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The effect of experience in Cournot play[1]

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Abstract

Strategic play requires that players in oligopolies be more sophisticated than in perfectly competitive markets. It thus seems reasonable to assume that player experience becomes important as the environment gets more complicated. We find that subject experience indeed plays an important role. While inexperienced symmetric duopolies play around the Nash-Cournot quantity, experienced duopolies reduce output and get closer to the monopolistic outcome. Both inexperienced and experienced symmetric quadropolies, however, produce output above the Nash-Cournot equilibrium but, even in this case, output is lower for experienced quadropolies. Experience, however, does not make markets less competitive with the introduction of cost asymmetry. Under cost asymmetry, and relative to the equilibrium prediction, high cost firms produce more output than low cost firms. Analysis of individual data tells us that experienced duopolies and quadropolies adjust output in the same direction as their rivals. Due to the strategic substitutability of quantity choice, we interpret this as an attempt at tacitly colluding. This is true for both duopolies and quadropolies.

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1. Introduction

The structure of competitive markets is quite robust with respect to the level of expertise of the participants. The nature of play in these markets is quite different from oligopolistic markets where firms are not price takers and need to understand (at least at the intuitive level) the nature of strategic interaction between rivals. Besides a valid robustness check, the role of experience in understanding the nature of play in these markets may thus be important[2].

Based upon these ideas we conduct experiments where each subject participates twice in a quantity setting market. Following standard convention we call first time participants as inexperienced and second time participants as experienced subjects. All experiments were run with symmetric and asymmetric cost oligopolies. We find that experience can indeed be an important factor in quantity setting oligopolies. The role of experience varies depending upon the market and cost structures.

Our findings can be summarized as follows. First, in line with results reported in the literature, inexperienced subjects in symmetric cost environments play around the non-cooperative Nash-Cournot equilibrium. Observed quantities are slightly above the theoretical prediction for duopolies and a little higher for quadropolies.

Second, we observe the well known result that an increase in the number of firms makes the market more competitive. Both inexperienced and experienced quadropolies produce output above the Nash prediction.

Third, and in contrast to the behavior of inexperienced subjects, experienced duopolies choose and output notably smaller than the Nash-Cournot prediction. In fact, in three out of four symmetric duopoly experiments subjects choose output on the collusive side, with one of them approaching remarkably close to the monopolistic output. Experienced quadropolies still produce slightly more than the equilibrium prediction, but less than the inexperienced counterparts.

[2] Nagel and Vriend (1999) study the role of experience in a variation of the quantity choosing game. The price of the commodity is fixed for all periods and firms send costly information signals to attract buyers. They find that experience does not matter in this setting.

Fourth, we find that asymmetric cost duopolies are more competitive than their symmetric counterparts[3]. However, there are important differences in output selection between the low and high cost firms. In all cases (inexperienced and experienced, duopoly and quadropoly) low cost firms tend to produce around the non-cooperative equilibrium. The high cost firms, on the other hand, produce more than their respective Nash-Cournot equilibrium quantities. Deviation from the equilibrium is higher for high cost firms and is higher for quadropolies than for duopolies. Further, compared with experienced players, the deviation from equilibrium is greater for inexperienced subjects.

Fifth, an analysis of individual data tells us that experienced subjects tacitly collude more than inexperienced ones. Given the negative slope of the reaction function, we know that the best responses for individual subjects must be negatively correlated with respect to the rivals' chosen quantity. However, we find that the output choices for experienced duopolies are positively correlated. Even though experienced quadropolies tend to be relatively more competitive, we find that the correlation coefficient for them is positive in most cases. This result is surprising and indicates that subjects clearly attempt to change output in the same direction, thus suggesting attempts at tacit collusion. Another interesting result from the individual analysis is that greater support is found for Cournot conjectures under asymmetric costs. This is true for inexperienced and experienced subjects.

Finally, we run individual regressions where individual play is explored by estimating some decision rules. Our results do not support the best response dynamics. In fact a large number of the subjects adjust output in correlation with rival outputs. This may be indicating attempts to collude. Surprisingly, we obtain the same result also for experienced duopolies. This proportion, however, drops for quadropolies indicating that collusion becomes difficult with a large number of firms.

The results we present for the asymmetric cost experiments are along the lines of the results presented in Mason *et al*. (1992) for inexperienced subjects. Our results, however, differ from theirs for experienced subjects. We find that experienced asymmetric duopolies are relatively more competitive than their inexperienced counterparts. Though,

[3] This result is also reported for inexperienced subjects in Mason *et al*. (1992).

not a direct test of his theory, the findings in our paper can be better interpreted given the predictions in Vasconcelos (2005). He analyzes the incentives to collude for quantity setting oligopolies in a repeated game framework. He shows that the incentives to collude are decreasing in the degree of asymmetry. Further, smaller (less efficient) firms have a greater incentive to deviate from possible collusive outcomes. It is interesting to note that we observe similar results in a random-matching framework.

Our paper adds to an already wide body of literature on quantity setting oligopolies[4]. The broad results from the quantity experiments are the following. Obtaining successful collusion[5] in experimental quantity setting oligopolies is difficult, and the non-cooperative Nash-Cournot equilibrium is a good predictor of the quantity choices under random matching (Holt, 1985; Huck *et al*., 2001; and Huck *et al*., 2004). Successful collusion only sometimes emerges with duopolies under fixed matching while quadropolies result in outcomes that are much more competitive than predicted. Further, outcomes under asymmetric costs outcomes are relatively more competitive (Mason *et al*., 1992). Our results add to the existing literature in that we show that subject experience is indeed important, and that it influences the outcome differently, depending on the quantity of firms and the asymmetry of the costs. Further, we conduct analysis of individual data shows that experienced subjects attempt to collude both under symmetric and asymmetric costs under both duopolies and quadropolies.

The paper is structured as follows. In Section 2 we discuss the experimental design. Section 3 presents the results detailed by market, while Section 4 analyzes individual behavior. Section 5 concludes.

2. The experimental design

A total of 278 students participated in 63 duopoly and 38 quadropoly experiments at George Mason and Chapman universities. Subjects were told that they had to commit for

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[4] See meta survey is Huck, Normann and Oechssler, 2004.

[5] The effect of changing information on collusion is found in Fouraker and Siegel (1963) and Huck *et al*. (1999 and 2000).

two series of experiments and were paid \$20 upon showing up for the second experiment[6]. The experiments lasted around 2 hours for inexperienced and 90 minutes for experienced subjects. Out of the 16 duopoly and 10 quadropoly (inexperienced) experiments subjects were then used for 15 duopoly and 9 quadropoly experiments at George Mason University. At Chapman University, out of the 16 duopoly and 10 quadropoly experiments subjects then came back for 16 duopoly and 9 quadropoly experiments[7]. Subjects were provided computerized interactive instructions[8].

All experiments were conducted for 2 and 4 firms with symmetric and asymmetric costs. Three different treatments were run with inexperienced subjects for both duopolies and quadropolies. The experiments were then repeated with once experienced subjects. In the first series of experiments the upper production cap was kept at the monopoly level of output and slightly above the monopoly level for the asymmetric cost case (with the lower cap at zero)[9]. As monopoly output is different for the high and low cost firms we set the production cap slightly above the monopoly outcome for the asymmetric cost experiments (see Table 1 for details).[10]

In all experiments, except one, we use the linear demand $P = A - Q$. Demand and seller costs were adjusted so that $A - c = 90$. For the symmetric cost cases, the individual quantities in the Nash-Cournot equilibrium are $q^{(n=2)} = 30$ and $q^{(n=4)} = 18$ for the duopoly and quadropoly, respectively, which give total market quantities of $Q^{(n=2)} = 60$ and $Q^{(n=4)} = 72$. The competitive and monopoly and levels of total market outputs are $Q^{comp} = 90$ and $Q^{monop} = 45$, respectively. In one series of experiments the slope was changed to 0.83. To facilitate comparisons, most results are presented as proportions with respect to the Nash-Cournot equilibrium or to the competitive quantities.

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[6] A large show up fees may have wealth effects on subject behavior. Note that our show up fees (\$20) was only \$6 more than the show up fees for two subsequent experiments (i.e. \$14). We would like to thank Han-Theo for making this point.

[7] The decrease in the number of experiments with experienced subjects is due to no shows.

[8] Instructions can be seen in the Appendix.

[9] This was done to check the robustness of the results. Note that production caps have not been consistently set in the literature

[10] We study the role of production caps in detail in a companion paper.

For the asymmetric cost experiments parameters A and c were set such that $A-c=90$ for the high cost firm, and 95 for low cost firm. The Nash-Cournot individual equilibrium quantities are 28.33 and 33.33, respectively. The various equilibrium outcomes for 2 and 4 sellers are listed in Table 2.

Table 1			
	Number of experiments	Production caps	
		Inexperienced	
Symmetric	Duo/Quad	Duopoly	Quadropoly
Set 1	5/5	{0,45}	{0,45}
Set 2	6/5	{0,90}	{0,90}
Set 3	4/-	{7,45}	-
Set 4	7/5	{0,45}	{0,45}
Asymmetric			
Set 5	9/5	{0,50}	{0,50}
		Experienced	
Symmetric		Duopoly	Quadropoly
Set 6	5/5	{0,45}	{0,45}
Set 7	5/4	{0,90}	{0,90}
Set 8	5*/-	{7,45}	-
Set 9	7/4	{0,45}	{0,45}
Asymmetric			
Set 10	7/5	{0,50}	{0,50}
(*) The slope was changed from 1 to 0.83 in this experiment. (**) To obtain group size multiply number of experiments by 2 for duopolies and by 4 for quadropolies.			

Table 2			
	Competitive	Cournot	Monopoly
Symmetric Duopoly (b=1)	90	60	45
Symmetric Duopoly (b=.85)	90	72	54
Asymmetric Duopoly	90	61.66	47.5
Symmetric Quadropoly	90	72	45
Asymmetric quadropoly	90	74	47.5

3. Experimental results

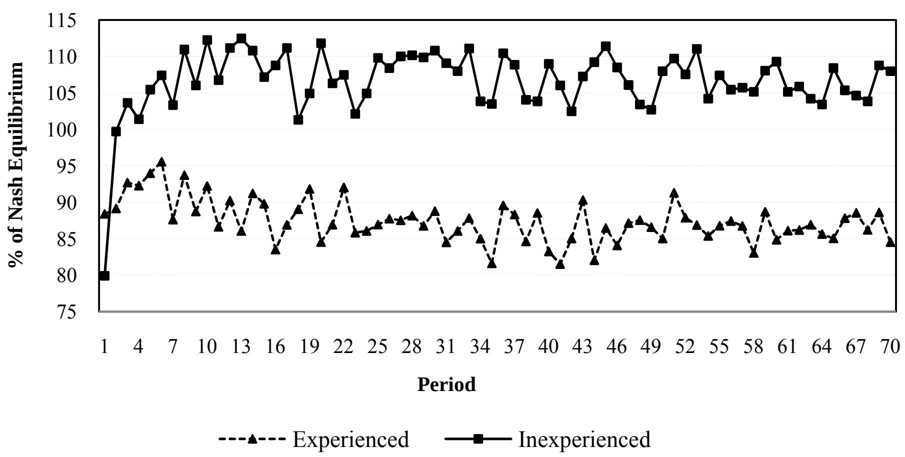
First we analyze results from pooled data for the different cases. We present the analysis for the first 70 periods for all experiments[11]. We then compare the results for the different treatments, namely duopoly vs. quadropoly, symmetric vs, asymmetric cost, and experienced vs. inexperienced. We leave the individual data analysis for the next section.

[11] Subjects were told the duration of the experiment at the time of recruiting. We ran the experiments for the entire period promised. For data analysis we have chosen the minimum of the periods. None of our results change if we include the additional periods.

3.1 Symmetric Dupoly

Experienced symmetric duopolies find it easier to tacitly collude on output in three out of four cases[12]. In the three cases, output produced is closer to the monopoly level than the Nash-Cournot equilibrium. Tacit collusion is obtained in our experiments despite the fact that we have random matching, a property that facilitates one-shot equilibrium behavior. Our result contrasts with previous results on quantity setting markets where, with inexperienced subjects, duopolies seldom collude and the output produced is closer to the Nash-Cournot equilibrium.

Figure 1: Symmetric Duopoly-Average Output



The results for the fourth series of experiments (at Chapman) are much more competitive than the first three[13]. In this treatment the output produced under the experienced and inexperienced treatment are not statistically different (p-value = 0.23). However, one sees that experience does matter in this case also. Variance for inexperienced subjects (6.94) is more than twice the variance observed for experienced subjects (2.29).

[12] Given the strong results in the first two series, we ran a third series of experiments where we changed parameters (slope (0.83) and production cap (min cap=7)) both for the inexperienced and experienced treatment. The results in these experiments were similar to our two series of experiment reporting tacit collusion.

[13] Note that these experiments were run with 7 randomly matched duopolies compared with group sizes of 5, 6 and 4 at GMU. Group size varied at GMU due to many experiments being run at the same time combined with no shows. Though, not important for fixed matching, it could be the case that increasing the number of players in a random matching framework makes the markets more competitive.

Figure 1 shows the average individual quantities per period for both inexperienced and experienced subjects. Outputs are shown as a percentage of the Nash-Cournot equilibrium output levels. Table 3 shows the details for the different series of experiments. With inexperienced subjects we obtain results along similar lines of the literature. Inexperienced subjects produce output slightly above the Nash-Cournot equilibrium output level.

Table 3 Duopoly Symmetric Costs				
		Average output (% of Cournot)		
	Cournot (Monopoly)	All periods	First 15	Last 15
ALL				
Inexperienced	100 (75)	106	104.27	104.33
Experienced		**87.44**	**90.56**	**86.43**
T1[14]				
Inexp	100 (75)	99.43	109.30	95.40
Exp		**81.17**	**83.03**	**79.70**
T2[15]				
Inexp	100 (75)	104.17	99.70	103.60
Exp		**77.53**	**80.50**	**76.23**
T3[16]				
Inexp	100 (75)	104.13	98.03	105.03
Exp		**64.22**	**67.43**	**63.64**
T4[17]				
Inexp	100 (75)	115.33	107.70	111.87
Exp		**114.47**	**117.27**	**113.77**

3.2 Asymmetric duopoly

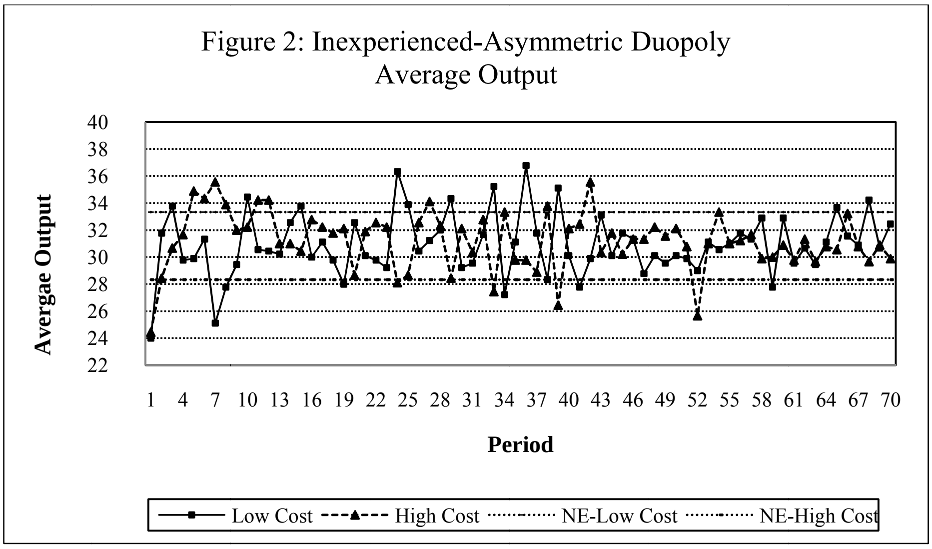
Asymmetric duopolies play closer to the Nash-Cournot equilibrium in both the inexperienced and experienced treatments. Experienced asymmetric duopolies are much more competitive than experienced symmetric duopolies (see tables 3 and 4). Further, experienced asymmetric duopolies are also more competitive than their inexperienced counterparts. Our results clearly point towards the competition enhancing effect of asymmetric costs.

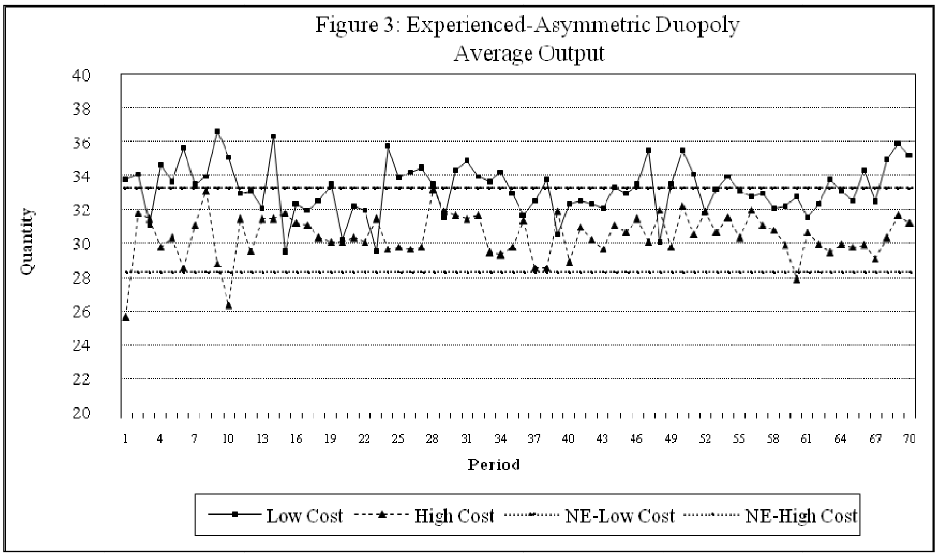
Studying firms based on their cost efficiency, we find that the high-cost firms produce output above the Nash prediction. The low-cost firms, meanwhile, produce output at, or slightly below, the equilibrium prediction, while high-cost duopolies deviate more, producing output greater than the equilibrium prediction (Table 5).

[14] T1: Upper competitive bound.
[15] T2: Upper monopoly bound.
[16] T3: Lower bound of 10 and upper competitive bound, with slope set at 0.83.
[17] T4: Upper competitive bound (Chapman).

Table 4 Duopoly Asymmetric Costs (overall)			
	Average output (% of Cournot)		
	All Periods	1st Half	2nd Half
Inexperienced	100.8	101	100.5
Experienced	103.3	103.5	103.4

Table 5: Duopoly Asymmetric Costs				
	Average output (% of Cournot)			
	Nash-Cournot equilibrium	All Periods	1st Half	2nd Half
Inexperienced				
LC	33.33	30.93 (92.8%)	30.79 (92.38%)	31.06 (93.19%)
HC	28.33	31.22 (110.20)	31.52 (111.26%)	30.91 (109.11)
Experienced				
LC	33.33	33.23 (99.7%)	33.37 (100.1)	33.31 (99.94%)
HC	28.33	30.44 (107.45%)	30.42 (107.38%)	30.46 (107.52)





Inexperienced duopolies are more competitive[18]in our experiments. These results are in line with Mason *et al*. (1992). The high cost firms produce output that is a higher proportion of the Nash-Cournot equilibrium, although it decreases slightly in the last periods. Low cost firms, on the other hand, produce less than the equilibrium, but with a very moderate increase in the last periods.

[18] Note that our experiments run for 70 periods relative to the 36-46 periods in Mason *et al.* (1992).

The results under experience change. Experienced low cost duopolies produce output closer to the Nash-Cournot equilibrium and are more competitive than their inexperienced counterparts (99.7% vs 92.8% for all periods). However, experienced high cost duopolies are only slightly less competitive (110.2% vs 107.45 for all periods). Interestingly, output for experienced high cost firms is stable across the experiment.

3.3 Symmetric Quadropoly

First, we confirm the well known result that an increase in the number of firms makes the market more competitive. Both inexperienced and experienced quadropolies produce output above the Nash-Cournot prediction. Experience still matters, though not as much as for a duopoly. Conducting a difference of means *t*-test reveals that output under experience is significantly lower ($p = 0.0$) compared to average output for inexperienced subjects. Average output with experience is smaller than under inexperience. These results hold for all treatments. Our results are along the lines observed in earlier quantity setting experiments where increasing entry results in increased competition. This result is observed as subjects tend to produce above this equilibrium quantity in higher proportion than duopolies[19].

[19] See Huck *et al.* (2004) as well as forward market experiments by Le Coq and Orzen (2006), where increasing the number of firms increases competition by a greater amount than the introduction of forward markets.

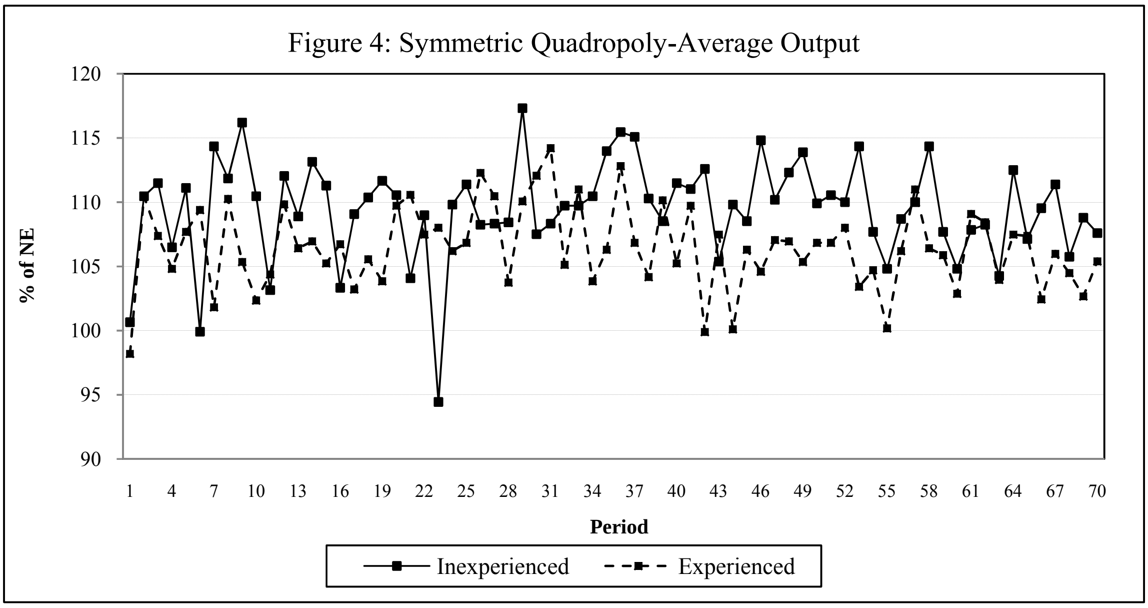


Table 6: Quadropoly Symmetric Costs				
		Average output (% of Cournot)		
	Cournot (Monopoly)	All periods	First 15	Last 15
All				
Inexperienced	100	109.44	109.44	108.78
Experienced	(62.50)	**106.50**	**106.05**	**106**
T1				
Inexp	100	111.72	109.89	111.22
Exp	(62.50)	**104.22**	**101.22**	**105.39**
T2				
Inexp	100	109.89	105.61	112.39
Exp	(62.50)	**109.67**	**106.65**	**109.06**
T2				
Inexp	100	107.61	112.83	104.22
Exp	(62.50)	**104.5**	**106.56**	**101.06**

From Table 6 one can see that quadropolies are competitive in all the experiments. Inexperienced subjects are more competitive than experienced ones. Experienced subjects produce output closer to the Nash-Cournot equilibrium prediction. Further, the difference is statistically different. All quadropoly experiments were run with slightly different production caps to check the robustness of the results. Changing production caps does not seem to matter as far as overall results are concerned.

3.4 Asymmetric Quadropoly

Results under asymmetric quadropolies are along expected lines. First recall that we have 2 low-cost and 2 high-cost firms in a quadropoly. In this sense the degree of cost asymmetry is not extreme. As in the case of duopoly, the cost difference was kept at a moderate level.

Output is slightly above the Nash-Cournot prediction, with a higher quantity produced by the inexperienced subjects. The relative deviation from the equilibrium is also higher than in the asymmetric duopoly case (see tables 5 and 7) but not very different from the symmetric quadropoly (see Table 6). It seems that the role of asymmetry is diminished with four firms. This could be due to the fact that the degree of competition, because of the larger number of firms, is already high and outweighs the effects of the introduction of cost asymmetry.

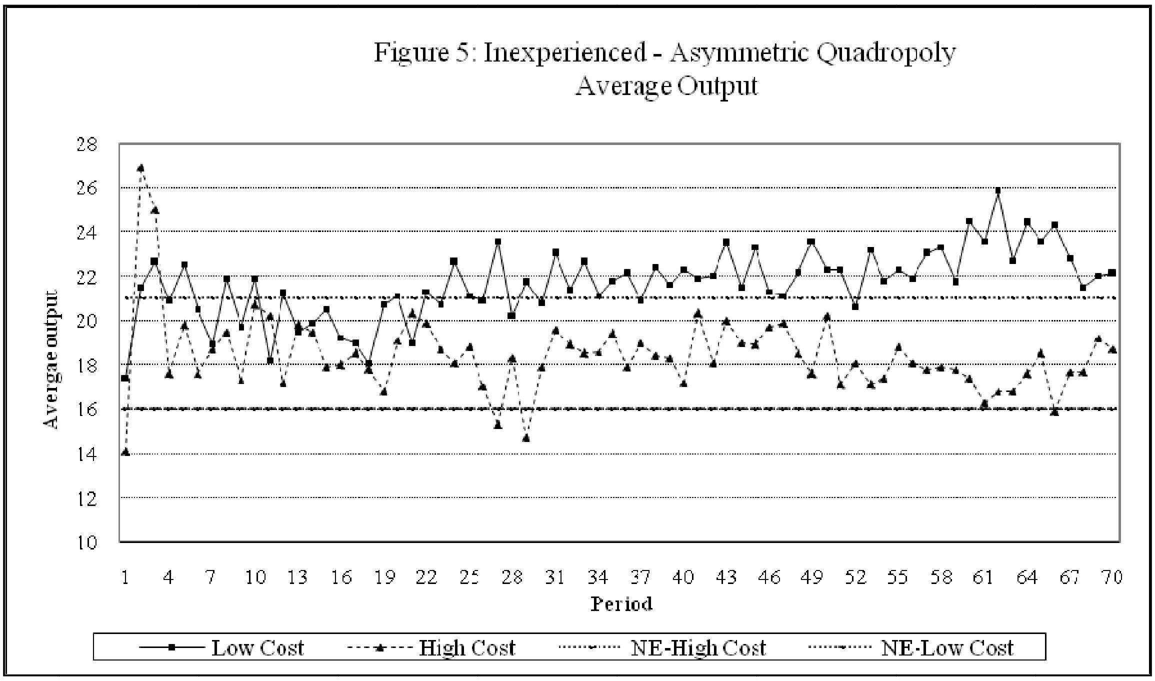
As under duopolies, we find that high-cost firms are more competitive, producing output above the Nash-Cournot equilibrium prediction. For the low-cost firms, on the other hand, the average output is much closer to the equilibrium prediction (Table 8 and figures 5 and 6). A test for difference of means tells us that the observations under low and high cost experienced subjects data are statistically different from the inexperienced low and high cost sample ($p = 0.0$ [20]).

Table 7:
Quadropoly Asymmetric Costs (overall)

	Average output (% of Cournot)		
	All Periods	First 15	Last 15
Inexperienced	108.4	107.9	110.2
Experienced	104.2	104.1	102.4

[20] $p = 0.01$ for the duopoly HC experienced vs. HC inexperienced pair.

Table 8: Quadropoly Asymmetric Costs				
	Cournot quantity	All periods (% of Cournot)	First 15 (% of Cournot)	Last 15 (% of Cournot)
INEXP				
Low Cost	21	21.66 (103.1)	20.47 (97.5%)	23.15 (111.90%)
High Cost	16	18.45 (115.3)	19.45 (121.56)	17.61 (110%)
EXP				
Low Cost	21	20.93 (99.7)	20.37 (97%)	21.09 (100.4%)
High Cost	16	17.61 (110.1)	18.16 (113.50)	16.79 (104.9%)



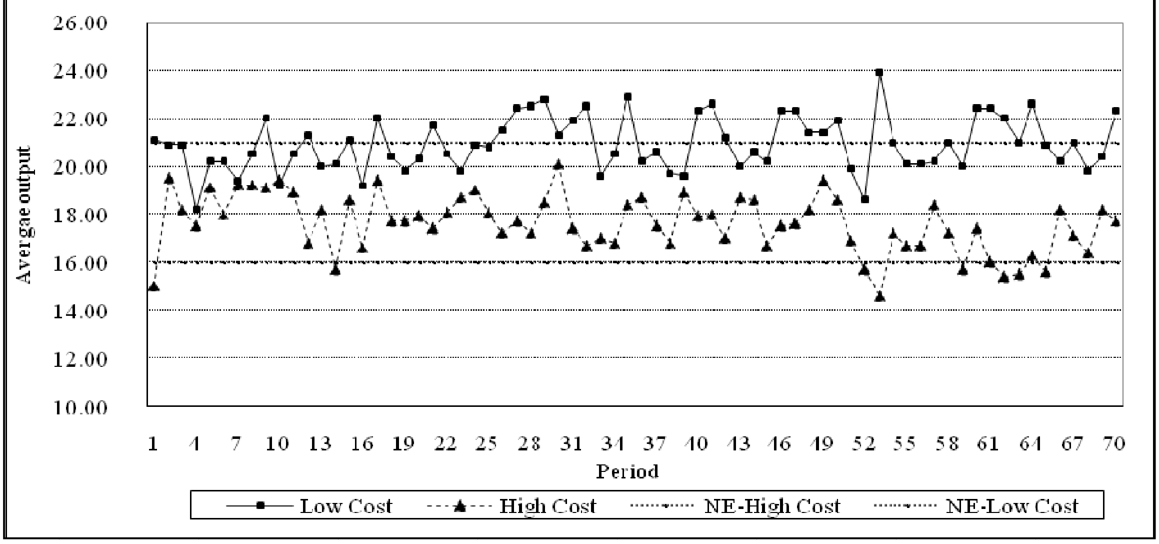
What is noteworthy in the quadropoly experiments is that even symmetric firms find it difficult to collude. In fact, quantities are slightly lower in the case of asymmetric firms (108.4% vs. 109.44% for inexperienced and 104.2% vs. 106.5% for experienced firms- comparing Tables 6 and 7). Experienced high-cost firms deviate more from the Nash-Cournot equilibrium than do symmetric firms. Low-cost symmetric inexperienced firms meanwhile deviate much less from the non-cooperative prediction. It seems that the introduction of asymmetry does not matter when the number of firms is large enough.

Further note that, in the early periods, and relative to the Nash-Cournot equilibrium, the high cost firm produces output that is a higher proportion of the non-cooperative equilibrium. However, the output trend converges for both the low and high cost firms towards the end of the experiment. In the last 15 periods the proportion of output for low and high cost firm is 111.9% and 110%, respectively.

The results under experience are similar in the sense that the output in the initial 15 periods is greater than the output in the last 15 periods. Though the output trend is decreasing, both the low and high cost firm produce output that is smaller than without experience. This is especially true for a duopoly that decreases its output from 111.9% (inexperienced-last 15 periods) to 100.4% with experience. Similar numbers are obtained for the high cost firm, although its output is marginally greater (104.9%) than the non-cooperative equilibrium in the last 15 periods. Our results tell us quadropolies can reduce average output even under asymmetric costs. This is true while evaluating the change in output within periods experienced subjects.

Comparing experienced asymmetric duopolies and quadropolies one sees that experienced low cost firms in both cases play at the Nash-Cournot equilibrium (99.4%). Interestingly, high cost firms in produce output above the Nash-Cournot equilibrium. These firms are not substantially more competitive in a quadropoly than in the duopoly. It is striking how close the results are for the two market structures when subjects are experienced. It is clear that subject experience matters even under asymmetric costs.

Figure 6: Experienced- Asymmetric Quadropoly
Average Output



Our findings that asymmetric firms find it more difficult to tacitally collude to produce below the Cournot equilibrium agree with the prediction in Vasconcelos (2005). Further, the behavior of the high and low costs firms are similar to the predictions in Vasconcelos. However notice that in Vasconcelos, deviations are defined with respect to the collusive equilibrium in the repeated game. In our case, deviations are defined with respect to the one-shot Nash-Cournot equilibrium behavior.

4. Subject experience and individual play

In this section we study the effect of play on subject experience. First, we study best response play for duopolies by calculating the Pearson correlation coefficient on the outputs chosen in each period. The Pearson correlation coefficient is a measure of linear dependence between two variables. We use the Pearson correlation coeffcient for the same period due to our random matching design. Subjects are randomly matched in each period and hence they should not form conjectures on rival play from the last period. It thus seems reasonable that subjects make conjectures on the play of the rival for the same period and best-respond to it. In this sense subjects play according to the one shot framework.

We pool all individual output choices across all experiments (Figures 7 and 8 below show these choices for the duopolies) with the reaction functions for the two firms. We then calculate the Pearson correlation coefficient between two players. Given that Cournot reaction functions suggest *own* output being negatively correlated with *others'* output, one would expect the correlation coefficient to be negative. Though small and not significantly different from zero, the Pearson correlation coefficient is indeed negative for inexperienced duopolies (Table 9). This tells us that the direction of output changes of the best responses moves in the expected direction. We do not find strong evidence in favor of best-response play for inexperienced subjects.

Again pooling data from all experiments, the results for experienced duopolies go in the opposite direction, with the Pearson correlation coefficient being positive. A *t*-test comparision tells us that the coefficient is statistically different from zero. This tells us that the strategic substitutability relation does not hold, and instead output choice corresponds to strategic complementarity for experienced subjects. This is important as it tells us that experienced duopolies do not play according to the best-response model and their behavior may be interpreted as tacit collusion on the part of subjects[21].

[21] Note that, looking at the Chapman data individually we find that the Pearson Correlation coefficient is positive and significant for both experienced and inexperienced subjects.

Table 9: Symmetric Duopoly-Pearson Correlation Coefficient Own vs others' quantity		
	Pearson Correlation	*t*-test
Inexperience	-0.002	0.852
Experience	0.577	0.0041

A scatter plot for asymmetric duopolies is similar to the symmetric case. The results for asymmetric duopolies also go in the same direction. The Pearson correlation coefficient for inexperienced subjects is again negative, but not significantly different from zero (Table 10), thus telling us that subjects do not exactly play as is posited by the Cournot reaction functions. The value of the coefficient for experienced subjects, however, is positive and the coefficent is statistically different from zero.

Table 10: Asymmetric Duopoly-Pearson Correlation Coefficient Own vs others' quantity		
	Pearson correlation	*t*-test (p value)
Inexperience	-0.183	0.517
Experience	0.013	0.00

Figure-7: Symmetric Duopoly-Best response

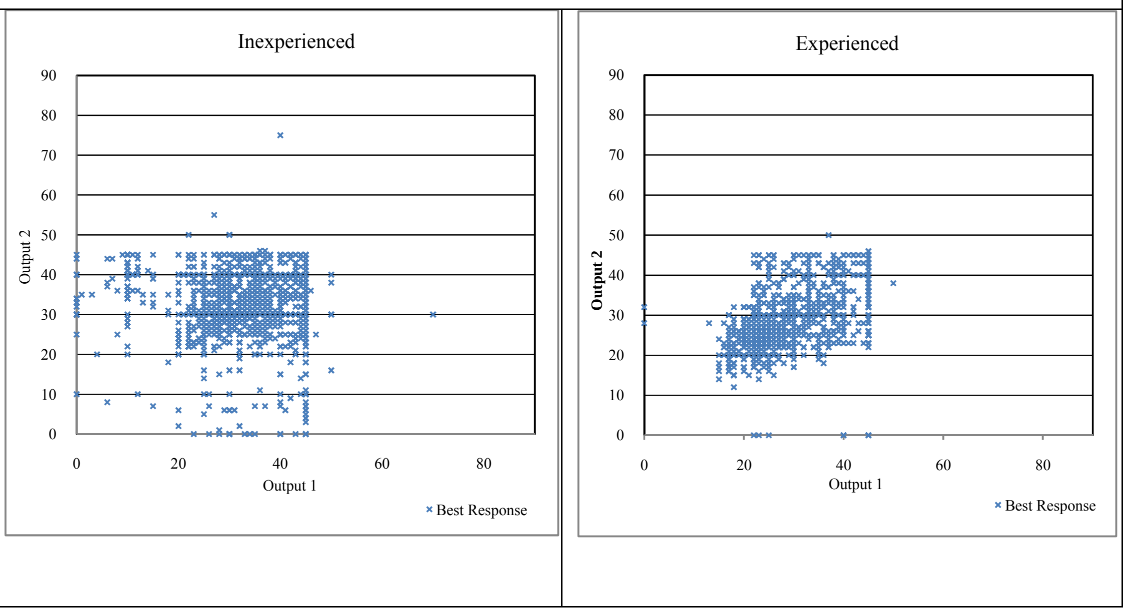
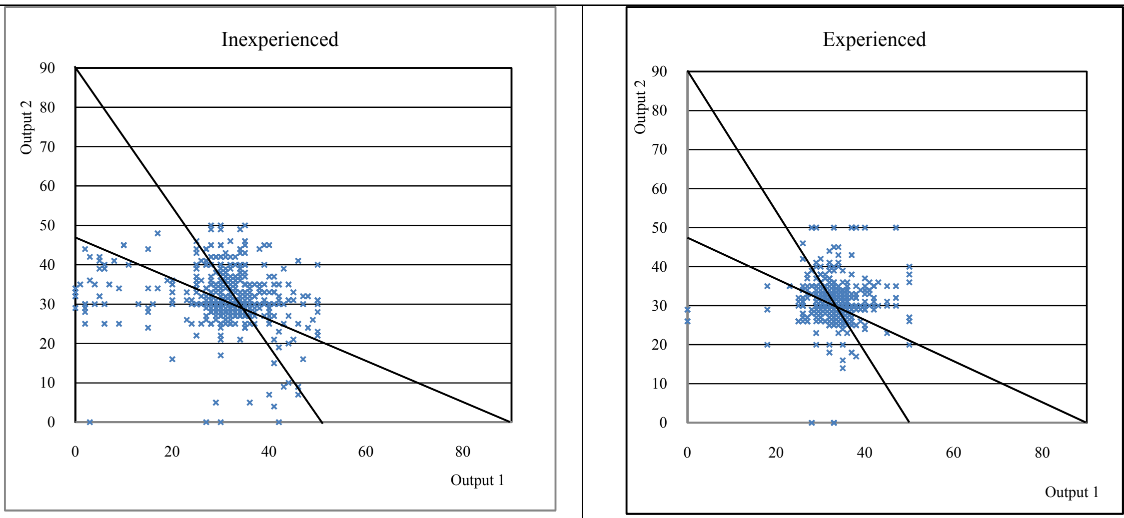


Figure-8: Asymmetric Duopoly-Best response



An analysis of the data for symmetric quadropolies goes along similar lines as obtained for symmetric duopolies. We report the Pearson correlation coefficient for own output against the total output produced by others in Table 11 (Tij; i indicates experiment, j indicates player). The sign of the Pearson correlation coefficient is negative (in 10 out of 12 cases) for inexperienced symmetric quadropolies and the coefficents are significantly different from zero. This indicates that inexperienced quadropolies play according to the suggested best response dynamics. However, the results for experienced quadropolies are reversed. Ten out twelwe quadropolies have a positive Pearson correlation coefficient, with the correlation coefficient being significantly different from zero in all the cases. This result is particularly striking as we find that individual output changes is positive in response to output changes by everyone else despite the fact that the level of output is even higher than the Nash-Cournot equilibrium. Even though not successful, this suggests that subjects attempt at tacit collusion.

Table 11: Symmetric Quadropoly- Pearson Correlation coefficient[22] Own vs Others' Output								
	Inexperienced							
	T11	**T12**	**T13**	**T14**	**T21**	**T22**	**T23**	**T24**
Pearson correlation	-0.084	-0,122	-0,153	-0,154	-0,014	-0,099	-0,066	-0,131
t-test (*p*-value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	T31	**T32**	**T33**	**T34**				
Pearson correlation	-0,0781	0,0321	-0,07	0,020				
t-test (*p*-value)	0.00	0.00	0.00	0.00				
	Experienced							
	T11	**T12**	**T13**	**T14**	**T21**	**T22**	**T23**	**T24**
Pearson correlation	0,018	-0,096	0,003	0,03	0,077	0,171	0,06	0,13
t-test (*p*-value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	T31	**T32**	**T33**	**T34**				
Pearson correlation	0,061	-0,127	0,036	0,069				
t-test (*p*-value)	0.00	0.00	0.00	0.00				

The results for asymmetric quadroplies are in line with what is suggested by earlier analysis. We find that the Pearson correlation coefficent for both inexperienced and experienced quadroplies is negative (with all coefficients being significantly different from zero, see Table 12).

[22] Tij: refers to treatment *i* and pair *j* (*i*,*j*=1,2,3,4). For example, T11 refers to player 1 paired against total out of players 2, 3 and 4 in T1. Similarly, T12 refers to player 2 paired against total output of players 1, 3 and 4 in T1. Unlike in the duopoly case, where there is only one correlation –player 1 vs. player 2-, in quadropolies, the identity of the player is important, as there are different correlations to consider. This is also the reason to give coefficients separately for the different treatments.

Table 12: Asymmetric Quadropoly- Pearson Correlation coefficient[23] (Own vs Others' Output)				
	Inexperienced			
	T11	**T12**	**T13**	**T14**
Pearson correlation	-0,031	-0,042	-0,098	-0,0197
t-test (*p*-value)	0.00	0.00	0.00	0.00
	Experienced			
	T11	**T12**	**T13**	**T14**
Pearson correlation	-0,037	-0,146	-0,049	-0,120
t-test (*p*-value)	0.00	0.00	0.00	0.00

4.1 Individual regressions

In this section we study choices made by individual´s in each experiment. Individual behavior is explored in greater detail by estimating possible decision rules used by subjects. Given that we have a random matching design we assume that subjects will rely on past choices of their rivals, their own output, and the conjectures they make on their rivals' outputs for the same period[24]. Given this, we assume that the decision rule takes the form[25],

$$x_{it} = \beta_{0i} + \beta_{1i} t + \beta_{2i} x_{it-1} + \beta_{3i} z_{it} + \beta_{4i} z_{it-1} + e_{it}\text{ , (1)}$$

where x_{it} is own output in period t, z_{it} is the sum of outputs in t for i's rivals, and e_{it} is a residual term. This form permits a subject's output choice to depend on lagged own and rivals' output and on twice lagged rivals' output. Given the random matching structure it did not seem reasonable to include greater lags. The t term allows for a time trend. The residual term, e_{it}, captures the error in estimating the true decision rule as well as random experimentation by subjects.

Further, note that, in our random matching, where matches are repeated with a low probability and player identities are not known, the error term may also capture some form

[23] As in Table 10, Tij: refers to treatment *i* and pair *j* (*i*,*j*=1,2,3,4).
[24] We also did some individual analysis based on own and other lags. As one would expect, other lags are not significant in a random matching framework. However, own lag, the period and other output for the same period are.
[25] The same decision rule has been estimated in Rassenti *et al*. (2000).

of global learning across the subject pool. This may further imply that the error terms are correlated across subjects within periods. Due to this, we estimated the equation above using the model of Seemingly Unrelated Equations (SURE) with first differences. The following equation was finally estimated,

$$\Delta x_{it} = \beta_{0i} + \beta_{2i}\Delta x_{it-1} + \beta_{3i}\Delta z_{it-1} + \beta_{4i}\Delta z_{it-2} + u_{it}, \qquad (2)$$

where Δ is the first difference operator. Due to the large number of equations estimated we present the percentage of coefficientes significant at 5% and 1%. In tables 13 and 14 we present the results from the SURE regressions for duopolies and quadropolies, respectively. We find that the proportion of subjects with the coefficient for own putput negative and significant both for duopolies and quadropolies is similar (with >93% of the coefficients being significantly different from zero). If subjects are following an adaptive adjustment process it seems reasonable that they rely on own output in past period to infer about future outputs. Further, the negative coefficient indicates that subjects are adjusting output downwards as the experiments progressive. These results hold for both market structures. The common result, though not of the same magnitude, is that the proportion of subjects who adjust output in the same manner as the rivals increases with experience. This suggests that subjects correctly form conjectures on rival output and this ability improves with experience.

Looking at duopolies one sees that the subjects do not adjust output according to the best response dynamics. In fact, a larger proportion of the subjects adjust output in the same manner as their rivals. This indicates attempts at collusive behavior. The fact that we observe it for inexperienced subjects is surprising[26]. This proportion goes up substantially for experienced subjects. One sees that the coefficient is significantly different from zero and positive for 52.32% of the subjects (5% confidence level). This number is substantially smaller for quadropolies indicating that enforcing collusion becomes difficult as the number of subjects increases.

[26] Rassenti et al. (2000) report similar results in their experiments.

Table 13: Duopoly Coefficients for Individual Regressions % Symmetric (Asymmetric)						
Inexperienced	Negative and significant			Positive and significant		
Null	10%	5%	1%	10%	5%	1%
$\beta_{2i} = 0$	(84.88)	2.17	93.48 (83.33)			(5.05)
$\beta_{3i} = 0$	17.38 (48.88)	15.21 (37.77)	13.04 (26.67)	36.95 (11.10)	28.25	21.74 (5.05)
$\beta_{4i} = 0$	23.35	16.84	4.34	15.19	13.02	6.51
Experienced	10%	5%	1%	10%	5%	1%
$\beta_{2i} = 0$			100 (94.44)			
$\beta_{3i} = 0$	9.20	6.90	4.60	59.42	52.32	47.72 (94.44)
$\beta_{4i} = 0$	4.60			47.13	42.53 (61.10)	33.33 (55.55)

Table 14: Quadropoly Coefficients for Individual Regressions % Symmetric (Asymmetric)						
Inexperienced	Negative and significant			Positive and significant		
Null	10%	5%	1%	10%	5%	1%
$\beta_{2i} = 0$		96.44	94.64 (95)			
$\beta_{3i} = 0$	24.96 (46.67)	19.60 (30)	12.50 (25)	19.66	14.30	8.90
$\beta_{4i} = 0$	26.80	23.20 (30)	10.70 (20)	(10)	7.20	3.60 (5)
Experienced	10%	5%	1%	10%	5%	1%
$\beta_{2i} = 0$		98.03 (95)	94.23 (90)			
$\beta_{3i} = 0$	26.93	19.23	13.46 (20)	37.27	29.57	23.80
$\beta_{4i} = 0$	19.25 (25)	11.55 (15)	7.70 (10)	23.00 (5)	21.10	17.30

The coeffcient β_{3i} tells us whether subjects best respond or not to other output (a negative sign corresponds to the relation between own and others' output in the Cournot reaction function). One can see that both under symmetric and asymmetric costs the adaptive rule to adjust their output in the future periods. Note that a greater proportion of inexperienced subjects best respond to other output (48.88% vs 17.38%) when costs are asymmetric. This is, however, not maintained for experienced duopolies where we see that a significantly large proportion of subjects adjust output in the same direction as the rivals. For example, 47.72% (94.44%) of the subjects adjust output in the same direction as rivals for symmetric (asymmetric) costs. We thus see that even under asymmetric costs the best response dynamics according to the Cournot model is not followed.

As in duopolies subjects in quadropolies use the adaptive rule to adjust output. Both symmetric and asymmetric inexperienced quadropolies use the Cournot best response dynamics 24.96% and 46.67% of the time, respectively. With experience, no clear result is obtained in terms of the best response dynamics. Similar proportion of symmetric cost quadropolies best respond (26.93%) to their rivals, or adjust output in the same direction (37.27%). Only a few experienced cost quadropolies best respond, 26.93% for symmetric and 20% for asymmetric costs. It seems that best response dynamic is seldom used as the environment gets more complicated. It may due to this reason that Rassenti *et al.* (2000) also fail to see subjects use best response as a decision rule.

5. Conclusions

We argue that, besides being useful as a valid robustness check, experience may be important when it comes to studying strategic play. Our subjects play in the standard quantity setting oligopoly twice. Our results replicate earlier known results for inexperienced subjects both for duopolies and quadropolies. We find that subjects' experience is important in understanding play in quantity setting oligopolies and find important differences in the way experienced subjects play.

First, we find that experienced duopolies play closer to the collusive outcome. This result is supported by the positive Pearson correlation coefficients and the regressions results that we obtain. A positive correlation coefficient suggests that subjects best respond by changing their output in the same direction as their rivals. Second, although experienced quadropolies produce output closer to the Nash-Cournot equilibrium, the Pearson correlation coefficient on individual play is positive and statistically significant. This suggests that even though the environment is much more competitive firms still try to sustain collusion by adjusting output in the same direction as their rivals, even if the final result is not a successful collusion.

This last result is interesting because until now the competitive nature of markets with 4 firms was quite robust. Analysis of individual data, however, tell us that output adjustments do not agree with the best response dynamics. The fact that subjects understand that collusive outcomes can be attained by adjusting output in the same manner suggests that studying the effect of greater level of experience may be a fruitful exercise.

In the experiments with moderate cost differences we find that the high cost firm produces output well above their non-cooperative prediction. Experienced low cost firms play closer to the non-cooperative equilibrium, while experienced high cost firms produce output slightly above it. Our experiments with inexperienced duopolies replicate the results in Mason *et al*. (1992). If we only take sales data into account, then an interesting implication of the high cost firm deviating more from the non-coopertaive equilibrium is that firms may look more similar than they are. Observed outputs thus may not truly reflect firm asymmetries when cost differences are not high. Regardless, we observe that cost differences are important and both experienced and inexperienced subjects play according to the predicted best reponse dynamics. In this sense our results support the assertion made in Mason *et al.* (1992) that firm asymmetry may be a desirable policy goal as it makes the inefficient firms much more competitive. Of course, it remains to be seen if our results hold in a fixed matching environment and with different degrees of cost asymmetries.[27]

Our experiments also raise several questions. First, with respect to the question about to what extent experience does result in collusive outcomes, it will be useful to see how do well trained subjects play in this setup. The second issue is regarding random matching. It seems that there is a group size effect in the random matching setup. Larger groups seem to be more competitive than relatively smaller groups even in the oligopoly setup. It may be thus useful to see whether the one shot prediction is obtained when group sizes are very large. The group size effect may also have to do with the fact that subjects may be playing some supergame in our experiments. That is, small groups may imply that

[27] We expect markets to be less competitive in a fixed matching environment.

there is greater common knowledge that everyone is playing the same game. This may not be the case if group size is large. How group size affects outcomes is an issue for further research. Group size seems to be especially relevant in a random matching framework. Our results suggest that larger groups are more competitive in average play than smaller groups. Another important issue maybe regarding the cost difference that should make a market more competitive. From our experimenmts it seems that a combination of group size and cost differences affects competition. Whether they re-enforce each other even under experience is a further research question.

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APPENDIX

INSTRUCTIONS: for both inexperienced and experienced subjects.

Introduction: This is a study of decision-making. Funding for this project has been provided by public funding agencies. If you follow these instructions, and make decisions carefully, you might earn a considerable amount of money. You will be paid **IN CASH** at the end of today's session.

Important: At any stage you can raise your hand to ask any question relating to the experiment.

Overview: In today's session each of you is a quantity-setting seller in a market. There are TWO sellers in each market. The experiment is made up of several **weeks.** Each **week** is made up of one **trading day (**called **Final Day)**. You will be randomly and anonymously matched against other opponents.

Trading in Final day proceeds as follows: At the beginning of each day you, as a seller, can offer to sell units of a fictitious good. Each good will have a certain unit cost. All sellers have the same unit costs. The market price is determined by the sum total of quantity offered by ALL sellers in a trading day.

The **price** received by sellers is the **same for everyone**. **Example 1** below explains how the price is determined.

Example 1: Let the market demand be P=10-TQ (P = market price, TQ = total quantity offered by all sellers). Let us suppose that you offered to sell **2 units**.

Let us also suppose that the number of units offered by the other seller is **3**. The total quantity (TQ) offered by all sellers then is (3+2=) 5. This implies that the market price,

P = 10-TQ = 10-5 = **5**.

Note that the price declines as the total quantity offered (TQ) increases. For all TQ greater than, or equal to, 10 the market price (P=10-TQ=10-10=0) is zero.

Further note that the market price can never be negative.

Example 2 below explains the relationship between the total quantity offered (TQ) and the market price (P).

Example 2: Notice that the market price (P=10-TQ) decreases as the total quantity (TQ) sold in the market increases. The table below gives some possible prices for different total quantities (TQ):

Market demand: P=10-TQ	
QUANTITY (TQ)	PRICE (P)
1	P = 10-1 = **9**
2	P = 10-2 = **8**
4	P = 10-4 = **6**
6	P = 10-6 = **4**
7	P = 10-7 = **3**
8	P = 10-8 = **2**
9	P = 10-9 = **1**
10	P = 10-10 = **0**

Procedures for trading are explained in more detail below.

1. Sellers earn profits by selling units. The profit for any unit sold is the selling price minus the cost of the unit. The selling price will be the same for all units, as will be unit costs. Thus a seller's total profit is;

Profits = (Selling Price – Unit Cost) × Number of units sold

If you offered to sell 2 units at a unit cost of 1/unit, then your total costs would be 2. Then, continuing with **Example 1** we know that the market price is **5**. A seller's profits will then be,

Profits = (5-1) × 2 = 4×2 = 8.

2. Buyers. The buyers are automated. The price is determined according to the demand in **Example-1**. Given total quantity (TQ), the market price P=10-TQ. In our example TQ=5, this implies that P = 10-TQ = 10-5 = 5.

Note that the same demand will not be used in the experiment.

There are several important things to understand.

- The higher (lower) is the total quantity (TQ), the lower (higher) is the price (P)

(see **TABLE** in **Example 2** above).

- Your sales are affected by the quantities chosen by the other seller. The higher (lower) is the other seller's quantity lower (higher) is the sales price. The same will be true if you increase your quantity and the other seller does not.

An example,

(a) You offered to sell 2 units in **Example 1**, and the other seller offered 3. If however, the other seller would have offered 2, then TQ=4 and the resulting price would be P=6 (see **TABLE** above). Your profits would then be,

Profits = (6-1) × 2 = 5×2 = 10.

The trading week:

a) Each seller can offer to sell some quantity (or none) in the final day. While choosing the quantity you should keep in mind that,

(i) you earn profits only by selling units at a price above Unit Cost and

(ii) the higher is total quantity, the lower is the sales price (see **table** above).

(iii) you earn zero if you sell nothing.

b) The total quantity offered to sell (TQ) at the end of the final day determines the price. The price is determined as explained in **Example 1** above.

Your EARNINGS = (Selling Price – Unit Cost) × Number of units sold.

How to read the screen and submit your offer?

On the right side of the screen, there is a **history table**. A record of all the plays is displayed in the table.

On the left side of the screen, there is a **graphical display** section.

You can try different possible combinations of your offer, the sum of all the other sellers offers and observe your potential profit **on the right side of the display section**.

After you have decided your offer for that day, click the CONFIRM button. NOTE that whenever you click the CONFIRM button, you are confirming **your offer only**. The actual number of units offered by other sellers may be different from yours. Also, NOTE that you **must** click the CONFIRM button in order to submit your offer.

The left side of the graphic display section shows your quantity, the sum of other sellers' quantity and the profit given the price on a particular day.

4) Overview:

a) Today's experiment will consist of a number of **weeks**. Each trading week consists of only **one day (**called **Final day)**. The final trading week will not be disclosed in advance.

b) Each of you can choose to offer a quantity for sale in the final day. The final quantity offered for sale will be the sum of the quantities (TQ) offered at the end of the final day. This final quantity determines the final price (P) you will receive for all the goods. You will be randomly and anonymously matched against other opponents.

c) In today's experiment each one of you will have a Unit Cost of 10 in each period. Each participant has identical Unit Costs, and Unit Costs are the same in all trading days. Note, you are also informed about the other seller's Unit Costs in a history table on the Right Side of the screen.

d) You will be paid \$0.18 U.S. for every 1000 "experimental dollars" you earn in the market. Thus, for example, every 5555.56 experimental dollars equals \$1. Your total earnings for today's experiment will be the sum of your earnings in the experiment, plus your \$20 (U.S.) appearance fee (paid together with the earnings of the next experiment).

e) Some participants may make their quantity decisions earlier than others. If you make your quantity decision before other sellers, please wait quietly while others finish. The monitor will make sure that there are no unnecessary delays.

f) Please note that, talking with, or looking at, other participants is not allowed. The market will be closed and all participants will be asked to leave without further payment if any participant communicates in any way other than the manner described in these instructions.

g) At the end of the experiment you will be called out and your earning will be paid to you in cash.

You will now practice before you start the experiment. You can practice up to 5 weeks. Please click on "Ready to Practice" if you fully understand the instruction.