each period the instructor will ask you to make a choice of how much you wish to produce. Once you have made your choice, write that number on your Quantity Register along with your participant number, market number and period in their proper places (an example is shown at the end of the instructions). Also, for your own record, write your choice on your Record Sheet in the box under the correct period. Next, fold your Quantity Register in half, raise your hand, and one of the helpers will pick up your register. After all the Quantity Registers have been collected for that period they will be totaled for each market and posted on the blackboard by market number. To calculate your earnings for the period, use your Record Sheet to help you in subtracting your units from the market total, and then look up your earnings at the appropriate intersection on the payoff table. Use your Record Sheet to record your earnings for this period, then go on to make your choice for the next period.

You will play this game with the same people in your market for the entire experiment. Please do not talk with anyone in the room during the experiment. If you have a question at any time, raise your hand and the instructor will answer your question.

SUMMARY

1. You will participate in a market with three other people for a number of periods.

2. Each participant will make a choice to produce a number of units between 0 and 30 units in each period.

3. After you have chosen how much to produce in that period you will write it on a Quantity Register along with your participant number, the number of the market you are in, and the current period. Hand this in to the instructor.

4. When all the registers are collected, the instructor will post the total units produced in each market for that period.

5. You will then fill out your Record Sheet, record your earnings, and make a choice for the next period. The amount you earn will add to your final grade.

If you have questions that you feel were not adequately answered in the instructions, please raise your hand and ask your questions at this time.

Example of a Completed Quantity Register

Quantity Register

Participant Number__15__ Market Number__6__ Period__1__

My choice of number of units to produce this period is:__14__

RECORD SHEET

PARTICIPANT NUMBER __________ MARKET NUMBER __________

1	PERIOD - - - - >	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	TOTAL UNITS DELIVERED															
3	NUMBER OF UNITS YOU DELIVERED															
4	SUM OF OTHERS' CHOICES															
5	YOUR EARNINGS FOR THIS PERIOD															

TOTAL EARNINGS
FOR ALL PERIODS ________________

Appendix 2

A sample spreadsheet (using LOTUS™ notation) is constructed as follows. The intercept of the demand curve is in cell B1 and is currently set at 26. The slope of the demand curve is in cell B2 and is set at its absolute value (0.5, in this case). Marginal cost is in cell B3 and is set at 1. The number of firms in the market group (used in calculating the equilibria for an n-firm oligopoly) is in cell B4 and is set at 4. The columns in the payoff table are titled "Sum of Others' Choices" and the units extend across row 9 starting with a zero in cell C9. The rows are titled "Number of Units You Delivered" and extend down column B starting with a 1 in cell B10. The payoff table itself is in the cell range C10..BA39 with the cell in the upper left corner (C10) having the formula ((B1-((B2)*(C$9+$B10)))*$B10)-($B10*B3). This cell can be copied down and across to fill the entire table.

The worksheet is designed so that changing any of these parameters will automatically update the worksheet and recalculate the collusive, Cournot, competitive and Stackelberg quantities for the firm. The collusive level of output for the firm is currently 6.25 units, which can be calculated by the formula (B1-B3) / (2*B2*B4). The Cournot quantity for the firm is 10 units, using the following formula (B1-B3) / (B2*(B4+1)). The competitive quantity for the firm is 12.5 units and is calculated by (B1-B3) / (B2*B4).

In a variation of this game that explores Stackelberg leader-follower conditions, the Stackelberg leader's equilibrium output is 25 units, calculated by (B1-B3) / (2*B2), and the Stackelberg follower's equilibrium is 6.25 units, calculated by (B1-B3) / (2*B2*B4). A derivation of the formulas used to determine these equilibrium quantities can be found in Appendix 10A in Carlton and Perloff.

Endnotes

1. Some economists consider a quantity-setting market to be less realistic than a price-setting market, and may favor a Bertrand price-choice approach (Holt, forthcoming). For instance, the quantity-setting market incorporates an implicit assumption that the total output delivered to the market is auctioned off by a competitive process that leaves no excess supply or demand (Davis and Holt). On the other hand, in price-choosing experiments with more than two producers, participants can be expected to compete away all profits, leading to a relatively uninteresting--and unrewarding--price war (Spence). We feel the quantity-choosing experiment is preferable for the classroom simply because it is more likely to demonstrate collusive and Cournot outcomes.

2. The spreadsheet and instructions in the appendices can easily be modified to accommodate more than four participants per market. However, in our experience having more players adds little to the exercise, and requires an even larger payoff table.

3. We highly recommend using rewards when conducting experiments in the classroom. Games played for "suitable" rewards are said to satisfy two of the requirements of good experimental practice: salience (motivational relevance that links the reward to the task) and dominance (anticipated rewards dominate any other costs or benefits that might affect performance of the task). More extensive coverage of these issues can be found in Friedman and Sunder, and in Davis and Holt.

4. A complete copy of the payoff table can be obtained from the authors, or easily generated in a spreadsheet. The spreadsheet described in Appendix 2 was used to generate the 30 x 50 table. It incorporates the following inverse demand function: $P = 26 - 0.5Q$. The supply relation uses a constant marginal cost: $MC = 1$. The spreadsheet automatically calculates the profit for every combination of outputs in the matrix.

5. In the four-firm example, the collusive output for the individual firm, as calculated by formula, is actually 6.25 units, for a profit of $78.125. Since this is not an integer, an exceptionally refined cooperative agreement, similar to a "bid rigging" scheme, would be for three of the participants to produce six units of output (for a profit of $75 each) and the fourth to produce seven units (for a profit of $87.50), with the extra unit rotating among the cartel members from period to period. Although this would maximize the joint earnings of the participants, in practice the extra unit is often never produced since it adds yet another dimension of coordination that makes it even harder to collude.

6. This game was conducted in a graduate class where, initially, motivational rewards in the form of grades were not considered necessary. However, as evidenced by average *losses* of $271 per firm, Industry A probably would have behaved more conservatively had rewards been used. The reckless competition evident in periods 1-10 also revealed an unanticipated constraint in the payoff table: the "sum of others' choices" sometimes exceeded 50 units. When this happened players were told that the default payoff would be that of the 50^{th} column of the payoff table, which was always a negative number, but not as large in absolute value as it would have been on a longer table. Players also had to be advised to deliver no more than 30 units.

7. Of the hundreds of quantity-setting experiments that have been conducted with monetary rewards, the only stable equilibrium commonly observed is that of tacit collusion (see Fouraker and Siegel; Dolbear, et al.; Holt, 1985; Beil; and Plott, Sugiyama, and Elbaz).