Coordination and Critical Mass in a Network Market – An Experimental Evaluation*

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and

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Abstract. In this paper we present the results of an experiment aimed at testing the ability of consumers to coordinate actions in a market in which network externalities are present. Such markets are characterized by the necessity for consumers to believe that a certain minimum number of people will buy the good (the critical mass) in order to make purchase worthwhile. In our experiment, subjects were asked offered the option of buying a good at a certain price. Subjects were told the value of the product, but this value depended on how many other subjects bought. The experiment was run under two treatments – when subjects were homogeneous in their values and when they were heterogeneous. In each case, there were treatments with low prices and with high prices.

Interestingly, subjects found it easier to purchase when they were heterogeneous than when they were homogeneous. In particular, the only treatment in which cooperation was not usually attained was in the homogeneous treatment when the price was high. We attribute this to critical mass. In the high priced homogeneous treatment the critical mass for all players was high, thus leading to great risk in purchase. In the heterogeneous game the critical mass for the marginal player was also high, but the subject knew that the critical mass for higher value subjects was much lower and that those subjects would therefore be likely to buy. This made purchase less risky, allowing equilibrium to be reached. One implication is that a firm facing a critical mass problem can efficiently help convince consumers that critical mass will be obtained by subsidizing high critical mass consumers (low value consumers), since potential consumers will be likely to already be convinced about the purchase of low critical mass consumers.

Keywords: Networks, Critical Mass, Experimental Economics, Coordination.

JEL Classification Codes: C91, D43, D11.

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I. Introduction

A network market is a market in which the benefit each consumer gets from a good is an increasing function of the number of consumers who own the same or similar goods. A major problem facing a producer interested in *introducing* a network good is the ability to attain critical mass. Since utility depends on the number of consumers, consumers must be convinced that the market will be sufficiently large to justify their purchase. This problem is comprised of two components. First, consumers must be convinced of the producer’s intentions regarding sales. Producers have a clear incentive to overstate their production intentions in order to get consumers to believe that the good will be particularly valuable. If consumers anticipate this, the producer’s declarations may not be credible. Second, consumers must also be convinced about the intentions of other consumers. Even if the producer is intent on creating a sufficiently large market to attain critical mass, each consumer must be convinced that other consumers will, in fact, purchase the good. This, of course, requires that those other consumers believe others will buy, which requires that they believe that others also believe this, and so on. Thus, common knowledge of beliefs is required to guarantee that critical mass will, indeed, be reached. This can be likened to a coordination problem in which there are multiple equilibria, with some equilibria being Pareto superior to others.

In this paper we present the results of an experiment designed to test the consumer's abilities to coordinate in such a network market. In our experiment, subjects are presented with a chart showing the value they receive from purchase of a good as a function of the number of players who purchase the good, and are asked to decide whether they would like to purchase the good given the price. The experiment is run under two treatments – when subjects are homogeneous and when they are heterogeneous. The results of this experiment demonstrate the conditions under which coordination is attained, and also shed light on the critical mass issue. Some implications for firm strategy are discussed.

The paper proceeds as follows. In Section II we present some background about network goods, and give a brief survey of the relevant experimental studies. In Section III the model is developed, the experiment and the experimental design are presented, and our hypotheses are laid out. Section IV contains the results of our experiments, and a discussion and conclusions appear in Section V.

II. Background and Related Literature

A. Network goods and critical mass

For a network market to exist in equilibrium, it must contain enough consumers to cause the utility of each consumer to be at least as great as the price paid for the good. This necessity to attain "critical mass" in a network market has been recognized since the pioneering works of Rohlfs (1974), who analyzed the telecommunications market, and of Oren and Smith (1981) who extended Rohlfs' work. A more recent analysis, including an empirical evaluation of the fax market, is presented in Economides and Himmelberg (1995a, 1995b).

For critical mass to be attained, consumers must believe it will be attained.[1] The ramifications of such a requirement with respect to producer behavior, and how this behavior affects consumer beliefs, were analyzed extensively in Katz and Shapiro (1985), Economides (1996) and Etziony and Weiss (2001). These studies, however, implicitly assume that consumers believe that all other consumers will act as they do, so that "proper" producer behavior will result in critical mass being reached. This assumption is by no means obvious, as it requires common knowledge of beliefs among consumers. To demonstrate this, consider a market with two potential consumers. The purchase of the good is assumed to be worthwhile only if both purchase, however, neither consumer knows whether the other consumer will, in fact, purchase the good. Consumer A will purchase if he believes consumer B will purchase. B will purchase if he believes A will purchase, i.e., if he believes A believes B will purchase. So, in turn, A will purchase if he believes B believes A believes B will purchase, and so on. Thus, in the absence of an ability to coordinate decisions, common knowledge of beliefs is required. This requirement has not been previously discussed in the literature.[2]

A similar argument does, however, exist with regards to competition between different technologies in the context of network goods (see Farrel and Saloner (1986) for an early discussion of this issue). Yang (1997), among others, shows that even

[1] Rohlfs (1974) does not consider this issue. Rather, in his model the producer initially distributes the service for free (thus achieving critical mass) for a limited time, and then charges for the good once critical mass is obtained.

[2] The fact that each consumer bases his decisions on his expectations regarding the decisions of others is analyzed in Crawford (1995) and Broseta (2000) in the context of coordination games.

when consumers know that one technology is superior to another, they may choose to purchase the inferior good if they believe other consumers will do the same. A well-known example (see, for example, Park, 2000) is the adoption of Matsushita's VHS standard for video-recorders instead of the Beta system created by Sony. Those early purchasers of the Beta system, considered by many to be superior to VHS, soon found that they would have been better off purchasing the VHS system, because it turned out to be the surviving standard.

In other cases, a superior standard may never come to market because of its inability to achieve critical mass. Thus, for example, the Dvorak Simplified Keyboard is believed by many to be strictly superior to the QWERTY keyboard (see David, 1985), but because of the cost of transferring to this standard, it has not been adopted (Shapiro and Varian, 1999, pp.184-6).

The main difference between these studies and the issue we raise is that in those studies consumers are uncertain *which* products other consumers will buy, while in ours consumers are uncertain *whether* other consumers will buy the product at all.

B. Related Experimental Literature

There have been many experimental studies of the ability of subjects to coordinate. Most of these studies, including the pioneering works of Van Huyck, Battalio and Beil (1990, 1991), are concerned with discerning the conditions under which consumers succeed in coordinating on Pareto superior equilibria in a setting where multiple equilibria are present. These studies tend to use multiple player versions of Rousseau's Stag Hunt game, in which subjects are asked to choose a number from a small finite set, with the choices of all subjects affecting the payoffs of all other subjects. Equilibrium is attained whenever all subjects choose the same number. Since there is more than one number, there is more than one equilibrium, and these equilibria are Pareto ranked, so that the higher the number the more utility each subject received. The Pareto optimal outcome is attained when all subjects choose the highest number. This choice, however, is risky, since alternative choices by other subjects will cause this subject to sustain losses.[3]

[3] See Ochs (1995) for a survey of articles on this topic, and Van Huyck, et al. (1995), Van Huyck, et al. (1997), and Rankin, et al. (2000) for more recent contributions.

One recent article in this genre, more directly connected to our experiment is concerned with coordination in critical mass games. Devetag (2001) considers a variation of the coordination game. Subjects must choose a number between 1 and 7. The choice of 1 yields a payoff of 1 in all cases, while the choice of a larger number yields higher profits if and only if a minimum number of people choose this number. Specifically, choosing the number i yields a payoff of i if at least i subjects choose that number, and 0 if not.[4] The highest payoff is attained when all players choose the number 7, but if even one player does not choose 7 they all receive 0. This is similar to a network good setting since some players get zero payoff, but in this setting the zero payoff is not achieved by choice, while in a network good setting it is.

An additional related experimental setting deals with the attainment of critical mass in provision of public goods games.[5] The concern in these studies is the free rider problem. In these games, the provision (or amount) of a public good is dependent on a minimum amount of money being contributed to finance the provision of this good. Once this good is provided, all consumers, whether or not they contributed, benefit from consumption of the good. Thus, there is an incentive to free ride by not contributing, with the hope of benefiting from the contributions of others. The clear difference from a network market is that in the latter only those who purchase the good benefit, while in the former everyone benefits. In addition, in a network market a private good is actually being bought, but there is an externality effect that makes the product more valuable if more is purchased.

III. The Experiment and Experimental Design

A. Theory

Consider a market with n potential consumers. Define the set of actions by these consumers $E=(e_1,\dots,e_n)$, where $e_i \in E$ equals 0 if player i chooses not to purchase the good, and 1 if he does. The size of the network, then, will be $N = \sum_{i=1}^{n} e_i$. The outcome of the game will be defined by the price, P, the utility from the network good, $R(N)$,

[4] In one version of the experiment, the payoff equals i+n-1 if n≥i, where n is the number of people who chose i.

[5] See Marwell and Ames (1979, 1980, 1981). See also Ledyard (1995) for a survey.

with $R' > 0$, consumer surplus for each player, Π_i, and the domain of the strategies as follows:

1. $\{\Pi_1(E,P),...,\Pi_n(E,P): \Pi_i(E,P) = e_i[R_i(N) - P] \forall i \in [1,...,n], e_i \in (0,1)\}$.

In order to guarantee the existence of more than one equilibrium, we require that with homogeneous players $R(1)$-P<0 and $R(n)$-P>0. This simply states that if only one player purchases the good he loses, and if all purchase the good they all gain. With heterogeneous consumers, we first order the consumers in decreasing order according to utility, with $R_i(N) > R_j(N)\ \forall i < j$. We then require that $R_1(1) - P < 0$, and $R_i(k) - P > 0\ \ \forall i \in [1..k]$: $1 < k \le n$.

Critical mass is then defined as the *minimum* number of people needed to consume the good so that no consumer loses from the purchase. In the case of homogeneous players, this is the value ω for which $R(\omega$-1)-P<0 and $R(\omega)$-P>0. With heterogeneous players the critical mass is different for each player, and will equal ω_i, such that $R_i(\omega_{i-1}) - P < 0$ and $R_i(\omega_i) - P > 0$. In either case, $\partial\omega/\partial P > 0$ and $\partial\omega/\partial R(N) < 0$.

<u>B. The experiment</u>

In each session, seven consumers participate in multiple rounds of a network market game. The consumers are presented with a table in which they are informed of the value of the good to them, as a function (increasing) of the number of buyers. A price is then set, and each consumer decides whether to purchase the good. If he does not, he gets no benefit from the good. If he purchases the good, his income is increased or decreased by the difference between the value, given the number of purchasers, and the price paid for the good. This experiment was run with two different payoff tables – one with homogeneous players (Table 1), and one with heterogeneous players (Table 2) – and in each treatment with a low price and a high price.

<u>i. Homogeneous players</u>

The payoff table presented to the subjects was as follows:

Table 1

Homogeneous Players

Number of Purchasers	1	2	3	4	5	6	7
Income of Purchasers	0	20	50	90	130	180	230

Numbers were in terms of Agorot (1/100 of a Shekel). For any price between 0 and 230 there are two Nash equilibria – no one buys or everyone buys – with the latter Pareto superior to the former. The critical mass depends on the price, and can be read directly from Table 1. Thus, for example, if the price is between 50 and 90 critical mass is 4 – if at least 4 players purchase the good, all purchasers benefit.

ii. Heterogeneous players

Heterogeneous players were presented with the following table:

Table 2

Heterogeneous Players

Number of Purchasers		1	2	3	4	5	6	7
Income of Purchaser	A	0	260	270	280	290	300	310
	B	0	210	230	250	260	280	290
	C	0	140	160	180	200	220	240
	D	0	90	120	140	160	180	210
	E	0	60	80	100	120	140	160
	F	0	10	30	50	70	90	110
	G	0	5	20	30	50	70	90

For any price below 210 there are again two equilibria. However, while the inferior equilibrium of no one purchasing is still available, the second equilibrium is not necessarily everyone purchasing. The non-trivial equilibrium can be read off of the diagonal in Table 2. Thus, for instance, if the price is 150 the non-trivial equilibrium is to have three purchasers (A, B and C). If indeed, this equilibrium is realized, A will gain 120 (270-150), B will gain 80, and C will gain 10. If player D also purchases he will lose 10, but A, B and C's profits will rise to 130, 100, and 30, respectively.

Critical mass differs for each player. At a price of 150, critical mass for players A through E are, respectively, 2, 2, 3, 5, and 7, while F and G will never purchase. At a price of 80, critical mass for players A through G are, respectively, 2, 2, 2, 2, 3, 6, and 7.

C. Experimental Design

Seven double sessions were run between March and May 2001, in a computer laboratory in Bar-Ilan University. The experiment was programmed using Visual Basic. Four different treatments were run – the homogeneous treatment with a low (30) and high (170) price, and the heterogeneous treatment with a low (110) and high (180) price. In eight of the fourteen sessions only the homogeneous treatment was run, and in the other six both the homogeneous and the heterogeneous treatments were run. Fourteen computers were used at each point in time, i.e., two sessions of seven people each were run at each sitting. Because two sessions were being conducted simultaneously and in the same room, subjects did not know with whom they were playing.

The subjects were undergraduate students at Bar-Ilan University, and were recruited in classrooms, with many of the students being drawn from introductory economics courses for non-economics majors. Upon arrival subjects were randomly assigned to computer terminals, which were separated from each other by cardboard dividers, so that no subject could see the screen of other subjects. Each subject was given a copy of the instructions (see Appendix), and these instructions were read out loud to assure common knowledge. After the instructions were read and questions answered, the subjects were given a quiz to make sure that they understood the instructions.

The payoff table (Table 1 for the homogeneous treatment and Table 2 for the heterogeneous treatment) and the good's price were shown on the subject's terminal, and the subject had to simply press on either the "yes" button or the "no" button in response to the question: Do you wish to buy the good. In the case of the heterogeneous treatment the entire table was shown, and the row pertinent to that player was darkened. Each cell in the payoff table was set up so that if a player pressed on that cell, a dialog box opened which explained the meaning of the number in that cell. For example, clicking on the cell 5E in Table 2 would open a window that said, “If player E purchases the good, and four other people also purchase the good, then player E will receive a value of 120 for the good.”

Each subject was given a starting balance in his account (a show-up fee), and any further winnings (losses) were added to (subtracted from) this sum.[6] The experiments lasted approximately 75 minutes, and subjects earned between 40 and 80 Shekels, with the mean earnings being around 50 Shekels (around $12 – more than twice the minimum wage for students). Subjects were paid in cash after the experiment was concluded. After each round, the subjects were notified how many players purchased the good, and how much was gained or lost in the last round. Players were notified about the number of rounds they were playing, and were notified before the treatment was changed. In the heterogeneous game players were randomly assigned an identity, and this identity was retained throughout all the rounds until the price was changed. The randomization was then redone, and again retained throughout the remaining rounds. This was done so that those who found themselves assigned to be players F or G, and who therefore optimally never purchase, would not necessarily (though he may) be in this position throughout the experiment.

In ten out of the fourteen homogeneous sessions the low price was given first, and the high price afterwards, while in the other four the high price was given first. Out of the six sessions in which the heterogeneous game was also played, in four of them the homogeneous game was played first, while in the other two (sessions 9 and 10) the heterogeneous game was played first. In either case, a new set of instructions was read and a new quiz was conducted between the homogeneous and heterogeneous games.

D. Expectations

With respect to the homogeneous games, we posit the following hypotheses.

H1: All subjects in the homogeneous game will purchase the good, both when P=30 and when P=170.

This is the Pareto optimal outcome. However, the critical mass when P=170 is 6, and the critical mass when P=30 is 3, so if hypothesis 1 is rejected, we posit instead:

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[6] More subjects were recruited for each session than were needed. Subjects who were not included in the experiment were given 20 Shekel and registered for the next experiment, in which they were guaranteed participation if they arrived on time.

H2: Subjects in the homogeneous game will be more likely to purchase the good when P=30 than when P=170.

In addition:

H3: Pareto optimality in the homogeneous game in the rounds in which P=170 is more likely to be attained when the subjects play this game after they play the P=30 game, than when they begin by playing the P=170 game.

The reason to expect this is that the players can be expected to learn to cooperate when P=30, and then carry this cooperation over to the P=170 game. But if they begin with the P=170 game they have not seen a history of cooperation, and so are likely to be cautious because of the high critical mass (and, hence, the large possible losses).

In the heterogeneous game we also predict optimality as our initial hypothesis:

H4: In the heterogeneous games we expect only subjects A and B to purchase when P=180, and only subjects A, B, C, D and E to purchase when P=110.

Assuming this does not strictly hold, we do not have any concrete expectations regarding under-purchase deviations (a situation when someone who should purchase in equilibrium does not) from optimality in the different treatments. On the one hand, when the price is high (P=180) only two people are expected to purchase in equilibrium, so a mistake by one person is enough to cause big losses to the purchaser (note that the value falls to 0 if a subject is the only purchaser). If *P*=110, however, there are 5 expected purchasers, so a single non-purchase can only cause limited damage. On the other hand, it should be easier to reach an implicit agreement with one other player than with four other players. Thus, the probability of losing should rise with the critical mass. Hence, there is a tradeoff, and the total effect is unclear.

This, of course, is relevant only for those who are purported to purchase in the optimal equilibrium. With respect to over-purchasers (those not expected to purchase in equilibrium), however, the losses to the extra-marginal players (players C and F in the high and low priced games, respectively) from a non-equilibrium purchase are approximately equal, so we can posit the following hypothesis:

H5: In the heterogeneous game, the probability of over-buying is independent of the price.

We also posit the following hypothesis:

H6: Players near the margin are more likely to err than players distant from the margin.

This follows from the fact that the further you are from the margin, the more you will lose from suboptimal choices. Thus, for instance, when *P*=110, assume subjects A-E purchase. Then subject F will lose only 20 (90-110) if he purchases (and G does not), while subject G will lose 40 (70-110) if he purchases (and F does not). Similarly, if F and G do not purchase, subject E loses potential profits of 10 (120-110) if he chooses not to purchase, while D would lose 30 (140-110) if he does not purchase. Note that this hypothesis is reasonable assuming the players are not playing the inferior equilibrium of no purchase. If they are, their actions are best responses, and so cannot be considered deviations.

Finally, with respect to the order of play:

H7: We expect the order of play to have no effect on equilibrium play. If, however, there are deviations from equilibrium, they are likely to more plentiful when the heterogeneous game is played before the homogeneous game.

The last part is posited simply because of the time it takes to learn what is going on.

IV. Results

A. Homogeneous Game

The results of the homogeneous sessions are shown in Figures 1.1-1.14. The solid lines in each graph signify the Nash equilibria, and the dotted line signifies critical mass. The first ten frames show the sessions in which the price was initially set at 30, requiring a minimum of three purchasers to reach critical mass, and then the price was changed to 170. In the last four frames the order was reversed. In frames 9 and 10 the heterogeneous game was played before the homogeneous game, so the first round appears as round 17. Note that the number of rounds was not identical across sessions. This occurred because the server speed was slower than anticipated, so we decreased the number of rounds per treatment (after the first experiment[7]) in order to save time. Subjects were always informed of the number of rounds at the start of the treatment.

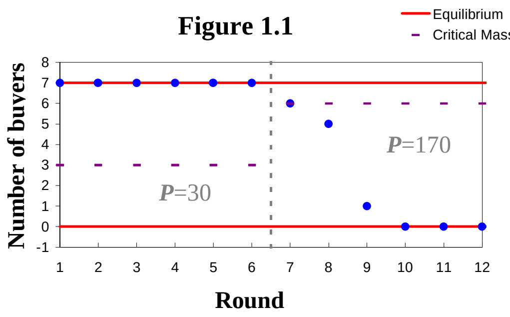


Figure 1.1

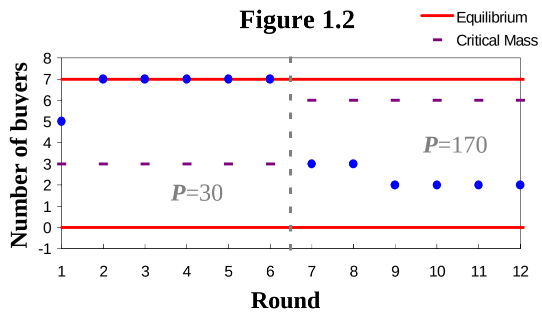


Figure 1.2

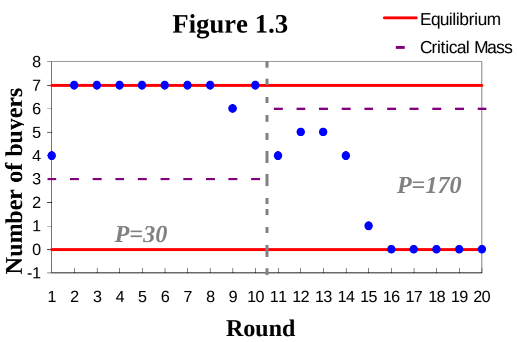


Figure 1.3

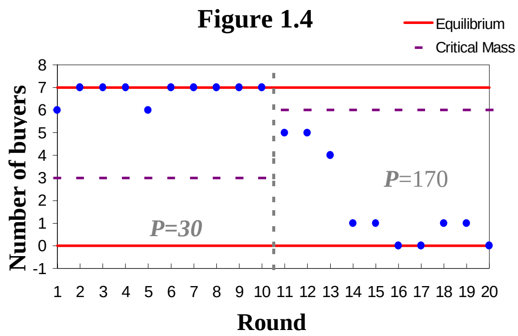


Figure 1.4

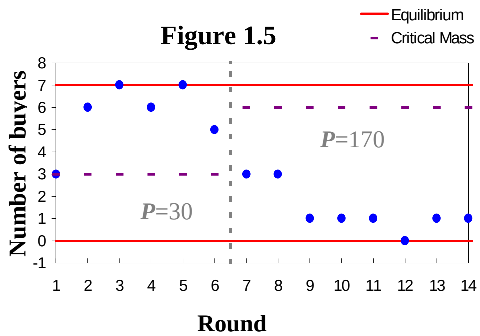


Figure 1.5

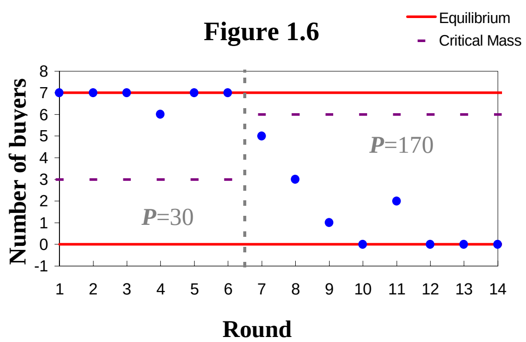


Figure 1.6

[7] In the first session (1.11 and 1.12) the experiment was ended prematurely (after only four round of the second treatment) because the rounds took more time than anticipated, and our alloted time was over.

Figure 1.7

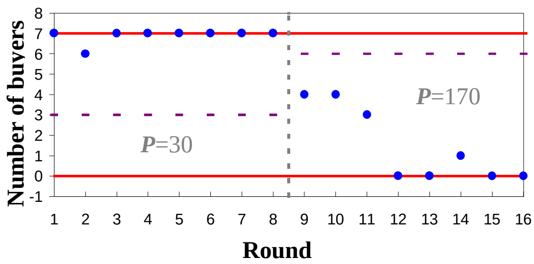


Figure 1.8

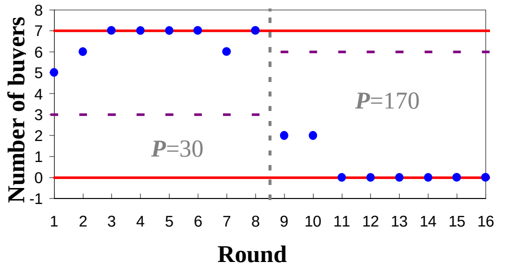


Figure 1.9

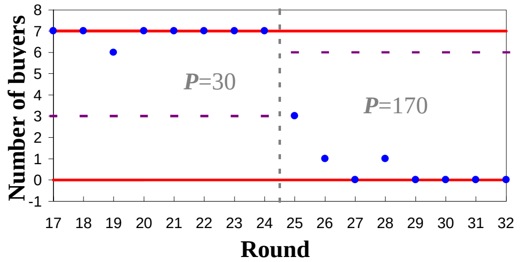


Figure 1.10

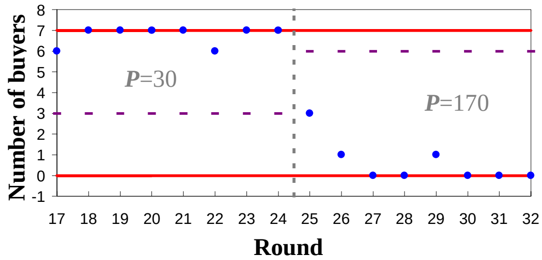


Figure 1.11

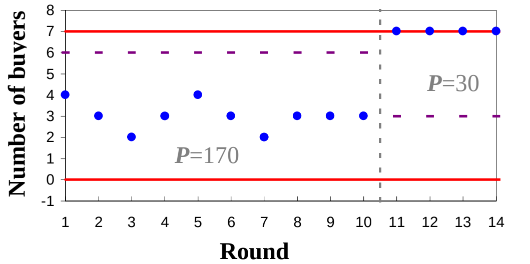


Figure 1.12

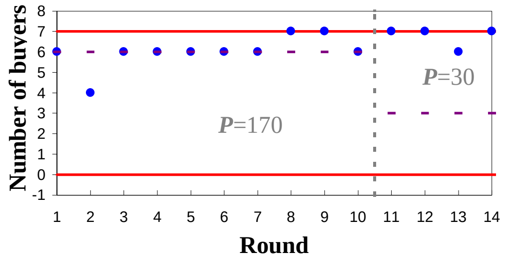


Figure 1.13

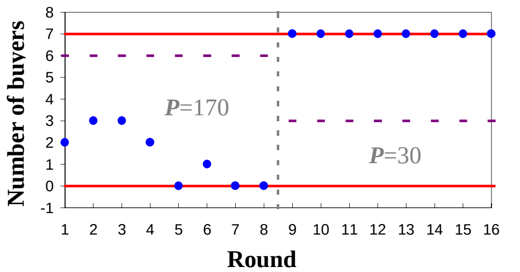
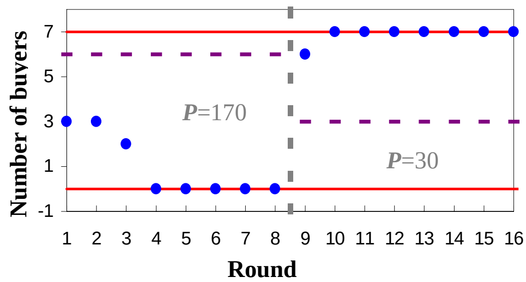
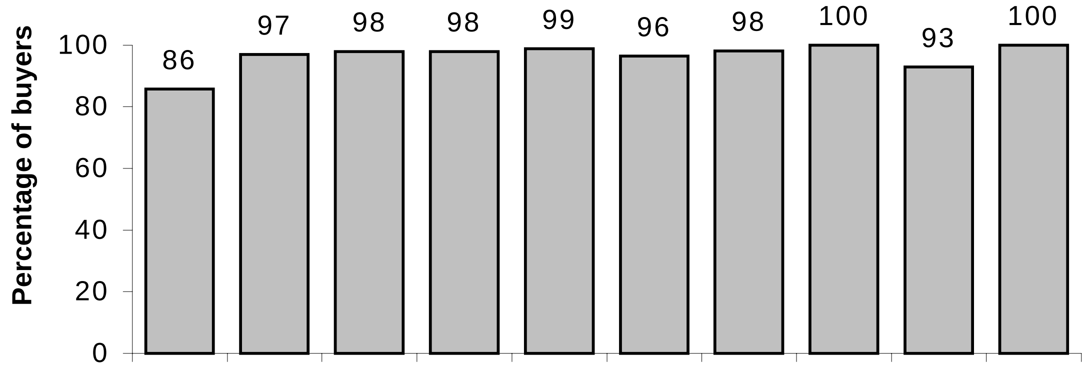


Figure 1.14



Consider first the rounds in which *P*=30. As seen, independent of whether these rounds were played before and after *P*=170 nearly all consumers purchase the goods in all rounds. This is true even in the first round, when 86% of the subjects purchased the good. By the second round this increase to 97%, as seen in Table 2 which summarizes the data for all the *P*=30 rounds.

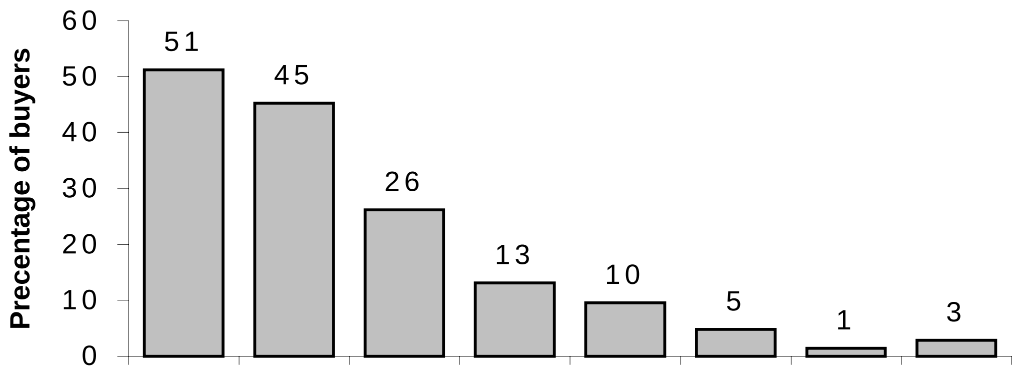
Table 2
Summary of *P*=30 Rounds



Round	1	2	3	4	5	6	7	8	9	10
Number of participants	98	98	98	98	84	84	64	64	14	14

The results when *P*=170 were significantly different. In all but two cases (1.11 and 1.12) play degenerated to, or close to, the inferior equilibrium of no purchasers. In 1.12 critical mass was reached on round 1, and the superior equilibrium was attained in rounds 8 and 9. In 1.11 between 2 and 4 players purchased the good in each round, with no movement towards either equilibrium. Figure 3 gives the aggregate results (not including 1.11 and 1.12) in the high priced rounds. As seen, over 50 percent of the subjects tried to achieve cooperation in the first round of the high price game. When this did not succeed, the results degenerated to no cooperation. Note that the rate of purchase remained high in the second period also, but then fell quickly.

Table 3
Summary of *P*=170 Treatment



Round	1	2	3	4	5	6	7	8
Number of participants	84	84	84	84	84	84	70	70

Considering our propositions, H1 (purchase in all games) is rejected because this equilibrium is not reached when P=170. H2 (more purchases with the low price than with the high price), however, is not rejected. As stated, deviations from the cooperative equilibrium occurred mainly when the price was high. Surprisingly, H3 (learning to cooperate) is rejected. In fact, the only time the Pareto superior equilibrium was reached when P=170 was when the experiment started with these sessions. It seems that a history of full cooperation by the subjects was not helpful in maintaining cooperation when the price (and critical mass) increased.

B. Heterogeneous Game

The results from the heterogeneous rounds are presented in figures 4.1-4.6. Note that 4.1-4.4 were played immediately after 1.5-1.8, respectively, and 4.5-4.6 were played before 1.9-1.10, respectively. In these figures, the bold line in each column represents the non-trivial equilibrium number of purchasers, and the darkened histograms represent the number of purchasers, but not their identities. A "^" depicts a purchaser who should not have purchased in equilibrium, while a "*" depicts someone who should have purchased but did not. Thus, for example, in the first round of 4.4 (depicted round 17) the equilibrium number of subjects purchased the good, but subject E did not purchase, although he should have, and subject F purchased, but should not have. Both of these players lost money on this round – subject F paid a price greater than his value, and player E paid an opportunity cost. In the following round, both players E and F "corrected" their play, but player G chose to purchase, leading to one extra purchaser. His loss in this round quickly convinced his not to repeat the exercise.[8]

[8] In post-experiment interviews, it turned out that one player in 4.1 did not understand the experiment despite our efforts to assure that this would not occur. This player accounts for all four deviations from the Pareto efficient equilibrium in this session (she was player G in the low price rounds and A in the high price rounds).

Figure 4.1

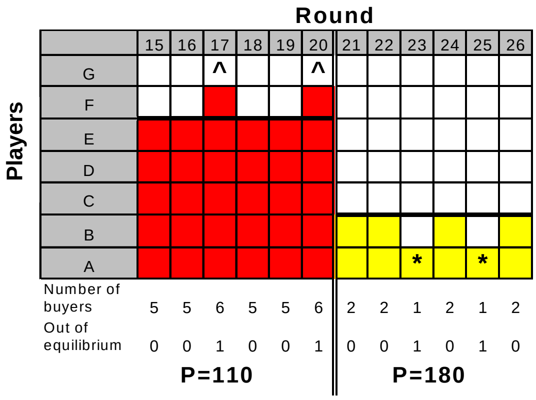


Figure 4.2

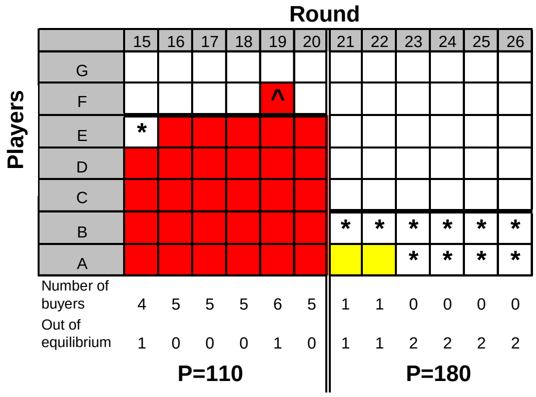


Figure 4.3

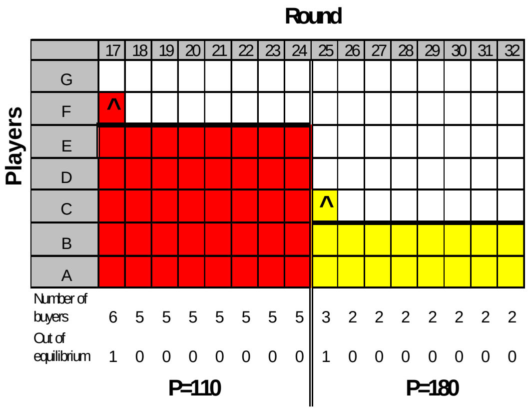


Figure 4.4

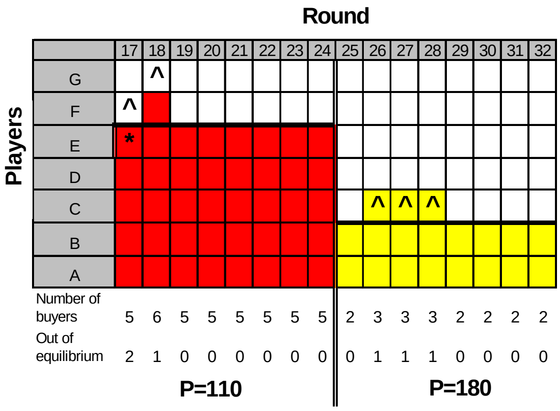


Figure 4.5

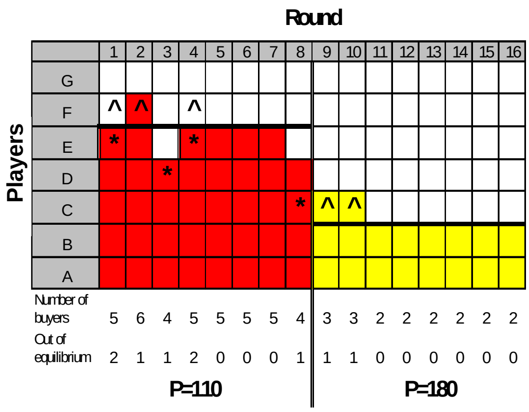
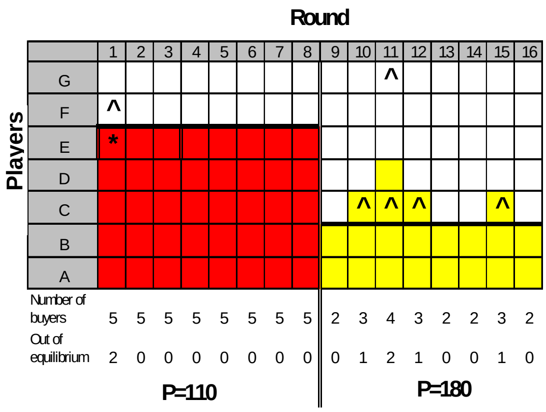
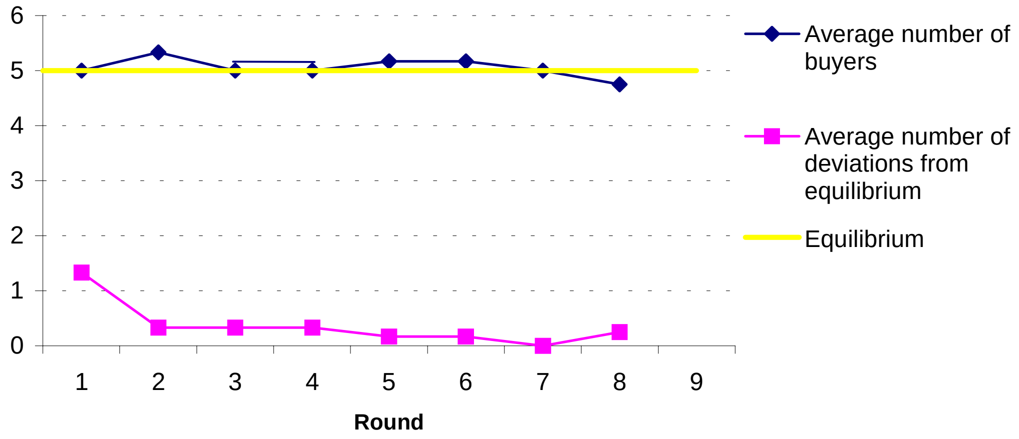


Figure 4.6



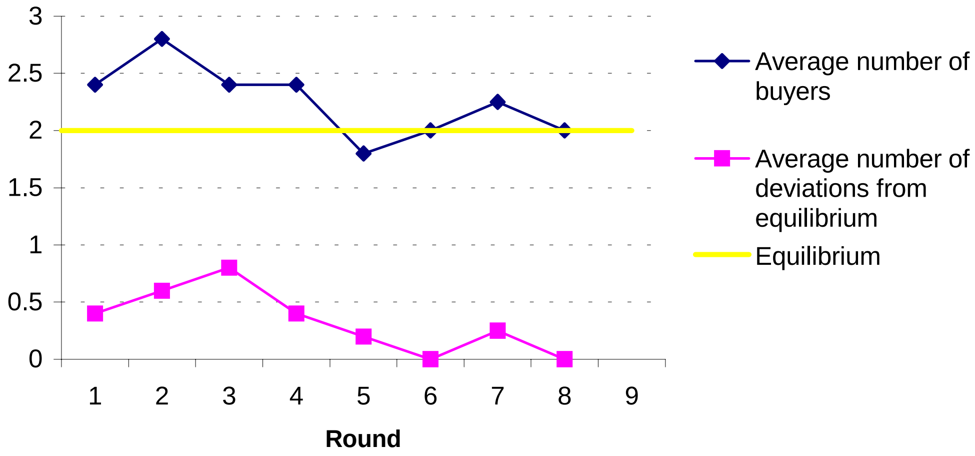
When the price was low (*P*=110), the superior equilibrium was reached in over 70% of the rounds. Not including the first round (when the game was being "learned"), in which only one group reached equilibrium, it was almost 80%. If we define equilibrium by the *number* of purchasers, without respect to their identities, there is an 80% success rate overall, and a 67% success rate in the first round. The average number of purchases, and the average number of out-of-equilibrium choices are shown in Figure 5. As seen, the number of purchasers is always close to equilibrium, and the amount of deviant behavior quickly approached zero. Note that the relatively high number of deviation in the first round did not affect the number of purchasers since these errors cancelled each other out (four over-purchasers and four under-purchasers).

Figure 5
Heterogeneous Treatment
Low Price



When the price was high (P=180) the results were similar, with the exception of the session depicted in 4.2. In this session there was only one purchaser in the first two periods, and this purchaser lost his entire purchase price (the value with only one buyer is zero). Thereafter the game degenerated to the inferior, no-purchase equilibrium. Not counting this session, the superior equilibrium was achieved in nearly 70% of the rounds, including 3 of 5 first rounds. The average number of purchasers and the number of deviators in this game (not including 4.2) are presented in Figure 6. As seen, the number of deviations falls to zero by the end of the game.

Figure 6
Heterogeneous Treatment
High Price



In post-experiment interviews a few interesting comments were made. Subject C in the low price session in Figure 4.5 told us that in the last round she chose not to buy because she wanted to see if what she did really affected the outcome. Subject G in 4.6 told us that in round 11 she decided to buy because she was bored. This also came out in other interviews. In particular, some players near the margin bought occasionally simply so they would not have to press "no" all the time. And, of course, for these players the cost of such behavior is relatively low.

Turning to our hypotheses, it would seem that H4 (Pareto optimal behavior) is not rejected. H5 (the same number of over-purchases when the price is high and low) is upheld since there are 10 deviations when the price is low and 11 when the price is high. With respect to under-purchases, however, there are 12 instances of players who do not purchase who should in the superior equilibrium when the price is high, and only 7 when the price is low. However, in 8 of the 12 deviations with the high price, equilibrium is reached (albeit the inferior equilibrium).

H6 is also not rejected. Of the 32 deviations from the superior equilibrium (not including those rounds in 4.2 where the inferior equilibrium was played), only 8 are not either just above or just below the equilibrium point. Of the 75% that correspond with H6, 17 are over-purchases, and only 7 are under-purchases. It is very possible that this pattern is explained by the subjects' "boredom" and desire to do something.

Finally, H7 is also not rejected. Play is similar across the sessions, but there are as many deviations from equilibrium play in rounds 4.5-4.6 as in the other four sessions together.

C. Discussion

The central issue that needs understanding is why subjects were unable to coordinate in the high-priced homogeneous game (even after a history of cooperation), while in all other games they were able to coordinate. Compare, for instance, a subject in the high price homogeneous game to subject E in the low-price heterogeneous game. In the former, the critical mass is 6 – five other players must also purchase the good in order to make purchase worthwhile. If this occurs, the player will earn 10, and if all 7 players purchase (equilibrium) he will earn 60. If only 5 subjects buy, he will lose 40. Player E in the heterogeneous game is in a similar position. The critical mass is now 5 – four other players must also purchase to make purchase worthwhile. If this occurs, he gains 10, and if an additional player purchases he gains 30. In addition, if one player does not buy (only four purchasers) he loses 10. It is not clear why, despite the fact that he stands to earn more in the homogeneous game, Pareto efficiency is not attained in this game while it is in the heterogeneous game.

We believe that the answer lies in the critical mass. While critical mass is similar in the two games for the players discussed, it differs in the two treatments for other players. Thus, in the homogeneous game the critical mass is identical – 6 – for all players. In the heterogeneous game, however, when the price is 110 critical mass for players A, B, and C is 2, for D it is 3, and only for E is it 5 (it is 7 for F and non-existent for G). This makes purchase far more secure. Subject E can easily see that it is almost a certainty that A, B, C, and most probably D will buy the product since they need very little participation to make such a move worthwhile. Thus, it is easy for them to decide to purchase – the risk seems very small. In the homogeneous game, however, this is not the case, and the risk is therefore much greater. We believe that this also explains another anomaly in the results – that 4 out of 6 "F" players purchased in the first round even though their critical mass was 7. Thus, they needed an even higher purchase rate than the players in the high price homogeneous game. We attribute this behavior to the recognition by these players that those with higher values are certain to buy, so it might be worth taking a chance, particularly since the potential loss is small because of the almost certain purchases of others. In the homogeneous game, conversely, *everyone's* critical mass was 6 when the price was high, and so the risk was far greater.

We conclude from this that the decisions made by consumers depend on the probability they attribute to other consumers "doing the right thing." Players seem to take into account not only their own critical mass; they also take other players' critical mass into account. A player with a high critical mass will therefore be more likely to purchase if they see that other players have a low critical mass.

One strategic implication is for a firm facing a critical mass problem (i.e., a firm that needs to convince consumers that critical mass will be attained). Rohlfs (1974) discussed at length free distribution of the good to a subset of consumers for a limited period in order to attain critical mass. While he says that this subsidy can be given to high or low value consumers, there is a preference to giving them specifically to the high value consumers. This is because if they are given to low value consumers, these consumers are apt to leave the market when the subsidy is stopped, thus causing the market to degenerate to the inferior equilibrium. We suggest the opposite. We believe that it is sufficient to subsidize a subset of the consumers rather than all of them. If the goal is to convince consumers that enough purchases will be made, it is sufficient to convince them that those with high critical mass will buy, since they are likely to already believe that those with low critical mass will do so. Thus, subsidize those at the margin and not those already "in the bag." This will allow the firm to more efficiently use its marketing budget.

V. Summary

In this paper we presented the results of an experiment aimed at testing the ability of consumers to coordinate actions in a market in which network externalities are present. Such markets are characterized by the necessity for consumers to believe that a certain minimum number of people will buy the good (the critical mass) in order to make purchase worthwhile. In our experiment, subjects were asked offered the option of buying a good at a certain price. Subjects were told the price of the product, but this value depended on how many other subjects bought. The experiment was run under two treatments – when subjects were homogeneous in their values and when they were heterogeneous. In each case, there were treatments with low prices and with high prices.

Interestingly, subjects found it easier to purchase when they were heterogeneous than when they were homogeneous. In particular, the only treatment in which cooperation was not usually attained was in the homogeneous treatment when the price was high. We attribute this to critical mass. In the high priced homogeneous treatment the critical mass for all players was high, thus leading to great risk in purchase. In the heterogeneous game the critical mass for the marginal player was also high, but the subject knew that the critical mass for higher value subjects was much lower and that those subjects would therefore be likely to buy. This made purchase less risky, allowing equilibrium to be reached. One implication is that a firm facing a critical mass problem can efficiently help convince consumers that critical mass will be obtained by subsidizing high critical mass consumers (low value consumers), since potential consumers will be likely to already be convinced about the purchase of low critical mass consumers.

The experiment presented in this paper has considered only one aspect of the critical mass problem – consumer beliefs about the actions of other consumers. It has not considered the more complicated problem of producer actions, and consumer reaction to these actions. We believe that this is fertile ground for future research on network markets.

Appendix A

In this appendix we present the instructions, translated from Hebrew. The instructions contained pictures of the screens they would see on the terminals to which they were assigned. Most of the instructions were identical for the two treatments. We thus present the two together, and indicate any differences between the two. We omit the parts of the instructions that request quiet, that request strict adherence to the instructions, etc. Also, some of the redundancy in the instructions has been cut out. Note that the numbers that appeared in the examples in the instructions were not those that appeared in the experiment itself.

Instructions

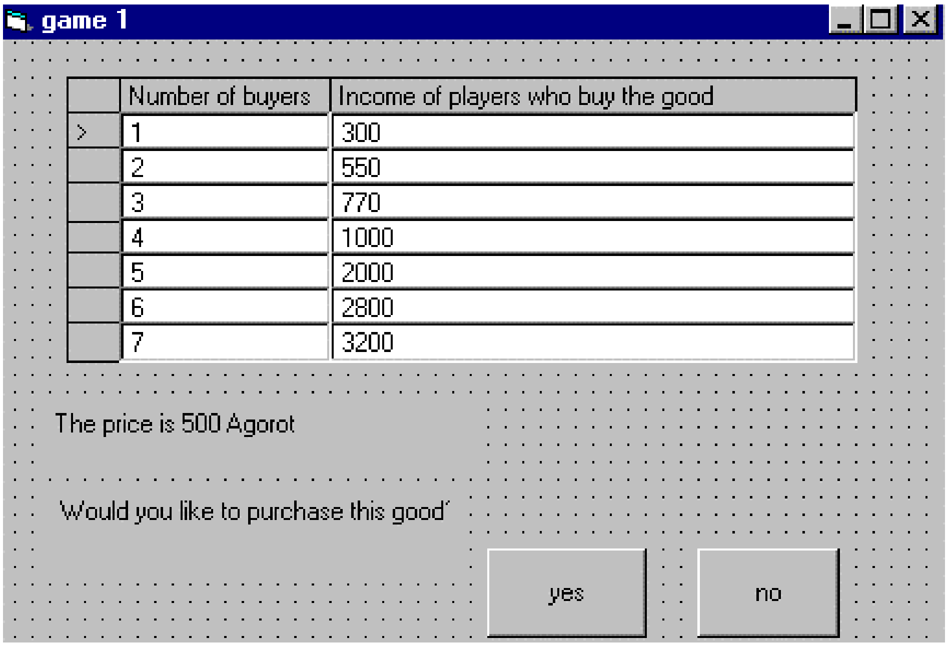
You have been asked to participate in an experiment in economics. At the start of the experiment you will get 30 NIS (New Israeli Shekels), which will be deposited in an account that will be at your disposal for use during the experiment. Depending on your actions, you may be able to earn additional funds, which will be added to your account. The amount accumulated in your account will be paid to you in cash at the end of the experiment.

In this experiment you will be using the computer's mouse. If you are interested in choosing a certain option, drag the mouse pointer to the appropriate box, and press on the left mouse button.

You are one of seven players taking part in a game. All players are identical, and (HETERO: The players are different from one another, as explained below, but) the information displayed on the screens will be identical for all players. Each of you will be offered the option of purchasing a good at a price that will appear on your screens. Should you decide to purchase the good, its price will be deducted from your account. If you bought the good it may bring you income, with the amount of income dependent on the number of purchasers. This income will be determined after all players have made their choices, and will be added to your account.

<u>Homogeneous Treatment</u>

When the game starts, you will see the following screen:



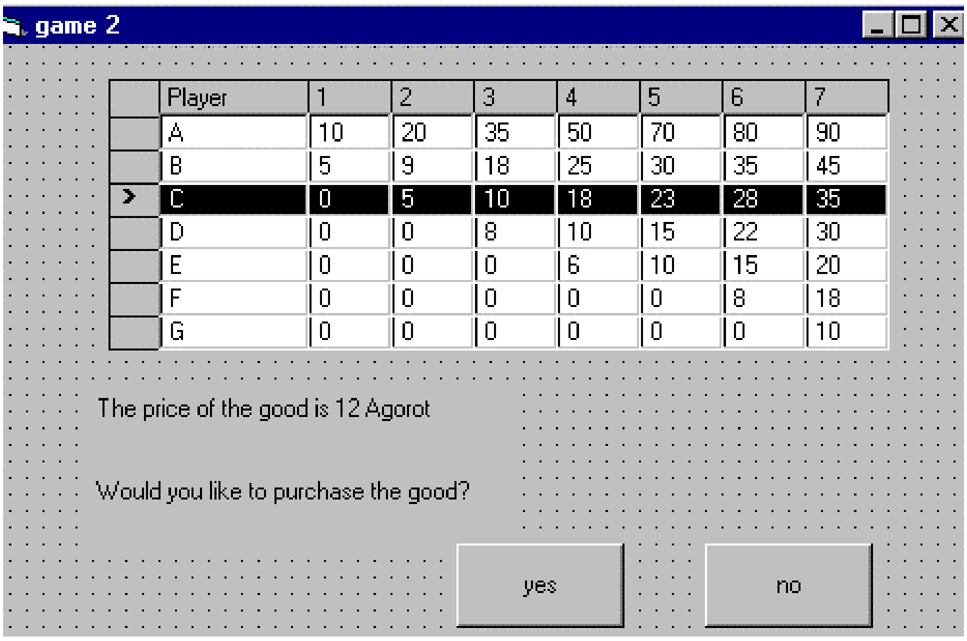
	Number of buyers	Income of players who buy the good
>	1	300
	2	550
	3	770
	4	1000
	5	2000
	6	2800
	7	3200

Explanation of chart: The left column contains the number of participants who purchase the good in this round. The right column contains the income each purchaser will get from the purchase. As the number of purchasers increases, this income grows. Thus, if two players buy the good, each will receive an income of 500 Agorot, and if five purchase, the income will be 2000 Agorot, etc.

In the bottom of the screen the price of the good appears. Note that the effect of the purchase on your account can be found by adding the difference between this value and the price you pay to your previous balance. For example, if you purchase the good for 500 Agorot, as does one other participant (for a total of two purchasers), your income from this purchase will be 550 Agorot, and the balance in your account will increase by 50 Agorot. All those who did not purchase the good will neither gain nor lose.

<u>Heterogeneous Treatment</u>

When the game starts, you will see the following screen.



	Player	1	2	3	4	5	6	7
	A	10	20	35	50	70	80	90
	B	5	9	18	25	30	35	45
>	C	0	5	10	18	23	28	35
	D	0	0	8	10	15	22	30
	E	0	0	0	6	10	15	20
	F	0	0	0	0	0	8	18
	G	0	0	0	0	0	0	10

Note that each player will have his own row (different from that of the other players), which will be darkened. In the example, the player we are concerned with is player C (as marked in the leftmost column).

Explanation of chart: The left column contains the identity of the different players. Note that one of the rows is darkened (row C). The darkened row shows your identity (each player will have a unique identity). The top row shows the number of purchasers, running from 1 to 7. The number in the table shows the income of each of the participants as a function of the number of purchasers. As the number of purchasers increases, so does the income of each purchaser.

In the bottom of the screen the price of the good appears. Note that the effect of the purchase on your account can be found by adding the difference between this value and the price you pay to your previous balance. For example, if player C bought the good for 12 Agorot, as did two other participants (for a total of three purchasers), player C's income from this purchase will be 10 Agorot, and the balance in his account will decrease by 2 Agorot. All those who did not purchase the good will neither gain nor lose.

Both Treatments

Given the chart and the price, you are requested to decide whether you would like to purchase the good. On the bottom of your screen this question appears. If you would like to purchase the good press "yes" and if not, press "no." After all players have made their choices your income will be calculated according to the table. A screen will appear, which will contain the price, the number of players who bought the good, and the amount added to or subtracted from your account balance. The calculation is carried out as follows: The income for each purchaser can be read off the table given the number of purchasers. From this income, the price will be subtracted, and the ensuing sum will be added to your account. Note that if this calculation yields a negative number, your balance will fall.

You have now completed the first round of the experiment. After you have seen your results, press OK, and the second round will begin. The experiment with this price will be repeated X number of times, and then the price will be changed, and remain at its new level for X additional rounds. The change in price will be announced before it occurs.

Are there any questions?

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