Do Forward Markets Enhance Competition?

Experimental Evidence [†]

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Abstract: Hedging risks is an important rationale for the existence of forward markets. However, Allaz and Vila (1993) show that duopolists can also have a strategic motive to sell forward, irrespective of exogenous uncertainties. Moreover, in their model the possibility of forward trading increases competitiveness between the two firms, raising consumer surplus and welfare. In this study we analyze the case of an *n* firm oligopoly in Allaz' and Vila's framework and derive comparative static predictions with regard to the market institution and the number of competitors. We then test the theoretical hypotheses in a laboratory experiment. Our findings support the main comparative-static predictions of the model but also suggest that, when compared to the increase in competitive pressure due to entry, the competition-enhancing effect of a forward market is weaker than predicted.

Keywords: Cournot Competition; Forward Markets; Spot Markets; Experiments.

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1. Introduction

Forward contracts are binding agreements between sellers and buyers that specify the terms, including the price, of the delivery of a good at a future date. Forward trading has a long history in agriculture but has become increasingly important in other sectors, particularly in financial asset trading and, relatively recently, in energy markets. From a public policy perspective it is of interest whether forward trading has desirable effects on welfare and efficiency. This question can be of practical and acute significance for policy makers who have to make decisions on market design. A prominent example is the recent energy crisis in California, which prompted an intense debate on the design flaws of the Californian electricity market. The Market Surveillance Committee (MSC), a group of independent advisers to the governing board of the Californian Independent System Operator, recommended to remove any restrictions on forward contracting, suggesting that this would not only prevent seasonal price peaks but also “significantly limit the ability of generators to exercise market power”.[1]

The idea that forward markets might enhance competition has also been discussed in the theoretical literature, starting with Allaz (1992) and Allaz and Vila (1993) (henceforth AV). Usually it is argued that agents make forward transactions solely as a protection against volatile market prices and other risks. AV suggest a further reason for the existence of forward markets. In a simple model of duopolistic quantity competition they show that a firm may obtain a leadership position by selling forward. Motivated by this opportunity, both players participate in the forward market and as a consequence compete more aggressively overall. Thus, compared to the case

[1] Wolak, Nordhaus and Shapiro (2000), p.15.

of pure spot market trading, production levels rise and prices fall, which generates an increase in consumer surplus and total welfare.

This is an intriguing result, but how effective is the introduction of a forward market compared to other means of improving competition in an oligopoly? In this paper we show that, relative to the increase in competitive pressure that would be caused by the entry of additional competitors, the competition-enhancing effect of forward trading is surprisingly strong. Our *n*-firm version of AV's model predicts that introducing a forward market raises competitiveness in the same degree as *squaring* the number of competing firms. In the second part of the paper we report the results of a laboratory experiment, which we designed to test the predictions of AV's theory. We think experimental evidence can be helpful in assessing the relevance of AV's results, which have caused some debate in the theoretical literature. For example, Harvey and Hogan (2000) express deep skepticism about AV's findings. They suspect that the theory's predictions depend on the particular game theory formulation, e.g. the way firms' conjectures about their opponent's response behavior are modeled. Furthermore, Harvey and Hogan suggest that if firms play the game repeatedly, as it is undeniably the case in most real markets, they might achieve outcomes that are "in-distinguishable from collusion" (p.8).

With our experiment we attempt to make a first step in explicitly testing whether and to what extent forward markets improve efficiency. While it is difficult to systematically study the effect of forward markets using field data because the important variables are difficult to measure and to control for, laboratory methods allow the experimenter to set and manipulate crucial parameters such the number of competitors, cost functions, demand behavior and exogenous shocks. To the best of our knowledge we are the first to test AV's predictions in the laboratory. Previous experimental work has investigated other aspects of forward markets; Sunder (1995) reviews experiments studying the *informational* efficiency of forward markets. A work that is more closely related to this paper is Reynolds's (2000) study of durable-goods monopolies, in which he examines the Coase (1972) conjecture experimentally. AV's finding resembles the Coase conjecture in that intertemporal competition is crucial in both approaches. However, there are also important differences, most notably perhaps that in AV's setup a monopolist would not be affected by the introduction of a forward market. Consequently, we focus on competing firms and their strategic interactions, the key elements driving AV's theoretical result. Phillips, Menkhaus and Krogmeier (2001) report an experiment where four sellers and four buyers have access to a forward market and/or a spot market under a double auction trading mechanism. They find that consumer surplus and market efficiency are highest when trading is only allowed on the forward market and lowest when trading is only allowed on the spot market. When transactions can be made on both markets buyers' earnings and market efficiency are intermediate. However, Phillips et al. focus on price competition, and in their design inventory costs provide sellers with an additional incentive to operate on the forward market. Therefore the strategic effect of forward trading is not clear.

In our thirty-two laboratory-controlled experimental markets firms choose quantities in a repeated game with fixed matchings, and prices are determined by a downward-sloping linear demand. We employ two benchmark conditions where either two or four sellers engage in standard Cournot competition and thus trade solely on a spot market. In the AV markets, two (or four) firms can first sell units on a forward market before they enter the spot stage. If they make transactions on the forward market the sellers commit to produce at least their forward quantities. In addition they can produce more units, which are then sold to the residual demand on the spot market. The spot market prices are simply determined by the residual demand function. The forward market prices are determined by a forward market demand function reflecting the assumption that buyers expect equilibrium play in the spot stage for any given residual demand.

We find that forward markets enhance competition and efficiency. Total production levels in the AV treatments are systematically higher than under Cournot, and prices are significantly lower. Consumer surplus increases by 28.4% in the Two-seller treatments and by 67.4% in the Four-seller treatments. However, our experimental results also indicate that the effect of introducing a forward trading institution is not as strong as theory suggests. Our experimental evidence rejects the hypothesis that a forward market is as effective as increasing the number of firms on the market. Instead, it proves to be far more effective to change the number of competitors in the Cournot markets from two to four.

The remainder of the paper is organized as follows. In the next section we study AV's two-stage model for the case of n symmetric firms. From this we derive the relevant comparative static predictions for our experimental treatments, which are described in detail in Section 3. Section 4 presents the results of the experiment. We discuss the results and provide some concluding remarks in Section 5.

2. The model

In the following we present AV's forward market model for the case of an n-firm oligopoly. However, we restrict the analysis to a two-stage setup (spot market plus one round of forward trading), which is the relevant case in our experimental design, whereas AV also consider the case of continuous trading in forward markets. Furthermore, we focus on symmetric equilibria.

First, consider the case of pure spot market trading. Firms produce a single homogeneous good and, facing linear cost and demand schedules, they simultaneously choose their production levels to maximize

$$p_i(x_i) = (A - X)x_i - cx_i \qquad \text{with } X = \sum_{j=1}^{n} x_j \qquad [1]$$

where A is a parameter of the inverse demand function, x_i is the quantity chosen by firm i, c is a cost parameter and X represents total production in the market. In equilibrium aggregate production is

$$X^* = \frac{n}{n+1}(A - c) \qquad [2]$$

and the equilibrium market price is

$$p^* = \frac{A + nc}{n+1}. \qquad [3]$$

Now assume that firms go first on the forward market before trading on the spot market. Note that in this complete information model there is no risk-hedging rationale for forward trading.[2] However, as we shall see, when a forward market is introduced the market participants trade units of the good prior to the production stage for *strategic* reasons. First, sellers simultaneously choose their forward positions f_i. Then the aggregate forward quantity F is offered on the market and a forward price p_F emerges as a result of the market process. After signing the forward contracts, firms enter the production stage and face the following payoff function (s_i is the number of units firm i sells on the spot market).

[2] See Allaz (1992) for a model that incorporates uncertainty.

$$p_i(f_i + s_i) = p_F f_i + (A - F - S)s_i - c(f_i + s_i)$$

$$\text{with} \qquad F = \sum_{j=1}^{n} f_j \qquad \text{and} \qquad S = \sum_{j=1}^{n} s_j \qquad [4]$$

The first term in Equation [4] represents firm *i*'s revenues from its sales on the forward market, the second term represents *i*'s revenues from spot market sales and the last term represents *i*'s production costs. Important for the results is the fact that in this second stage of the game the covered forward sales become strategically irrelevant for the competitors. The firms, being committed to deliver the forward quantities at the agreed contract price, now compete only for the residual demand on the spot market. Any quantity proposed on the spot will not reduce the price of the units that have already been sold forward. With $x_i = f_i + s_i$ and $X = F + S$, Equation [4] can be rewritten as

$$p_i(x_i) = p_F f_i + (A - X)(x_i - f_i) - cx_i . \qquad [5]$$

Thus, in the spot stage firms simultaneously choose production levels to maximize profits as displayed by Equation [5]. The forward obligations are fulfilled as agreed in the first stage, and any units exceeding the contracted production are offered on the spot market. In equilibrium this leads to a spot market price of

$$p_S^* = \frac{A + nc - F}{n + 1} . \qquad [6]$$

Because equilibrium behavior is expected for the spot stage, buyers are not willing to agree to a forward contract that specifies a price above p_S^*. On the other hand, if $p_f < p_S^*$ a speculator would be willing to sign all forward contracts available. Therefore, the forward market equilibrium must yield a contract price equal to the spot price. A comparison between Equations [3] and [6] shows that the market price in the two-stage setup is lower for any positive quantity signed in forward contracts.

Moreover, firms have an individual strategic incentive to make forward transactions. To see this consider again firm *i*'s total profits over both stages. Because $p_f = p_S^*$ these can now be written as

$$p_i(f_i) = \left(\frac{A-c-F}{n+1}\right)\left(f_i + \frac{A-c-F}{n+1}\right). \qquad [7]$$

The first bracketed expression depicts the firm's per unit profit, that is, the market price minus the per unit production cost. The second part is *i*'s production level with f_i being *i*'s forward position and the second term being the anticipated spot quantity. On the one side, forward contracts signed by firm *i* put the market price under pressure and lower *i*'s expected spot sales. However, these negative effects are mainly external: firm *i*'s competitors have to share these costs. On the positive side, by signing forward firm *i* gains directly by an immediate increase in sales. Firm *i*'s optimal response function is

$$f_i = \left(\frac{n-1}{2n}\right)\left(A-c-F_{-i}\right) \qquad \text{where } F_{-i} = \sum_{\substack{j=1 \\ j\neq i}}^{n} f_j\,. \qquad [8]$$

If player *i*'s competitors refrain from forward contracting, i.e. if $F_{-i} = 0$, the firm could obtain a Stackelberg leadership position producing a total of

$$x_i = \frac{A-c}{2}\,. \qquad [9]$$

However, this is not an equilibrium. Solving for the equilibrium forward position yields

$$f_i^* = \frac{n-1}{n^2+1}\left(A-c\right). \qquad [10]$$

From this the equilibrium levels for all variables can be derived immediately. Table 1 summarizes the results and compares them with the case of pure spot market trading.

Table 1: **Theoretical results**

	Cournot: Spot market only	*AV: Forward & spot market*
Total forward quantity	—	$F^{AV}(n)=\left(\frac{n^2-n}{n^2+1}\right)(A-c)$
Total spot quantity	$S^C(n)=\left(\frac{n}{n+1}\right)(A-c)$	$S^{AV}(n)=\left(\frac{n}{n^2+1}\right)(A-c)$
Total production	$X^C(n)=\left(\frac{n}{n+1}\right)(A-c)$	$X^{AV}(n)=\left(\frac{n^2}{n^2+1}\right)(A-c)$
Price	$p^C(n)=\frac{A+nc}{n+1}$	$p^{AV}(n)=\frac{A+n^2c}{n^2+1}$
Profit per firm	$p_i^C(n)=\left(\frac{A-c}{n+1}\right)^2$	$p_i^{AV}(n)=n\left(\frac{A-c}{n^2+1}\right)^2$
Consumer Surplus	$q^C(n)=\frac{1}{2}\left(\frac{n(A-c)}{n+1}\right)^2$	$q^{AV}(n)=\frac{1}{2}\left(\frac{n^2(A-c)}{n^2+1}\right)^2$

A number of comparative-static predictions can be derived from Table 1.

1. An increase in the number of firms implies lower prices and higher output under both market institutions, i.e., with $N > n$, $X^C(N) > X^C(n)$ and $X^{AV}(N) > X^{AV}(n)$.
2. For a given number of competitors, introducing a forward market enhances competition, i.e. $X^{AV}(n) > X^C(n)$.
3. In terms of total production, prices, total profits and consumer surplus adding a forward stage has the same effect as squaring the number of competitors, i.e. $X^{AV}(n) = X^C(n^2)$.

Thus, compared to the rise in competitive pressure caused by an increase in the number of firms the competition-enhancing effect of forward trading is surprisingly strong. The forward market effect is driven by a prisoner's dilemma among the competing firms. If all competitors refrain from forward trading they achieve moderately high payoffs. However, by deviating from this strategy a single firm can increase its profits considerably by gaining a leadership position on the expense of its competitors. In the non-cooperative equilibrium solution of this game, all firms make forward transactions at relatively low profit levels.

3. Design of the experiment

In this section we describe the design and the procedures that we used in our laboratory experiment to test the predictions derived from AV's model.

3.1. Treatments and Predictions

The experiment consisted of thirty-two independent multi-period oligopoly markets with symmetric firms and linear demand. We compared two market institutions, one in which firms could only sell on a spot market (Cournot markets, henceforth C) and one in which firms had access first to a forward market and then to a spot market (AV markets, henceforth AV). As a second treatment variable we studied the effect of varying the number of firms (two versus four). Thus, we employed four treatments in a 2x2 design as shown in Table 2. In all conditions human sellers chose quantities with simulated buyers determining the market price. The treatment comparisons are based on a between-subjects design.

Table 2: The four treatments

	Two sellers	*Four sellers*
Cournot: *Spot market only*	C2	C4
AV: *Forward & spot market*	AV2	AV4

To simplify the decision problem for the subjects we abstracted from production costs (i.e. $c = 0$). This does not alter the key characteristics of the theoretical predictions. In all treatments participants could choose quantities from a finite grid of whole numbers between 0 and 1000. The demand side of the market was modeled with the computer buying all supplied units according to an inverse demand function. In the Cournot sessions the price was computed as

$$p_t = \max\left\{1000 - X_t, 0\right\} \qquad [11]$$

where X_t denotes the total quantity in period *t*.[3]

Using automated demand is a standard procedure in Cournot experiments, but in the forward stage of the AV sessions it raises the question how the model's perfect foresight assumption should be implemented. In our design we provided the artificial consumers with the expectation of Cournot play in the spot stage, exactly as in AV's model. This implies that the forward price was determined by Equation [6] or, for the parameters we used, by

$$p_t^F = \max\left\{\frac{1000 - F_t}{n+1}, 0\right\} \qquad [12]$$

[3] The fact that we supplied each firm with the capacity to cover the whole demand makes it possible that total production exceeds 1000 units (in which case the market price is defined as zero). This has some implications for our statistical test procedures as explained in detail below.

where *n* is the number of firms (either two or four) and F_t is the total forward quantity chosen in period t.[4] The spot market price in the AV sessions was determined by Equation [11]. Payoffs were computed as the sum of revenues from forward and spot market.

The discreteness of the permissible choice space in the experiment introduces multiple, partly asymmetric equilibria for the stage games of some of our treatments (C2 and AV4). However, because the grid is relatively fine the equilibria of the discrete game are all very close to the equilibria of the continuous case. Hence, we use the latter for our point predictions. Table 3 lists the predictions derived from the model for all treatments. In Table 4 we have listed the predicted outcomes for two further important theoretical benchmarks, the cases of collusion[5] and of perfect competition.

Table 3: Equilibrium predictions for all treatments

	C2	*C4*	*AV2*	*AV4*
Total forward quantity	—	—	400	706
Total spot quantity	—	—	400	235
Total production	666	800	800	941
Price (e$)[6]	3.33	2.00	2.00	0.59
Profit per firm (e$)	1111.11	400.00	800.00	138.80
Consumer surplus (e$)	2222.22	3200.00	3200.00	4429.07

[4] We refer to a "period" as the complete cycle consisting of the forward stage and the spot stage.
[5] Perfect collusion in the AV setting involves two steps: (i) sellers must refrain from trading on the forward market, and (ii) they must then choose collusive quantities on the spot market.
[6] Prices were computed in "eCents" and then re-scaled to "e$" (1e$ was worth 100eCents). In the tables prices and earnings are shown in e$.

Table 4: Benchmarks of collusion and perfect competition

	Collusion		*Perfect Competition*	
	C Markets	*AV Markets*	*C Markets*	*AV Markets*
Total forward quantity	—	0	—	1000
Total spot quantity	—	500	—	0
Total production	500	500	1000	1000
Price (e$)	5.00	5.00	0.00	0.00
Total profits (e$)	2500.00	2500.00	0.00	0.00
Consumer surplus (e$)	1250.00	1250.00	5000.00	5000.00

3.2. Experimental procedures

The computerized experiments were conducted in March 2002 at the Centre for Decision Research and Experimental Economics (CeDEx) based in the School of Economics at the University of Nottingham. In total 96 subjects participated, recruited by e-mail after being randomly selected from a database of about 2000 Nottingham undergraduate students from all subject areas. No subject took part in more than one session and exactly sixteen subjects participated in each session. The participants earned, on average, £9.82 (ca. 14 US$ or €15.90 at the time of the experiment). The Cournot sessions lasted about one hour each, the AV sessions about two hours each, including the time spent for reading the instructions. In total we conducted six sessions: one C2 session and one AV2 session with eight independent markets each, and two four-seller sessions in each the Cournot and the AV treatment, with four independent markets per session. In all treatments subjects interacted for thirty periods, which was commonly known.[7]

[7] Note that thirty periods imply thirty decision rounds in the Cournot treatments but *sixty* decision rounds in the AV treatments, because the introduction of a forward market creates a two-stage game.

Subjects were paid according to their total profits earned during a session plus a £2 flat fee. We used an artificial laboratory currency denominated in "experimental dollars" (e$) where 1 e$ is equal to 100 eCents. Because predicted earnings differ substantially across treatments and because it could be expected that the AV sessions would last considerably longer than the Cournot sessions, we adjusted the exchange rates according to the treatments. We chose them such that expected cash earnings under Nash would be around £13 in both AV treatments and around £8 in both Cournot conditions (including the flat fee).[8]

When the subjects arrived at the laboratory they were randomly seated at computer terminals. Communication between subjects was not permitted throughout the session and dividers separated the individual workplaces so that the subjects could not see each other's screens. At the beginning of a session the instructions were handed out and then read aloud by the experimenter.[9] The experiment itself was fully computerized with subjects entering choices on their terminals. Furthermore, to make the incentive structure of the situation more transparent we equipped our software with a "results calculator", which participants could use to experiment with hypothetical decisions prior to submitting a real choice.[10]

After all participants had submitted their choices in a decision round the computer calculated market prices and profits. At the end of each decision round – i.e. at the end of a *period* in the Cournot treatment and at the end of the *forward stage* or the *spot stage* in the AV treatment – the participants were shown a "Results Screen" on their terminals. This screen displayed the subject's own choice, total production in the relevant market, the market price and the profits. Before the participants entered the

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[8] The exact exchange rates were 60 eCents (C2), 20 eCents (C4 and AV2) and 4 eCents (AV4) per British Pence.

[9] A copy of the instructions can be found in Appendix A.

next stage/period a “History Screen” was shown that listed all previous outcomes in the market in a summarized form.[11]

Before starting the decision-making part of a session, the sixteen participants were randomly allocated to either eight (two-seller conditions) or four (four-seller conditions) separate markets. We used a fixed-group procedure; i.e. the matchings were not changed during the thirty periods. The subjects were informed of this, but they were also told that we would not reveal to them, neither during nor after the session, with whom they were interacting during the experiment. Because each market has a commonly known finite horizon, equilibrium predictions are unaffected by repetition. Nevertheless, using a fixed-group procedure instead of random matching can induce repeated game effects and facilitate collusive strategies, especially in duopolies. However, the assumption that oligopolists interact repeatedly is indisputably a natural starting point despite the fact that AV’s model is static. In other words, the point made by AV can only be relevant for real markets if it does not break down in a dynamic setting with the same market participants competing over time. Part of Harvey’s and Hogan’s (2000) critique outlined in the introduction is that this feature of real markets has not been addressed in the model. Thus, the fixed-matching procedure makes our test more challenging for AV’s theory but also more realistic.

4. Experimental Results

4.1. Overview

Table 5 provides a summary of the data at an aggregate level, listing overall averages and standard deviations for each treatment.

[10] A detailed description of the way the results calculator worked is given in Appendix B.

Table 5: Summary statistics (standard deviations in parentheses)

	C2	*C4*	*AV2*	*AV4*
Average forward quantity	—	—	242.34 (122.40)	768.31 (237.59)
Average spot quantity	—	—	472.15 (102.02)	239.08 (141.41)
Average total quantity	636.73 (93.78)	909.22 (189.22)	714.48 (95.93)	1007.39 (132.63)
Median total quantity	647	827.5	720	965
Average forward price	—	—	2.52 (0.41)	0.56 (0.33)
Average spot price	—	—	2.87 (0.91)	0.50 (0.50)
Average price	3.63 (0.94)	1.54 (0.98)	2.75 (0.75)	0.54 (0.36)
Average total profits	2198.12 (332.44)	1184.25 (677.87)	1843.75 (314.75)	490.35 (296.79)
Average consumer surplus	2084.59 (623.03)	3638.64 (824.54)	2676.97 (536.32)	4481.98 (335.01)
Average total welfare	4282.70 (328.35)	4822.90 (161.52)	4520.72 (269.83)	4972.33 (48.05)

To formally test the predictions of the model we employ only non-parametric tests at the level of markets. Because we use a fixed-group design, each market generates one independent observation. Our data analysis focuses on three sets of questions.

1. Does an increase in the number of firms enhance competition and efficiency in both trading institutions?
2. Does forward trading enhance competition and efficiency in both the duopoly and the four-seller oligopoly? Moreover, is the introduction of a forward market as effective as doubling the number of competitors?

[11] Appendix C contains screenshots from different screens. The software was written in VisualBasic.

3. How does the data fit to the theoretical predictions and does behavior change over time? To what extent and in which way do the players use the forward market?

4.2. Test procedures and variables

a. General procedures

We use a one-sided Wilcoxon rank-sum test to test the comparative static predictions. Our null hypotheses state that changes in either the number of firms or in the market institution does not have an impact on total production or market prices. We test the null hypotheses against the one-sided alternative hypotheses suggested by the model. We also test for systematic differences between the C4 and the AV2 treatment, but use a two-sided alternative hypothesis because theory does not predict any differences between C4 and AV2. For testing the point predictions we use a two-sided binomial test to assess whether forward/spot quantities and prices are systematically higher or lower than suggested by theory. The following gives a more detailed account of the variables we use for our statistical analysis.

b. Test variable 1: Production levels across treatments

The question we are ultimately interested in is whether and in what way *welfare* is affected by the treatment variables. A simple indicator of total welfare in a market is average total production. However, this indicator becomes partially flawed when total supply is above 1000 units (total demand) because the excessive part of the production does not increase welfare above the efficient level. Taking the surplus production into account when calculating the average quantity in a market would raise this average, incorrectly indicating a higher welfare level. Thus, when computing the average total quantities for the purpose of making comparisons across sessions, we disregard any excess units above the maximum demand that may occur in some markets in some periods, and treat production levels above 1000 units as equal to 1000 units. This makes our comparative-static tests more conservative. However, note that we do not use this procedure for the testing of the *point* predictions, where excessive supply should be fully accounted for as a deviation from theory. To make this distinction clear we will use the term "truncated quantities" when referring to averages that are based on the modified production levels.

c. Test variable 2: Market prices across treatments

The second measure we use for the comparative static tests is the average market price, which is a simple indicator for competitiveness and consumer welfare. Using this additional measurement for inter-market comparisons would be redundant in the Cournot treatments, as there is a strict negative relationship between total quantities, our first test variable, and prices. However, this is not the case in the AV treatments where the market price and the distribution of welfare depend on how many units have been sold in the forward stage and how many in the spot stage. If the firms use both stages they can even make profits when the total production covers the whole demand of 1000 units. The reason is that buyers do not *expect* perfectly competitive prices on the spot market and are therefore willing to pay higher-than-competitive prices when buying on the forward market. Thus, the introduction of a forward market can have different effects on total welfare on the one hand and on the distribution of consumer surplus and profits on the other hand. As our second test variable we therefore compute, for each period, the average of the forward price and the spot price, weighted by to the number of units sold in each stage, and we then average the weighted prices across all periods. In the Cournot conditions we simply calculate the average prices in the different markets across periods.

4.3. Comparative-static findings

Table 6 lists the average truncated[12] production levels and the average prices for all markets and treatments.

Table 6: Average truncated production levels and market prices

		Truncated production		*Average market prices*	
	Market	*Cournot*	*AV*	*Cournot*	*AV*
Two firms	*1*	628.73	584.20	3.71	4.11
	2	541.70	742.03	4.58	2.45
	3	652.57	800.17	3.47	2.02
	4	620.50	814.47	3.80	1.99
	5	697.63	714.00	3.02	2.62
	6	683.53	713.20	3.16	2.83
	7	594.17	705.13	4.06	2.32
	8	675.00	633.40	3.25	3.65
Four firms	*1*	869.67	936.77	1.30	0.60
	2	913.83	946.67	0.86	0.54
	3	769.63	936.40	2.30	0.70
	4	906.97	967.87	0.93	0.35
	5	794.23	985.30	2.06	0.31
	6	814.67	957.80	1.85	0.43
	7	871.37	910.33	1.29	0.90
	8	828.87	962.77	1.71	0.46

Question 1: Do more firms imply higher quantities and lower prices? The answer is a very clear yes. When the number of sellers is changed from two to four, total (trun-

cated) production increases by 32.9% in the Cournot markets and by 33.2% in the AV treatments. At the same time, average prices decrease by 57.6% (Cournot) and 80.5% (AV). Moreover, Table 6 shows that even the highest average production level among the two-seller markets is still lower than the lowest average production level among the four-seller markets. This is true for both the Cournot and the AV treatment, and we find the exact opposite result for average prices under both market institutions. Table 7 reports the results of the statistical tests.

Question 2: Does the introduction of a forward market stage enhance competition? Again, our data produces clear results in favor of the theoretical prediction though the effect is somewhat weaker. The introduction of the forward market in the duopoly raises, on average, total quantities by 12.2% and lowers prices by 24.3%. In the case of four firms the increase in production is 10.8%, and the decrease in prices is 65.2%. Formal statistical results can again be found in Table 7.

Table 7: Wilcoxon rank sum test statistics, based on Table 6 (H_0: no change)

	Average total production		*Average market prices*	
versus	*C4*	*AV2*	*C4*	*AV2*
C2	H_1: C4 > C2 p-value: 0.0001	H_1: AV2 > C2 p-value: 0.0141	H_1: C4 < C2 p-value: 0.0001	H_1: AV2 < C2 p-value: 0.0141
AV4	H_1: C4 < AV4 p-value: 0.0002	H_1: AV2 < AV4 p-value: 0.0001	H_1: C4 > AV4 p-value: 0.0002	H_1: AV2 > AV4 p-value: 0.0001
AV2	H_1: C4 AV2 p-value: 0.0018	—	H_1: C4 AV2 p-value: 0.0018	—

[12] It is worth noting that the occurrence of excessive supply is asymmetric across treatments – it is virtually non-existent in the two-seller sessions but it does play a role in both four-seller treatments.

Thus, we reject the null hypotheses in favor of the central theoretical predictions. At the same time, however, the data also produces strong evidence that the outcomes in four-seller Cournot condition and in the two-seller AV treatment are *not* identical as predicted by the model. In contrast to the prediction the two-sided rank-sum test indicates that total production in C4 is systematically higher and prices are systematically lower than in AV2. Thus, the introduction of a forward trading institution is *not* as effective as increasing the number of competitors from two to four. Figure 1, showing the theoretical and average price levels in all four treatments over time, illustrates the empirical differences between AV2 and C4 in graphical form. Average prices in the two-seller AV and the four-seller Cournot condition differ from the theoretical prediction as well as from each other. In contrast, the AV4 prices are relatively close to the predicted level. Based on this, one might hypothesize that the four-seller AV results could be similar to the outcomes of a sixteen-seller Cournot treatment, as theory would predict, but this is speculative. In fact, some experimental evidence indicates that markets with more than two firms tend to be more competitive than theoretically expected, and it has been suggested that “these deviations are increasing in the number of firms” (Huck, Normann and Oechssler, 2001).

[FIGURE 1 HERE]

4.4. Theoretical vs. observed production and price levels

In this section we examine in more detail to what extent our data fits the theoretical predictions in *absolute* terms (*Question 3*). Figure 2 displays the average production levels[13] in all 32 markets, together with the corresponding theoretical predictions (dotted lines).

[FIGURE 2 HERE]

The figure suggests that quantities in the two-seller treatment tend to be lower than predicted, whereas they are generally above the theoretical levels in both four-seller conditions. However, when applying a sign test to the data we detect only in C4 a systematic, i.e. statistically significant, deviation from the predicted production level. With regard to prices the sign tests detects only in AV2 a statistically significant deviation from the prediction (see Table 8 for details). Thus, in addition to our above finding that C4 and AV2 are significantly different *from each other*, there is also some evidence in our data that suggests that C4 and AV2 both differ from the theoretical prediction, with C4 being more and AV2 being less competitive than predicted.

Generally, our findings in the benchmark treatments replicate previous experimental results on Cournot competition,[14] but do sellers in the AV treatments make use of the forward market as predicted? The data indicate that the discrepancies between theory and data, analyzed separately for the forward and the spot stage, are more severe in AV2 than in AV4. While deviations in the four-seller markets do not seem to be systematic, we find that in seven of the eight AV2 groups the forward quantities are lower, and the spot quantities higher, than predicted (p-value: 0.070). Table 8 summarizes the analysis.

[13] As explained above, the quantities reported in this subsection are not “truncated”. One consequence of this is that some markets in Figure 2 yield average production levels above 1000 units. This does not imply that these markets are fully efficient or produce outcomes that are more efficient than other markets. The averages are driven up by relatively few periods with very high excessive supply.

[14] See Huck, Normann and Oechssler (2001) for an overview.

Table 8: Predicted vs. observed average quantities and prices

Number of markets in which…	*…average quantities are…*			*…average market prices are…*		
	…below prediction	*…above prediction*	*p-value**	*…below prediction*	*…above prediction*	*p-value***
Overall						
C2	5	3	*0.727*	3	5	*0.727*
C4	1	7	*0.070*	6	2	*0.289*
AV2	6	2	*0.289*	1	7	*0.070*
AV4	2	6	*0.289*	5	3	*0.727*
Forward stage						
AV2	7	1	*0.070*	1	7	*0.070*
AV4	3	5	*0.727*	5	3	*0.727*
Spot stage						
AV2	1	7	*0.070*	1	7	*0.070*
AV4	5	3	*0.727*	5	3	*0.727*

* *Two-sided sign test based on average forward/spot/total quantities over all thirty periods*

** *Two-sided sign test based either on average forward or spot prices over all thirty periods or on weighted average market prices over all thirty periods*

The observation that markets characterized by relatively low forward quantities tend to produce high spot quantities and vice versa indicates that subjects respond to different levels of residual demand on the spot market (generated by different levels of forward market supply). This is in a sense consistent with theory, which predicts Cournot outcomes on the spot market for any given forward market choice. To illustrate in more detail how choices in the second stage correlate with the outcomes in the first stage, we have plotted the total spot quantities against the total forward quantities in Figures 3a and 3b, for all markets and periods. The figures also contain relevant theoretical benchmarks: first, the *ex ante* point prediction for both stages ("equilibrium prediction"), and second, the "*ex post*" prediction (i.e. after observing the empirical forward stage results) for the spot market ("Spot stage Cournot path").

[FIGURE 3 HERE]

Figures 3a and 3b reveal that the exact point predictions do not deliver a very accurate description of actual behavior. On the other hand, the data points are clearly scattered around the spot stage Cournot paths, which all but approximate the actual linear trendlines for the data. Also, the point predictions seem to satisfactorily describe *average* behavior, in particular in the four-seller markets.[15]

The determination of the forward market price in the model as well as in our experiment is based on the expectation of equilibrium play in the spot stage (*ex post* prediction). If firms do choose Cournot quantities on the spot market, forward prices and spot prices are identical in *every forward market contingency* and not only along the equilibrium path.[16] Figure 4 compares the theoretical with the empirical forward and spot prices and illustrates some distinctive differences between the two-seller and the four-seller markets. The pattern in the AV2 time series indicates that, on average, the duopolists choose (a) lower than *ex ante* predicted quantities in the forward stage (forward prices above theoretical level) and (b) lower than *ex post* predicted quantities in the spot stage (spot prices above forward prices). These outcomes are consistent with partly collusive behavior in both stages. In contrast, average prices in AV4 are relatively close to the theoretical levels as well as to each other.

[FIGURE 4 HERE]

[15] The predicted total quantities in AV4 are 706 units and 235 units for the forward and the spot market respectively. The corresponding empirical averages are 768 and 239.
[16] See Ferreira (2001) for a detailed discussion.

An interesting question is whether the discrepancies between point predictions and data decrease over time. We have little evidence for this. In fact, behavior is remarkably stable over the thirty periods. For example, while the production levels in four of the eight AV4 markets move closer to the prediction in the second half of the experiment, the opposite is the case for the other four markets. This is true for forward quantities, spot quantities and total quantities, and we get similar results for the other treatments when comparing the outcomes of the second with the outcomes of the first half of the sessions.

5. Conclusions

In this paper, we report the results of a laboratory test of Allaz and Vila's (1993) model of quantity competition in two-stage markets. Treatments with two and four sellers per market were conducted and compared with results from benchmark conditions of two and four competitors in standard Cournot markets. Our subjects respond strongly to the treatment variables with quantity changes in the predicted directions leading to according price changes. Furthermore, our data supports Allaz and Vila's hypothesis that forward markets promote competition. However, the predicted equivalence of introducing a forward market and increasing the number of sellers from two to four is strongly rejected. Our findings indicate that this is due to the AV2 markets being *less* competitive than predicted by theory as well as the C4 markets being *more* competitive than predicted. In this sense the competition-enhancing effect of the forward market is weaker, and the effect of adding more competitors stronger, than the theoretical comparative analysis predicts.

An obvious candidate for an explanation of the differences between the two-seller and the four-seller conditions that we observe is the notion that implicit collusive agreements are easier to achieve with two than with four competitors. Thus, as suspected by Harvey and Hogan (2000), it seems that repeated play in a duopoly makes a tendency towards collusive outcomes likely. However, despite this our data also suggest that forward trading does have a clear and substantial positive effect on competition, even in two-seller markets.

Experiments may play a significant role in the empirical research on forward trading because they can disentangle different reasons for forward transactions, which may all be relevant in the field at the same time. Particularly risk-hedging motives are undeniably relevant in real forward markets and may conceal or overlap with strategic motives. Furthermore, there is a literature (e.g. Newbery, 1997, and Lien, 2000) that considers the possibility that the forward market effect may help incumbent firms to deter entry. In the laboratory the motives for forward trading and their interactions can be studied systematically in a controlled environment. Experiments can also be used to evaluate the importance of particular factors that are relevant for the applicability of AV's theory to real markets and that have been identified in recent theoretical developments. For example, Hughes and Kao (1997) and Ferreira (2001) re-examine the model and discuss the role of observability in AV's approach, showing that the improvement in efficiency may break down if firms cannot observe each other's forward positions. On the other hand, Ferreira also finds that the competition-enhancing effect may even be stronger than in AV if observability is partial. Experimental investigations can help to assess the importance of these and other theoretical arguments. Thus, the present study should be viewed only as a first step in investigating experimentally how serious market designers should take forward trading institutions as a building block for improving efficiency on real-world markets.

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Appendix A: Instructions

Legend: *{…} Two-seller conditions only* *[…] Four-seller conditions only*
**…* Cournot conditions only* *#…# A&V conditions only*

Welcome! This session is part of an experiment in the economics of decision making. If you follow the instructions carefully and make good decisions, you can earn a considerable amount of money. At the end of the session you will be paid, in private and in cash, an amount that will depend on your decisions.

General Rules

The session will consist of 30 periods, in each of which you can earn "experimental dollars" (e$). At the end of the session you will be paid £2 plus an additional amount based on your total e$ earnings from all 30 periods. Your e$ earnings will be converted to cash using an exchange rate of *{60e$}[20e$]*#{20e$}[4e$]# = 1p. Notice that the higher your e$ earnings are, the more cash you will receive at the end of the session.

There are sixteen people in this room who are participating in this session. It is important that you do not talk to any of the other people until the session is over.

In this experiment each person in the room represents a firm. During the session [four]{eight} different markets will operate and at the beginning of the session the computer will randomly allocate you to one of these. Similarly, the other firms will be randomly allocated to markets. In your market there will be you and {one}[three] other firm[s]. Your e$ earnings will depend on your decisions and on the other [three] firm{'s}[s'] decisions. The firm[s] you are matched with will be the same throughout this session but you will not learn the identity of the person[s] who represent{s} [these]{this} firm[s].

Description of a period

#Each of the 30 periods consists of two successive stages. The first of these is called Stage A and the second is called Stage B. We will first describe Stage A, then Stage B.

Stage A#

At the beginning of *each of the 30 periods* #Stage A# you have to decide how many units of a good to produce. You make your decision by entering a number (any whole number between 0 and 1000) on your terminal. After all firms have made their decisions, the computer will calculate your profits for *that period* #Stage A#.

Your profits will be equal to the number of units you produce times the market price.

The market price will depend on how many units you and the other firm[s] in your market have produced in total. We will call the total number of units produced in your market "Total Production". The computer will calculate the market price in *a period* #Stage A# using the following formula.

$$\text{Price} = 1000 - \text{Total Production}$$

#{ $\text{Price A} = \dfrac{1000 - \text{Total Production in A}}{3}$ }

[$\text{Price A} = \dfrac{1000 - \text{Total Production in A}}{5}$]#

This formula gives you the market price in eCents (and 1e$ is worth 100 eCents). Thus, if Total Production were zero (that is, if neither you nor the other firm[s] in your market produced anything at all), then the market price would be *1000 eCents (equals 10 e$)*#{333 eCents (equals 3.33 e$)}[200 eCents (equals 2 e$)]#. But note that the higher Total Production is, the lower the market price will be.

If Total Production is equal to or above 1000 units, then the market price is 0. The market price cannot become negative.

At the end of *each period*#Stage A# you will see a “Results Screen”. The Results Screen will show how many units you have produced and how many units the other firm[s] in your market {has} [have] produced [in total]. It will further display the Total Production in your market, the market price*,* #and# the profits you have made in #Stage A#*that period and your accumulated profits from all periods. After the Results Screen, and before you enter the next period, your terminal will furthermore display a “History Screen” that shows the results from all previous periods in a summarised form.*

#Stage B

Stage B is, in principle, identical to Stage A, but with one important exception. The way the market price is computed in Stage B differs from the way it was computed in Stage A. The market price in Stage B is calculated as (this is again in eCents)

$$\text{Price B} = 1000 - \text{Total Production in A} - \text{Total Production in B}$$

That is, the market price in Stage B depends on both Total Production in Stage A and Total Production in Stage B. As before, the higher Total Production is, the lower the market price will be. Also as before, the market price cannot become negative: if Total Production in Stage B is so high that the formula for Price B would yield a negative result, then the computer sets Price B to zero.

Please notice also the following additional rule. If Total Production in the first stage (Stage A) is already equal to or above 1000 units, then there will be no second stage and neither you nor the other firm[s] in your market will be able to produce in Stage B! If this happens your profits for that period are set to zero, and instead of entering Stage B, you and the other firm[s] in your market will be automatically redirected to the next period.

Otherwise, your total profits in a period are computed as the sum of your profits from both stages.

```
  (Price A) x (Number of units you produce in A)
+ (Price B) x (Number of units you produce in B)
------------------------------------------------
```

```
= Your Total Earnings in a period
```

At the end of Stage B, you will again see a Results Screen showing similar information as the Results Screen described above. Additionally it will display your total earnings for that period and your accumulated earnings from all periods. After the Results Screen for Stage B, and before you enter the next period, your terminal will furthermore display a "History Screen" that shows the results from all previous periods in a summarised form.#

Further Instructions

Before you make a decision in *a period*#either Stage A or Stage B# you can experiment with different hypothetical choices by using the "Results Calculator". You can activate the Results Calculator by clicking on a button on the "Decision Making Screen". The Results Calculator is easy to use. You simply enter arbitrary numbers for your own production and for the production of the other firm[s]. When you press the Enter key, the Results Calculator will show you the resulting market price#s# and your profits for the hypothetical choices.

#When you are in Stage A, the Results Calculator will allow you to enter hypothetical numbers for both stages. When you are in Stage B, the Results Calculator will only allow you to enter hypothetical numbers for Stage B, and it will take the results from the real Stage A as given when calculating Price B.#

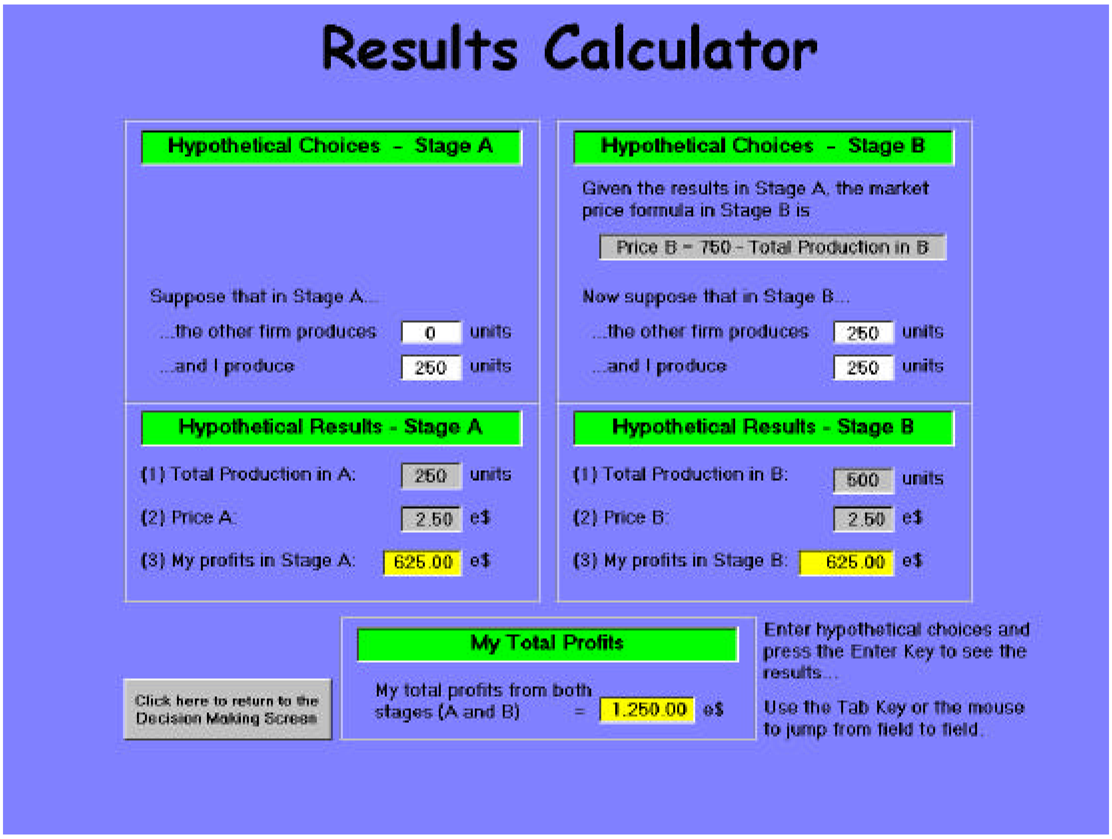
Appendix B: The results calculator

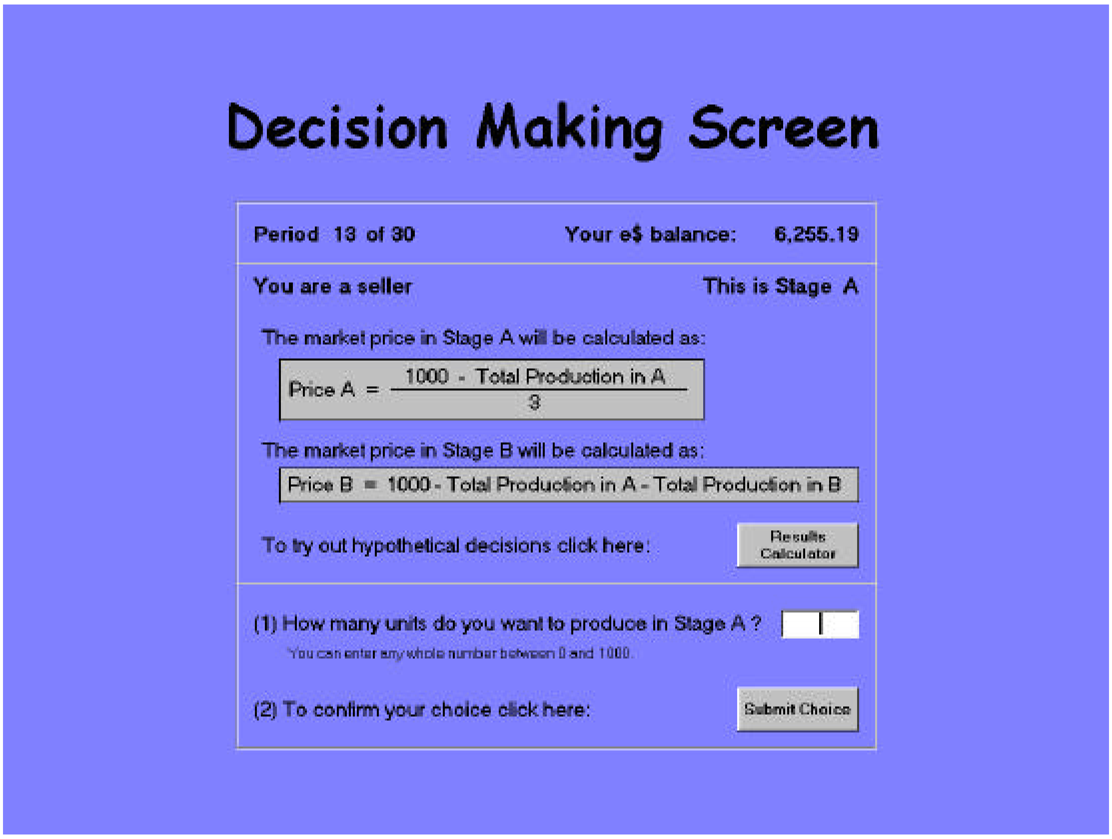
When using the calculator subjects were not constrained by any time restrictions. The basic function the calculator is similar to the profit calculator used by Huck et al. in various experiments (see for example Huck, Normann and Oechssler, 1999). A difference is that our calculator does not provide a “Max” button that computes the best response for given hypothetical choices of other firms. The way the results calculator could be used differed slightly between the Cournot and AV treatments. The following gives a description of the variant we programmed for the AV sessions; the result calculator used for the Cournot condition is just a simplified version of this. A screenshot is provided in Appendix C.

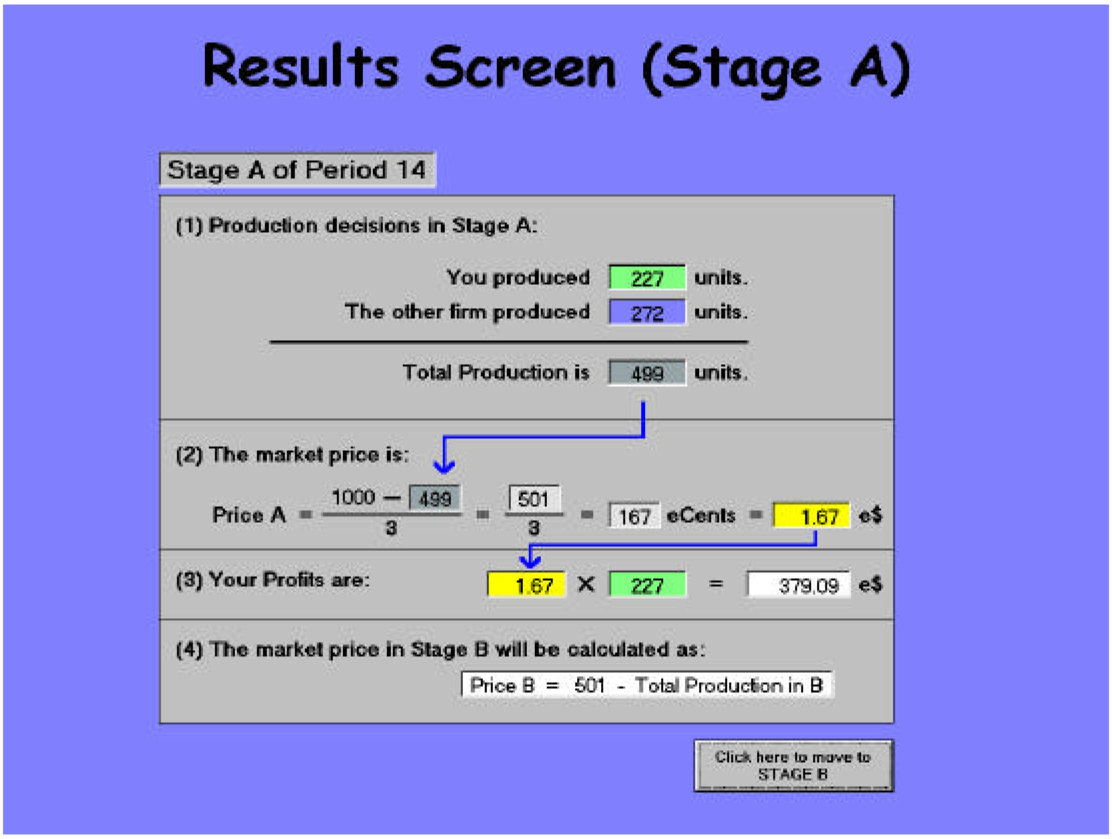
In the forward stage of a period the results calculator worked as follows. First, the participant could enter a hypothetical own quantity and a hypothetical (total) quantity chosen by the other firm(s) in his or her market. After hitting the Enter key, the screen displayed the resulting forward market price and the hypothetical forward profit for the subject. Then a new window opened that allowed the subject to enter further hypothetical quantities for the second stage (spot market), where the spot price, spot profits and total profits were calculated according to the hypothetical choices of both the forward and the spot stage.

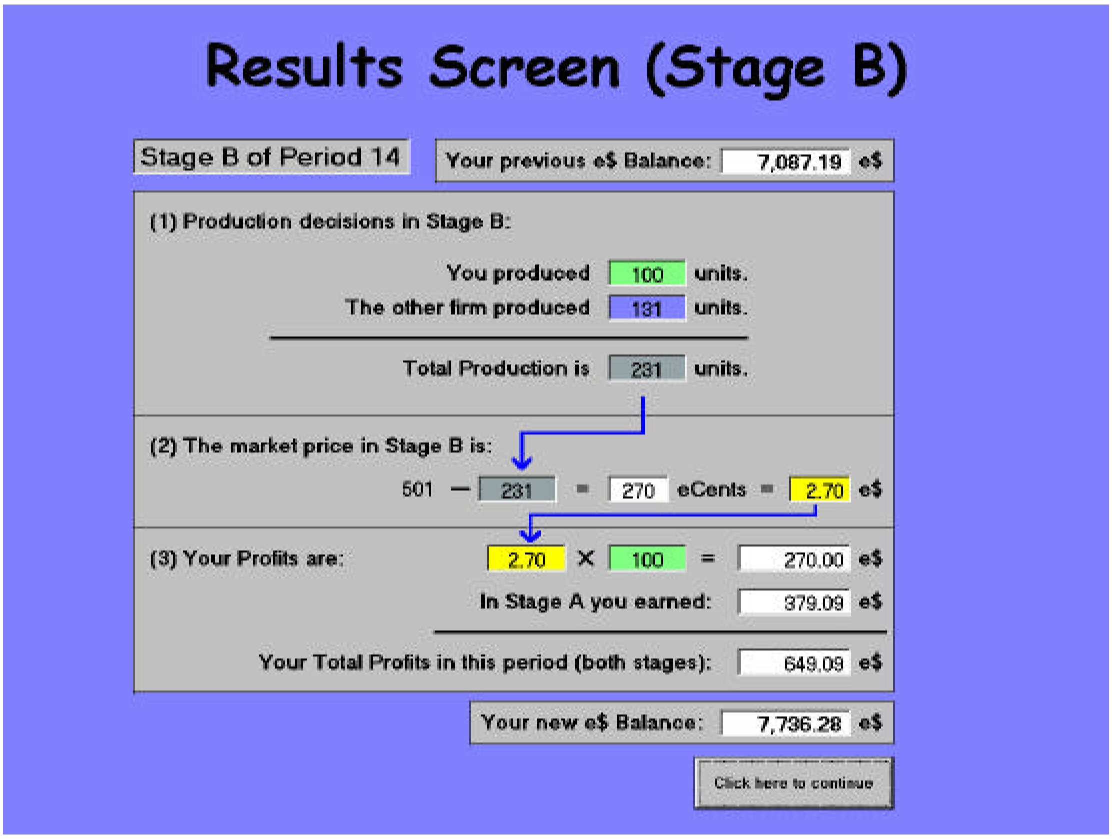
When the experiment was in the spot market stage of a period the subjects were only able to feed the results calculator with hypothetical *spot* quantities, and computations were then based on these hypothetical decisions and on the *real* forward quantities.

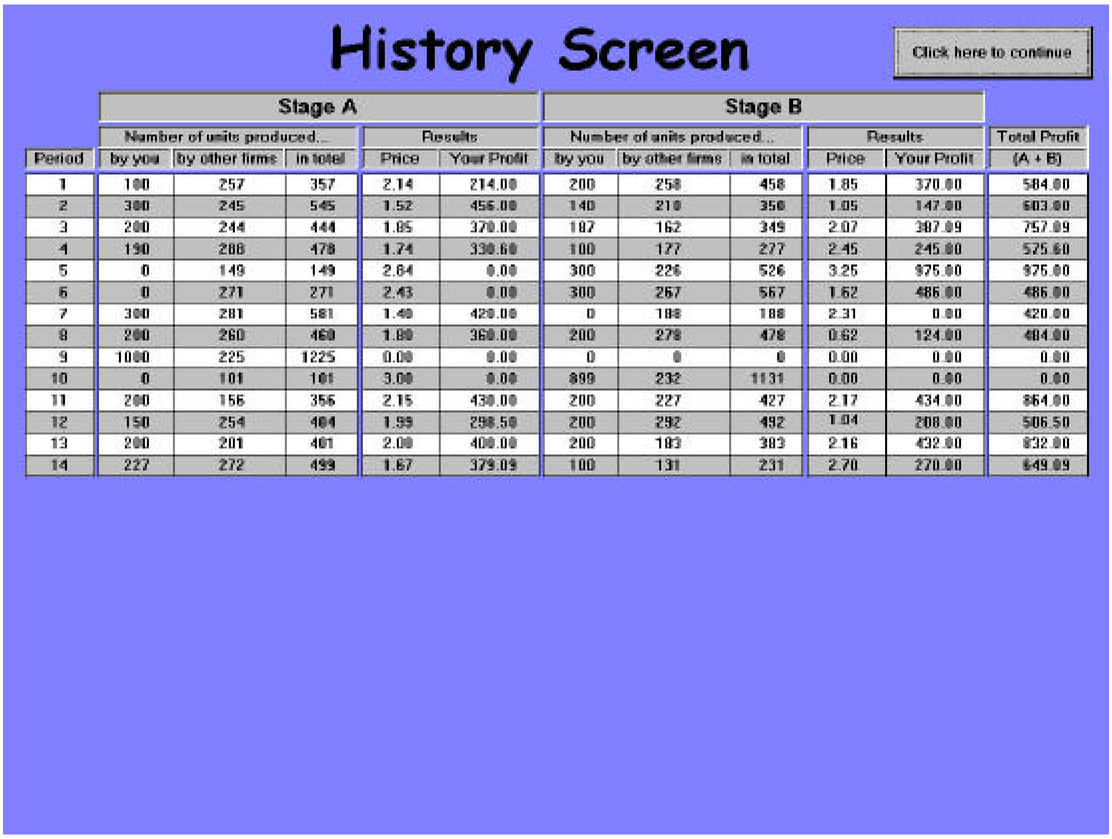
Appendix C: Screenshots






Results Screen (Stage A)
Stage A of Period 14
(1) Production decisions in Stage A:
You produced 227 units.
The other firm produced 272 units.
Total Production is 499 units.
(2) The market price is:
Price A = 1000 — 499 / 3 = 501 / 3 = 167 eCents = 1.67 e$
(3) Your Profits are: 1.67 X 227 = 379.09 e$
(4) The market price in Stage B will be calculated as:
Price B = 501 - Total Production in B
Click here to move to STAGE B


Results Screen (Stage B)
Stage B of Period 14
Your previous e$ Balance: 7,087.19 e$
(1) Production decisions in Stage B:
You produced 100 units.
The other firm produced 131 units.
Total Production is 231 units.
(2) The market price in Stage B is:
501 — 231 = 270 eCents = 2.70 e$
(3) Your Profits are: 2.70 X 100 = 270.00 e$
In Stage A you earned: 379.09 e$
Your Total Profits in this period (both stages): 649.09 e$
Your new e$ Balance: 7,736.28 e$
Click here to continue



History Screen

Click here to continue

	Stage A					Stage B					
	Number of units produced...			Results		Number of units produced...			Results		Total Profit
Period	by you	by other firms	in total	Price	Your Profit	by you	by other firms	in total	Price	Your Profit	(A + B)
1	100	257	357	2.14	214.00	200	258	458	1.85	370.00	584.00
2	300	245	545	1.52	456.00	140	210	350	1.05	147.00	603.00
3	200	244	444	1.85	370.00	187	162	349	2.07	387.09	757.09
4	190	288	478	1.74	330.60	100	177	277	2.45	245.00	575.60
5	0	149	149	2.84	0.00	300	226	526	3.25	975.00	975.00
6	0	271	271	2.43	0.00	300	267	567	1.62	486.00	486.00
7	300	281	581	1.40	420.00	0	188	188	2.31	0.00	420.00
8	200	260	460	1.80	360.00	200	278	478	0.62	124.00	484.00
9	1000	225	1225	0.00	0.00	0	0	0	0.00	0.00	0.00
10	0	101	101	3.00	0.00	899	232	1131	0.00	0.00	0.00
11	200	156	356	2.15	430.00	200	227	427	2.17	434.00	864.00
12	150	254	404	1.99	298.50	200	292	492	1.04	208.00	506.50
13	200	201	401	2.00	400.00	200	183	383	2.16	432.00	832.00
14	227	272	499	1.67	379.09	100	131	231	2.70	270.00	649.09

Appendix D: Figures

Figure 1: Theoretical and empirical average prices over time

3-period moving averages

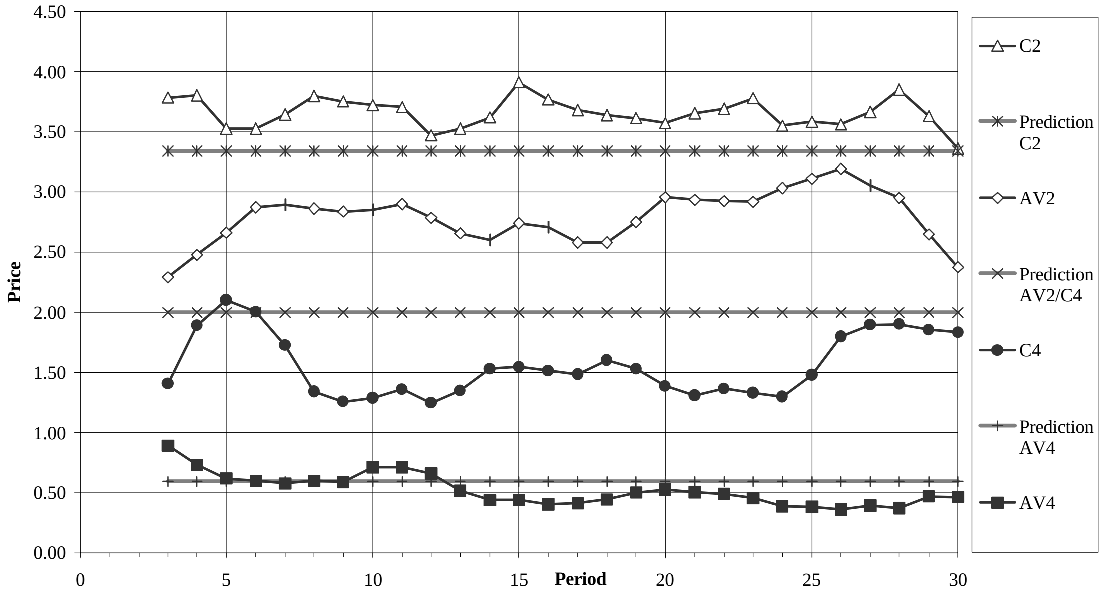


Figure 2: Average total production in all 32 markets

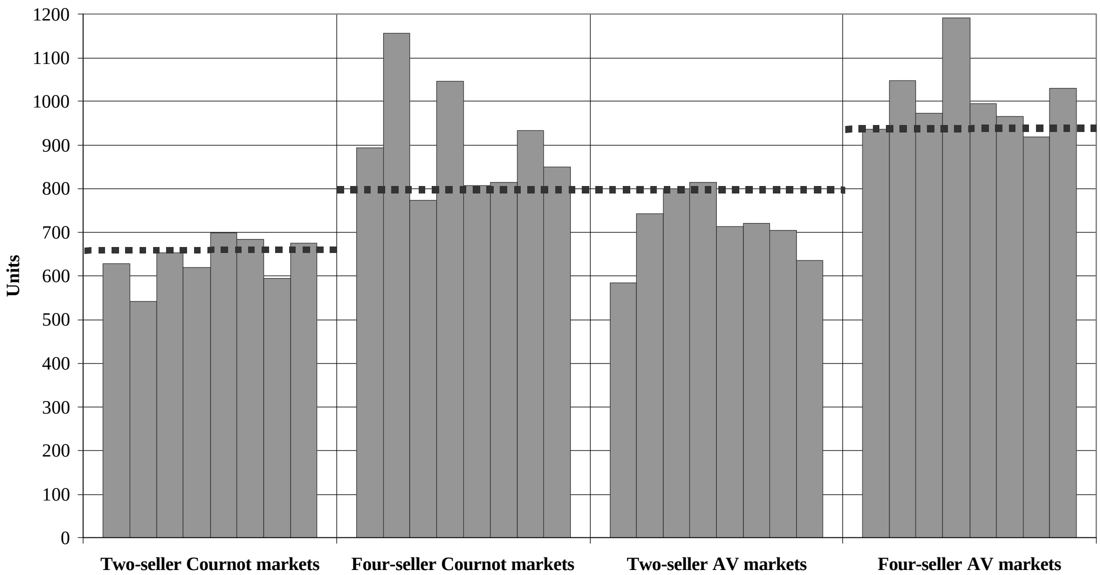


Figure 3a: Forward against Spot Market Quantities

- Two-seller Treatment -

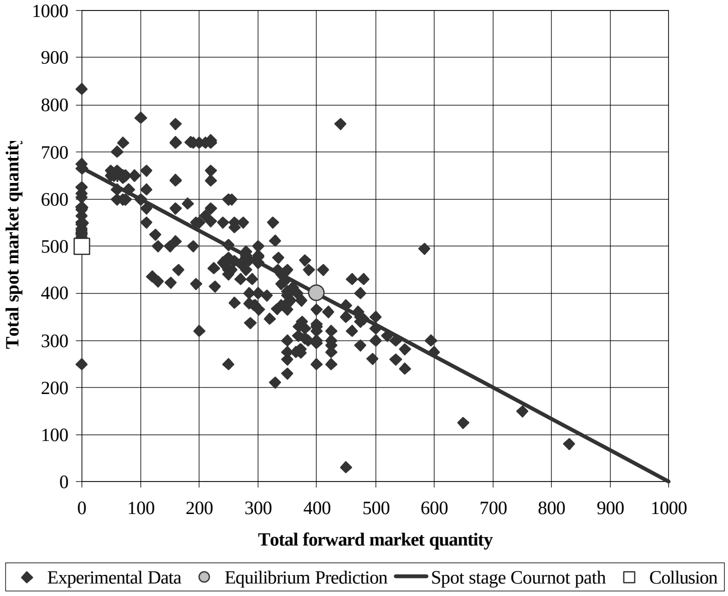


Figure 3b: Forward against Spot Market Quantities

- Four-seller Treatment -

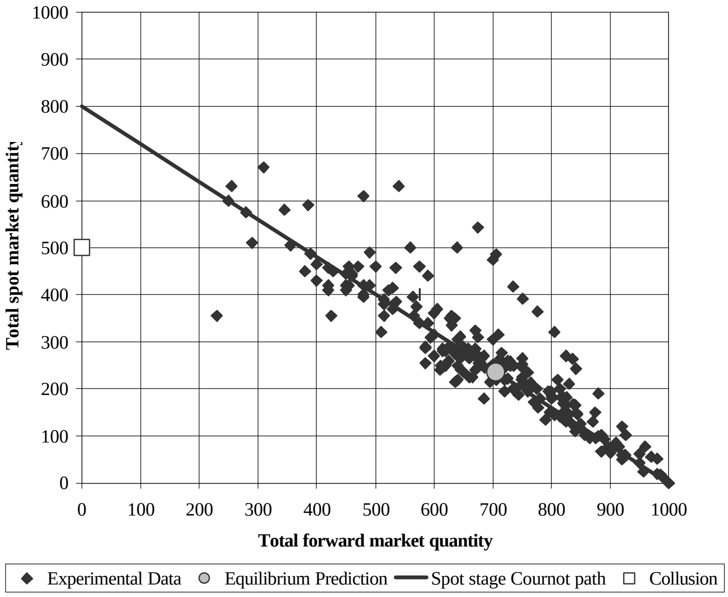


Figure 4: Forward and Spot Market Prices Over Time

(3-period moving averages)