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Abstract

A network market is a market in which the benefit each consumer derives from a good is an increasing function of the number of consumers who own the same or similar goods. A major obstacle that plagues the introduction of a network good is the ability to reach critical mass, namely, the minimum number of buyers required to render purchase worthwhile. This can be likened to a coordination game with multiple Pareto-ranked equilibria. Through a series of experiments, we study consumers' ability to coordinate on purchasing the network good. Our results highlight the central importance of the *level* of the critical mass. Neither an improved reward-risk ratio through lower prices nor previous success at a lower critical mass facilitates the establishment of a network market when the critical mass is sufficiently high.

Keywords: experimental economics, network goods, coordination game, critical mass.

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1 Introduction

In a network market the benefit each consumer derives from purchasing the network good is an increasing function of the number of consumers who own the same or similar goods. Establishing a successful network good is particularly challenging because consumers must be convinced that the market will be sufficiently large to justify their purchase. In this paper, we design a series of experiments to determine the conditions that lead to consumers' successful coordination on purchasing the network good. We find that these markets converge quickly and uniformly either to the inefficient equilibrium whereby no one buys the good or to the efficient equilibrium whereby everyone does. Whether they converge to the one equilibrium or the other depends above all on the *level* of the critical mass and whether they attain this critical mass in the very first round of play. When the critical mass requires that the majority of consumers purchase the good, none do, whereas when the critical mass is lowered sufficiently, everyone buys. These findings are robust to systematic variations in the price, profit levels and previous experience.

Network markets typically exhibit multiple stable equilibria. A successful network market is declared whenever the critical mass necessary to reach the Pareto superior equilibrium is attained. One way this can occur is through diffusion over time (see, e.g., Cabral, 1990 and Grajek and Kretschmer, 2012). This requires consumers to be sufficiently heterogeneous to justify purchase by some individuals early on when the number of purchasers is still small, i.e., even before they receive much value from the good as a network good.

Economides and Himmelberg (1995) highlight another way to reach a high-demand rather than a low-demand equilibrium: consumer coordination. To justify purchase, consumers must believe that a sufficient number of other consumers intend to buy the good. In this paper, we explore the consumer coordination problem associated with establishing a network good.

In our experiments, consumers simultaneously decide whether to purchase a unit of a network good. Utility is an increasing function of the number of players who purchase the good. The good's price is known and deducted from the consumer's utility in the case of purchase. The price is always sufficiently high such that being the lone purchaser of the good results in a loss. With the goal of determining the conditions that facilitate or hinder the establishment of a successful network market, we conduct seven experimental treatments that systematically vary the network good's price and consumers' utility function in ways that change the profitability of successful coordination and the critical mass, namely, the minimum number of buyers needed to render purchase worthwhile.

These markets converge uniformly and rapidly – usually within a few rounds – to either the efficient purchasing equilibrium or the inefficient non-purchasing equilibrium. Whether they converge to the one equilibrium or the other depends foremost on the magnitude of the critical mass and whether they attain this critical mass in the very first round of play. When the critical mass requires that most of the consumers purchase the good, they balk at purchasing, even if the reward-risk ratio is enhanced through lower prices or higher utility and even if participants have previously established a successful network market at a lower critical mass. Yet when the critical mass is reduced so that only a minority of consumers is needed to render purchase profitable, the efficient purchasing equilibrium is quickly reached. This result holds even if the maximum attainable profit from purchasing is shrunk to a minimum.

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. After introducing a theoretical framework in Section III, we detail the experimental design for two baseline treatments. Section IV presents the results and analysis of our baseline treatments and then presents follow-up experiments designed to address some issues that arise in the baseline treatments. Section V concludes.

2 Background and Related Literature

2.1 Network goods and critical mass

Since the pioneering works of Rohlfs (1974) that analyzed the telecommunications market, and of Oren and Smith (1981) that extended Rohlfs' work, it is well recognized that network markets often have more than one stable equilibrium, with some equilibria Pareto superior to others. Researchers have concerned themselves with conditions necessary for such markets to reach "critical mass," which can be understood as the minimum number of consumers required to allow the market to achieve the Pareto superior equilibrium (see Grajek and Kretschmer, 2010, and references therein). In extreme cases in which the good in question has no inherent value, with the entire value consumers derive from the good stemming from the ownership of other individuals (as in the fax market), the low-demand equilibrium entails the non-existence of the market – an outcome difficult to observe empirically.

To attain critical mass under such circumstances, 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 (2010). These studies, however, implicitly assume that consumers believe that all other consumers will act as they do, so that optimal 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, consider a market with two potential consumers, both of whom must purchase for the good to be worthwhile. Yet, 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. 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 regard to competition between different technologies in the context of network goods (see Farrell and Saloner (1986) for an early discussion of this issue). Yang (1997), among others, shows that even 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, 2004) is the adoption of Matsushita's VHS standard for video-recorders instead of the Beta system created by Phillips (and sold to Sony). Early purchasers of the

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

Beta system, considered 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. For example, many consider the Dvorak Simplified Keyboard strictly superior to the QWERTY keyboard (see David, 1985). But the cost of transferring to this standard inhibited its adoption (Shapiro and Varian, 1999, pp. 184-186).[3]

The main difference between these studies and the issue we raise is that in the former 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 in an environment in which purchase is worthwhile only if critical mass is reached.

2.2 Related Experimental Literature

There have been many experimental studies on 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 individuals succeed in coordinating on Pareto superior equilibria in a setting with multiple equilibria. These studies tend to use multi-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 receives. The Pareto optimal outcome is attained when all subjects choose the highest number. This choice, however, is risky, since the payoff each subject receives depends on the distance between that subject's choice and those of the other subjects, so the choice of an extreme value may result in losses.[4]

An additional related experimental setting deals with the attainment of critical mass in step-level (provision point) public goods games. In these games, the provision (or amount) of a public good depends on a minimum amount of money being contributed to finance the provision of the good. Once the good is provided, all consumers benefit from

[3] Liebowitz and Margolis (1990) cast doubt as to the accuracy of this example.
[4] See Devetag and Ortmann (2007a, 2007b) for recent surveys.

consumption of the good independent of whether they contributed. Thus, an incentive to free ride by not contributing exists, with the hope of benefiting from others' contributions. In a network market the issue of free riding does not arise because only those who purchase the private good reap its benefits. In addition, a network good is a private good, but there is an externality effect that makes the product more valuable if more is purchased.

Devetag's (2003) coordination experiments are more directly related to the issue of critical mass. In her experiments, subjects choose a number between 1 and 7. In the version of her experiment most similar to ours (labeled "increasing returns"), the choice of the number i by n subjects yields each of those n subjects a payoff of $i+n-1$ if $n \geq i$, and 0 if not. Thus, 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. The main difference between our settings is that the focus in Devetag is the ability to coordinate on a certain number choice, while in ours coordination is simpler since each subject has a binary choice – to either purchase the good or not.[5] Thus, coordination should be relatively easy to attain in our experiment. This allows us to focus on variables that affect the ability to coordinate that are present in network markets but are not considered in Devetag, such as the relative costs and benefits from coordination.

This issue is considered in Heinemann et al. (2009) who present subjects with a choice between a certain payoff and an uncertain payoff realized only if a "sufficient" number of subjects select the risky choice. In a within-subject setting, they vary the size of the safe payoff and the number of players necessary for successful coordination. The players make all choices simultaneously and once only, thus eliminating the possibility to learn. As expected, the higher the safe payoff or the higher the percentage of players needed for coordination, the more likely subjects were to choose the safe payoff. Their setup addresses critical mass, although the payoffs are not typical of a network market since the value to the risky choice took on only two values (one below and one at and above the critical mass), while the value to purchasing a network good usually increases steadily

[5] Another obvious difference is that in our setting an outcome of 0 is attained by choice, while in Devetag (2003) it is only achieved if the subject chooses poorly (out of equilibrium).

both above and below critical massd.[6] Thus, our setup is more fitting to test coordination in network markets. More importantly, the fact that play is repeated with the same cohort in our experiments allows us to test for the conditions under which subjects can learn to cooperate in order to attain the Pareto superior outcome.

Chakravarty (2003) and Keser et al. (2012) address experimentally consumer choice between competing standards, similar to the examples in section IIA. Chakravarty (2003) investigates producers' ability to price in a manner that draws consumers to their product. His study concerns the producer side of network markets, whereas ours focuses on consumer confidence and the attainment of critical mass. Consumers are the subject of the Keser et al. (2012) study, where, in a one-shot game, subjects choose between the standard that yields a higher payoff and the standard that is less risky since it has a lower critical mass. Both of these studies examine the choice between standards, while ours explores market penetration for a single network good.

3 Experimental Design

3.1 Theoretical Framework

Consider a market with n potential consumers. Define the vector 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, $R(N)$, with $R'>0$, and consumer surplus for each player, Π_i, given by:

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

In order to guarantee the existence of more than one equilibrium, we require that $R(1)$-P<0 and $R(n)$-P>0. These simple conditions state that if only one player purchases the good his surplus is negative, and if all purchase the good they all earn positive profits. As

[6] This is true also of the “Critical Mass” version of Devetag's (2003) experiment.

a result, there will be precisely two pure-strategy equilibria – no one purchasing and everyone purchasing – with the latter Pareto dominating the former.[7]

Critical mass is then defined as the *minimum* number of people needed to consume the good such that no consumer loses from the purchase. This is the value ω for which $R(\omega-1)-P<0$ and $R(\omega)-P>0$.

3.2 Experimental Design

With the goal of determining the conditions under which consumers are able to coordinate on the Pareto superior equilibrium, we conduct seven experimental treatments. The treatments share the following features. In each session, multiple groups of seven subjects decide whether to purchase a unit of the network good at an exogenously given price. All consumers are *ex ante* identical in that they share the same utility function $R(N)$ and make their purchase decisions simultaneously. If the subject chooses not to purchase the good he earns zero for that round, while if he purchases the good, he earns $R(N)-P$. The same cohort of seven subjects repeats the game for numerous rounds. At the end of each round, subjects observe their own profit and how many subjects in their group purchased the good.

In this section, we describe the baseline treatments. Because this experimental paradigm for studying network markets is new, we cannot foresee the relative importance of different factors in establishing a successful network market. Thus, we begin with two initial treatments, and allow the results of these treatments to inform the design of subsequent treatments.

Consumers' values from purchasing the network good are displayed in Table 1 below, and are identical for the two baseline treatments. The utility from purchase is given by $R(N)=40(N-1)$. If the subject is the lone adopter of the network good, his utility from purchasing in that round is zero. If one other subject also purchases, his utility increases to 40. With two additional purchasers, his utility is 80 and so forth, increasing by 40 units with each additional buyer. If all seven group members purchase,

[7] There also exists a symmetric mixed-strategy equilibrium in which each consumer purchases with probability *p*. In this equilibrium, each consumer is indifferent between purchasing and not purchasing given that every other player mixes with exactly probability *p*. We would not expect consumers to play this equilibrium, in part because it is Pareto dominated by the equilibrium in which all consumers purchase.

each earns a revenue of 240. Note that for any price below 240 there are two pure-strategy Nash equilibria – N=0 and N=7.

Number of Purchasers	1	2	3	4	5	6	7
Value to each Purchaser	0	40	80	120	160	200	240

Table 1: Each subject's utility in the baseline treatments as a function of the total number of subjects who purchase the network good.

The sole difference between the two baseline treatments is the price of the network good. The price is 60 in one treatment and 180 in the other.[8] In a within-subject design, subjects participated in both treatments. The purchase price for a unit of the network good was set at 60 for 20 consecutive rounds and 180 for another 20 consecutive rounds with the same cohort. To control for order effects, the price sequence was alternated across groups. Four cohorts participated in the (180, 60) price ordering and another four cohorts played the reverse (60, 180) price ordering.

Notice that when the price is 60 the critical mass (i.e., the minimal number of purchasers required for the network good to be profitable for each purchaser) is three. If three consumers are able to coordinate on purchasing, other consumers will also want to purchase the good and earn a positive profit. At a price of 180, successful coordination on purchasing the good becomes more formidable: the critical mass rises to 6. Namely, purchasing the good is profitable only if at least six of the seven subjects buy. Also complicating the success of this market is the fact that even if all seven subjects purchase the good, a subject's net profit is a mere 60 units (240 minus 180), whereas the maximum loss is 180 (a maximum profit-to-loss ratio of 1:3). By comparison, at a price of 60, a subject may earn up to 180 and risks only 60 (a 3:1 profit-to-loss ratio).

3.3 Experimental Procedures and Subjects

All of the experiments were conducted at Bar-Ilan University and Ben-Gurion University using z-Tree (Fischbacher 2007). Upon arrival, subjects were seated at a

[8] As mentioned above, there is also a mixed-strategy Nash equilibrium. This equilibrium is attained if each consumer buys with probability $p \approx 0.195$ when the price is 60 and with probability $p \approx 0.805$ when the price is 180.

computer terminal. They each read a printout of the instructions (included in the Appendix) at their own pace before one of the experimenters read the instructions aloud. Any questions were answered privately before proceeding to the experiment.

In total, 315 subjects participated in either the baseline treatments or one of the follow-up treatments to be discussed in the next section. A treatment including the instruction phase lasted no more than an hour and a half. Subjects were paid a 15 NIS show-up fee plus their cumulative earnings from the experiment where each point earned (or lost) in the experiment was converted to one agora (0.01 NIS). The 15 NIS show-up payment also served as an initial endowment to cover potential losses. No subject went bankrupt. Average subject earnings were 49.1 NIS in the baseline treatments or about $13 USD, well above the student wage of 19 NIS per hour.

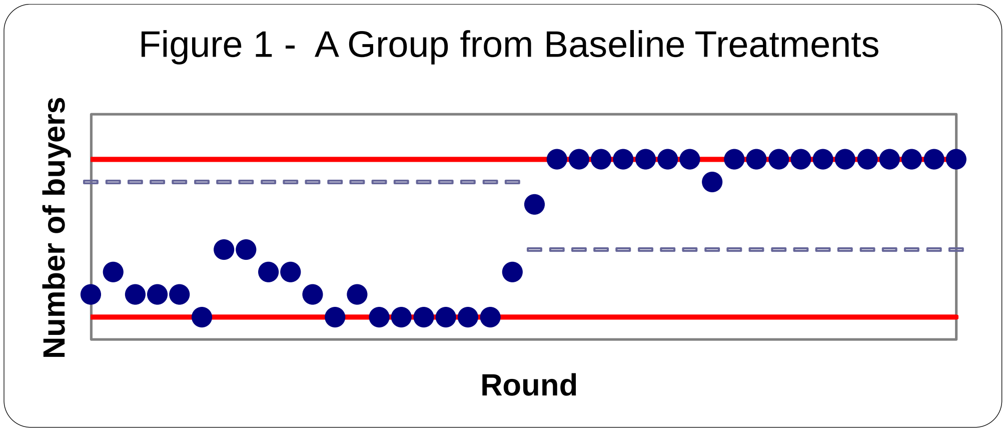
4 Results

4.1 Baseline Treatments (price = 60, 180)

5-round block	Price = 180, 1st	Price = 60, 2nd	Price = 60, 1st	Price = 180, 2nd
Rounds 1 to 5	0.75 (0.70)	6.70 (0.72)	7 (0)	2.15 (1.94)
Rounds 6 to 10	0.85 (1.10)	6.95 (0.22)	7 (0)	0.25 (0.54)
Rounds 11 to 15	0.75 (1.05)	7 (0)	7 (0)	0.35 (0.79)
Rounds 16 to 20	0.12 (0.33)	7 (0)	7 (0)	0 (0)
Average	0.65 (0.90)	6.91 (0.39)	7 (0)	0.70 (1.39)

Table 2: Mean numbers of purchasers out of 7 (standard deviation in parentheses) by price, by ordering in the sequence of two prices and by five-round blocks.

Four groups of seven subjects participated in this treatment with the price = 180 appearing for the first 20 periods followed by the price = 60 for an additional 20 periods. The first and second columns of Table 2 report the average number of purchasers (standard deviations in parentheses) for these groups by five-round blocks for the prices of 180 and 60, respectively. The entries reveal divergent trends for the two prices. For the low price, nearly all subjects (6.7 out of 7 on average) purchase the good already in the first five rounds. By round 10, all seven subjects in all four groups purchase the good and continue to do so for the duration. In stark contrast, when the price is high, less than one subject per group purchases throughout the entire experiment with the average number of purchasers falling to 0.12 in the final five rounds. Not all subjects so readily acquiesce to not purchasing. Figure 1 displays a group in which the same two or three lone subjects persist in buying the good at a loss through round 10, perhaps in an effort to encourage others to follow suit.



The height of the dot indicates the number of buyers that purchased the good in the round for one particular group of 7 subjects. The first 20 rounds correspond to the baseline P=180 treatment, while rounds 21-40 correspond to the P=60 treatment. The dotted line indicates the number of buyers needed to reach critical mass in each treatment, while the solid red lines reflect the two equilibria.

Four additional groups participated in the reverse price ordering of this treatment. Having the high price follow twenty low-price rounds controls for possible order effects, and introduces the possibility that a history of successful coordination on buying at the low price may carry over to the subsequent high-price rounds.[9]

The summary statistics in column three of Table 1 reveal that all seven subjects in all four groups unanimously and without exception purchased the network good throughout all 20 rounds of the experiment when the price was 60. Yet, the influence of this profitable coordination on subsequent purchasing decisions when the price rose to 180 appears modest. In no group or round did subjects reach critical mass when the price was 180. The number of purchasers in the high-price treatment did average above two

[9] In the minimum-effort game, Romero (2015) shows both theoretically and experimentally that increasing the cost of effort to c=0.5 leads to higher effort choices at c=0.5 than when the cost of effort is decreased to c=0.5.

subjects per round over the initial five rounds, implying a net loss of 140 for each buyer. In fact, purchases over the first five rounds of the high-price treatment were significantly higher when this treatment followed the low-price treatment than when it preceded it (non-parametric Mann-Whitney test z=–2.34, p=.02 where the unit of observation is a group's average purchases in rounds 1 to 5). Purchases, however, were still insufficient to achieve coordination on the superior equilibrium. The negative profits in these early rounds disciplined subjects into not purchasing. Purchases averaged below one in the next ten rounds and no one purchased in the final five rounds. Consequently, none of the other differences in group-level purchases as a function of the order of the high-price treatment (columns 1 and 4 in Table 2) are significant in any of the other five-period blocks (rows 2 to 4).[10]

In summary, eight groups participated in our back-to-back baseline treatments. Except for a change in the price of the good, these treatments are identical. Notwithstanding, this change in price engenders quick convergence to divergent equilibrium outcomes. Subjects in the high-price treatment converge on not purchasing the network good, whereas subjects unanimously purchase the good in the low-price treatment. Furthermore, treatment order is of no consequence. Subjects' inability to achieve efficient coordination when the price began high did not hinder their coordination when the price fell to 60. At the same time, even when subjects successfully coordinated on purchasing at the low price of 60 and then continued with the same cohort of subjects to the high price, these subjects utterly failed to achieve efficient coordination.

In a general sense, these findings are in line with Anderson, Goeree and Holt (2001) who show theoretically that in minimum-effort games there is a shift to less risky equilibria as costs rise. However, the finding in our specific setting that buyers are unable to coordinate efficiently at the price of 180 is surprising for several reasons. First, Devetag and Ortmann's (2007a) comprehensive survey of laboratory coordination games deems a number of features in our experimental setup efficiency enhancing. For instance, the reduction of the strategy space to two choices, the repetition of the game for 20 rounds with full feedback and the fixed matching protocol all promote efficient coordination.

[10] The p-values from the Mann-Whitney test are .14, .46 and .32 for each successive five-period block.

Moreover, all buyers recognize the potential for profit if they all purchase. If one is skeptical about the likelihood that others will purchase, then one might adopt a trial-and-error method. Trial and error suggests not purchasing and waiting to see if others purchase, or purchasing and making additional purchases contingent on the purchase decisions of others. A modest amount of forward reasoning ought to lead buyers to the insight that the former strategy, if followed by everyone, results in no one purchasing in the current and all future rounds, while the latter strategy leads to full coordination. Yet few buyers chanced early purchases, with the result that those who did soon resigned themselves to not buying.

The failure to reach efficient coordination when the price equals 180 raises numerous questions pertinent to the pricing and marketing of a network good. What is the source of the failure? Is the fraction of adopters needed for purchasing to be profitable (i.e. the critical mass) too high, or is the low profit-to-loss ratio the culprit? What is the maximum critical mass at which consumers are able to achieve efficient coordination? Are there conditions under which consumers might succeed in purchasing at a price of 180? Subsequent treatments address these questions.

4.2 Price Crawl Up (6 cycles of prices = 20, 60, 100, 140, 180, 220)

The finding that all subjects buy the good when the price is 60, but none do when the price is 180 raises two questions. First, at which intermediate price do subjects cease purchasing? Second, if prices are increased from 60 to 180 more gradually, can subjects build up to successful coordination at the high price? To answer these questions, we design an additional treatment that differs from the baseline treatments only in the prices of the network good and the ordering of these prices over time. Explicitly, seven players in a group decide simultaneously whether to buy a unit of the network good based on the same utility function as in Table 1.

In round one of the "price crawl up" treatment, the price is set at 20. The price then increases from one round to the next in increments of 40. Thus, over six rounds consumers observe the following sequence of prices: 20, 60, 100, 140, 180 and 220. Notice that included in this range are the two prices from the baseline treatments (60 and 180) as well as two intermediate prices (100 and 140) and one higher price of 220 at which subjects can still earn a positive net profit of 20 if they all purchase the good. The plausibility that this should succeed is strengthened by the findings of Devetag (2005) who shows that "groups of players are able to transfer efficient historical precedents to the minimum effort game" and of Weber (2006) who demonstrates that increasing the size of the group gradually can lead to cooperation in situations in which it was previously found to be unattainable.

We repeat this six-price distribution in the same ordering for six cycles with the same cohort of seven subjects, resulting in a total of 36 rounds. This treatment allows us to determine whether all subjects continue to purchase when the price is 100 or 140 (equivalently, when the critical mass is 4 or 5). Moreover, the gradual price increase along with the repetition of the same six prices over six cycles offer subjects an opportunity to learn to trust one another. As a result, efficient coordination may emerge where previously unobserved at the high price of 180, and perhaps even at 220.

Price	Critical Mass	Group							
		1	2	3	4	5	6	7	Average
20	2	6, 6.83, 7	7, 7, 7	5, 6.67, 7	6, 6.83, 7	7, 7, 7	7, 7, 7	7, 7, 7	6.43, 6.90, 7
60	3	6, 6.83, 7	5, 6.67, 7	5, 6.67, 7	6, 6.83, 7	7, 7, 7	6, 6.83, 7	6, 6.83, 7	5.86, 6.81, 7
100	4	6, 6.83, 7	4, 6.17, 7	4, 6.33, 7	5, 6.5, 7	7, 7, 7	7, 7, 7	6, 6.83, 7	5.57, 6.67, 7
140	5	2, 0.5, 0.5	3, 1.83, 0	1, 5.67, 7	4, 1.33, 0	7, 7, 7	6, 6.83, 7	7, 6.83, 7	4.28, 4.28, 4.07
180	6	0, 0.17, 0.5	0, 0, 0	0, 1, 0	1, 0.17, 0	5, 1.17, 0	6, 6.83, 7	7, 2.33, 0	2.71, 1.67, 1.07
220	7	1, 0.33, 0.5	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	3, 0.83, 0	5, 1, 0	1.28, 0.31, 0.07

Table 3: The three entries in each cell indicate the average number of purchasers of the network good by group and by price for the first price cycle only (first 6 rounds), for all six cycles (all 36 rounds), for the last two cycles only (last 12 rounds).

Seven groups participated in this price crawl up treatment. For each group, Table 3 displays the average number of purchasers at each of the six prices for the first cycle only, all six cycles (i.e. over all 36 rounds) and for the final two cycles only (i.e. last 12 rounds only). The results reveal some variation across groups in terms of the highest price at which they achieved efficient coordination. Three groups uniformly purchased at a price of 100 (but not higher), three other groups reached as high as 140 and one final group (group 6) succeeded in purchasing all the way up to and including the price of 180. No group was able to coordinate purchases on the highest price of 220.

The entries in Table 3 also reveal the speed and uniformity of convergence within each group to either everyone or no one purchasing at each of the six prices. To see this, note that the numbers of purchasers within a group over the entire six cycles and for only the last two cycles are almost the same (implying convergence within the first four cycles) and, in both cases, near seven (i.e. the efficient equilibrium) or near zero (i.e. the inefficient equilibrium). In fact, by the fifth cycle all groups had fully converged to one of the pure-strategy equilibria at all prices.[11]

The reason for such uniform convergence is intuitive: whenever a group attains critical mass in a given round, all subjects observe this at the end of the round. Those who didn't purchase will want to do so in the next cycle when this same price appears. On the other hand, if the group falls short of critical mass, all purchasers incur a loss and will think twice before buying again at this price.

The relationship between achieving critical mass early in the game and the likelihood of later convergence to the efficient equilibrium is striking. In fact, there exists a near-perfect correlation between whether a group's outcome for a given price in the first cycle attained critical mass and to which equilibrium this group converges at this same price in the final two cycles. Specifically, consider all seven groups and all six prices (i.e. 42 price-group combinations). In 40 cases either the group reached critical mass in the first cycle and converged to the efficient equilibrium by the fifth cycle at this same price, or the group fell short of the critical mass in the first cycle and subsequently converged to the inefficient equilibrium at this price by the fifth cycle.[12] The two exceptions are notable. One is the price of 140 for group 3: in the first cycle, only one consumer (four short of critical mass) bought the good. Notwithstanding, this group overcame this early negative experience to achieve full efficient coordination at this price two cycles later. The second exception cuts in the opposite direction: group 7 actually achieved critical

[11] The lone exception is the presence of a single subject in group 1 who bought at prices 140, 180 and 220 in the last cycle, thereby accounting for the entry average of 0.5 for the last two cycles in Table 3.

[12] A sign test rejects the high positive correlation between reaching critical mass in the first cycle and the fifth cycle (40/42 cases) as purely random ($p<.000001$).

mass at the price of 180 in the first cycle; however, this cooperation unraveled, perhaps as a result of the inability to coordinate purchases at the price of 220.

Overall, the results suggest that the problem of establishing a network market when the price is sufficiently high (180 or 220) is formidable. No group ever coordinated on purchasing at a price of 220. And only one of seven groups succeeded at a price of 180, even with a slow build-up to high prices preceded by efficient coordination on lower prices, and with six repetitions of these price cycles among the same cohort of subjects.

4.3 High Profit (price = 180)

Two possible explanations account for the collapse of the market when prices are high. First, the critical mass of six may be too high. In other words, in order to buy, one needs to believe that at least five of the other six consumers will also buy. Subjects appear to regard this belief as unfounded. Second, the potential profit-to-loss ratio is too low. The maximum profit one can earn from purchasing at a price of 180 is 60 units. A consumer might view this profit as too small to justify the price and maximum potential loss of 180. The remaining subsections describe additional treatments (summarized in Table 4) designed to distinguish between these two explanations.

Treatment	Number of Purchasers							Price / Max. Loss	Max. Profit	Max. Profit:Loss	Critical Mass	Nb. of Groups
	1	2	3	4	5	6	7					
High-Price Baseline	0	40	80	120	160	200	240	180	60	1:3	6	8
High Profit, u_{max} = 360	0	40	80	120	160	200	360	180	180	1:1	6	8
High Profit, u_{max} = 480	0	40	80	120	160	200	480	180	300	5:3	6	5
Low Critical Mass	0	40	200	200	200	200	240	180	60	1:3	3	8
Low Critical Mass, Reduced Profit	0	40	200	200	200	200	200	180	20	1:9	3	9

Table 4: Four follow-up treatments that differ from the high-price baseline treatment by the maximum possible profit and thus the maximum profit-to-loss ratio (ratio of profit if everyone purchases to profit if subject is only purchaser) or by the critical mass.

To evaluate the hypothesis that the maximum profit or the maximum-profit-to-maximum-loss ratio (henceforth abbreviated as "maximum profit-to-loss ratio") is too low to merit purchase of the network good, we introduce a “high profit” treatment that makes a single change to the baseline high-price treatment; namely, the utility from the network good if all seven consumers buy the good is increased from 240 to 360. This change results in an improved maximum profit-to-loss ratio of one-to-one (see the “High Profit, $u_{max} = 360$” row in Table 4). The remainder of the utility function, the price and the number of consumers in each cohort remain the same. Consequently, the critical mass remains unchanged at six.

Eight groups each participated in 15 rounds of this treatment.[13] Each entry in Table 5 reveals the number of rounds in which the indicated number of consumers bought the good for each of the eight groups. The first number refers to all 15 rounds, and the second (after the comma) to the final 11 rounds only.

Nb. of Buyers \ Group	1	2	3	4	5	6	7	8
0	7, 7	—	—	11, 11	—	—	8, 7	10, 9
1	4, 4	—	—	—	—	—	5, 4	5, 2
2	1, –	—	—	—	2, –	—	2, –	—
3	1, –	—	—	—	1, –	—	—	—
4	2, –	—	—	2, –	1, –	—	—	—
5	—	—	—	2, –	—	—	—	—
6	—	1, –	2, –	—	2, 2	1, –	—	—
7	—	14, 11	13, 11	—	9, 9	14, 11	—	—
Total Rounds	15, 11	15, 11	15, 11	15, 11	15, 11	15, 11	15, 11	15, 11

Table 5: The entries indicate the number of rounds in which a given number of subjects bought the good by group over all 15 rounds, for the last 11 rounds only for the High-Profit $u_{max} = 360$ treatment.

The main finding is that the design change of increasing the highest value from 240 to 360 results in four out of eight groups achieving efficient coordination (compared to zero

[13] Following the rapid convergence to equilibrium in the other static, baseline treatments, we reduced the number of rounds in this and subsequent treatments from 20 to 15.

out of eight in the comparable baseline treatment). The remaining four groups converged to the no-purchasing equilibrium. Yet two of these groups (groups 1 and 4) nearly reached the efficient outcome. In group 4, for instance, in both of the first two rounds, five buyers purchased the good – only one short of the critical mass. One buyer became discouraged in rounds 3 and 4, reducing the number of buyers to four and increasing each of their losses from 20 to 60. From round 5 onward no one bought the good. In fact, by round 5 all eight groups had uniformly converged to the purchasing or no-purchasing equilibrium or within one buyer of one of these equilibria. Moreover, for seven of the eight groups, whether the group attains critical mass in the very first round predicts to which of these equilibria the group converges. Group 5 is the exception in that only two subjects bought in each of the first two rounds; nonetheless, this group fought its way up to critical mass and the efficient equilibrium by rounds 5 and 6, respectively.

In short, augmenting consumers' utility in the case of fully efficient coordination by 50% (from 240 to 360) increased the percentage of groups that bought from 0 to half.[14] Another half of the consumer groups still did not buy. Intuitively, it seems clear that for some sufficiently high maximum utility, all consumers will buy.

To make this point, we designed another (and potentially more expensive) treatment in which the highest attainable utility was further inflated to 480 (double the original value), resulting in an improved maximum profit-to-loss ratio of 5:3 (see "High Profit, $u_{max} = 480$" in Table 4). Otherwise this treatment is identical to High Profit, $u_{max} = 360$.

Five groups each participated in 15 rounds of this treatment. Four of them quickly converged on purchasing. The fifth group had four buyers in round 1, three in round 2, one sole buyer in round 3 and zero buyers for the duration. Point made: increases in the profit reaped from efficient coordination boost the proportion of groups that reach this outcome from 0% in the High-Price Baseline treatment to 50% in High Profit, $u_{max} = 360$ to 80% in High Profit, $u_{max} = 480$.

[14] In a similar spirit, Brandts and Cooper (2006) find a higher degree of coordination in a minimum effort game when the payoff associated with the efficient equilibrium is substantially increased.

4.4 Low Critical Mass (price = 180)

To evaluate the role of the large critical mass in the collapse of the network market in the high-price baseline treatment, we restore the maximum attainable utility in this treatment to 240. The price of the network good remains 180, implying the same 3:1 profit-to-loss ratio as in high-price baseline treatment. However, we lower the critical mass by augmenting some of the interior utility levels. Specifically (and as can be computed from the "Low Critical Mass" row in Table 4), a subject who buys the good earns a net profit of –180 if he is the only purchaser, –120 if one additional subject purchases, 20 if two, three, four or five other subjects also buy and 60 if everyone buys. As a result, the critical mass here is three (as in the low-price treatment). Yet, the subject risks 180 to earn a paltry 20 if one to four subjects do not buy, increasing to 60 if everyone buys.

Eight groups played 15 rounds of this treatment. All eight groups achieved full efficiency. What is more, all eight groups already exceeded critical mass in the first round of play. By round 2, all but one group had uniformly converged to full efficiency. Subjects' predisposition to buy, much like in the low-price baseline treatment, speaks to the importance they attribute to the critical mass. When the critical mass is lowered to require purchases from fewer than half of the consumers, subjects buy decisively. This holds despite the opportunity to earn at most 60 and the potential risk of 180.

As a further test of the importance of critical mass relative to the profit potential, we designed a variation on the above low critical mass treatment. This variation reduces the highest attainable utility from 240 to 200. Everything else remains unchanged (see "Low Critical Mass, Reduced Profit" in Table 4). Consequently, a subject can earn at most 20, while risking up to 180. Notice that a consumer's marginal utility for additional consumers above critical mass is zero. This feature resembles a provision-point public good. The difference is that network goods are private goods; hence, the benefits accrue only to those who purchase them. Thus, this setup is more similar to a club good with a positive externality to participation.

Nine groups participated in 15 rounds of this treatment. All nine converged to the fully efficient equilibrium. Once again, all groups attained critical mass in the very first round. These findings highlight the centrality of the critical mass in subjects' decisions to purchase. Evidently, subjects are sufficiently confident that others will buy the good that the low profit potential of 20 versus the large wager of 180 does not deter them from buying.

4.5 Convergence to the Efficient Equilibrium and First-Round Play

A consistent theme that runs through all of the treatments is the speed with which groups converge to the efficient purchasing or the inefficient no-purchasing equilibrium. Success in the first round at attaining critical mass appears to predict convergence to the efficient equilibrium. To test more formally for this relationship, we regress whether a group of seven subjects reached the efficient equilibrium (all seven subjects purchase the network good) in the terminal round on whether the group attained critical mass in round 1. We treat each group-price-utility function combination as the unit of observation. Thus, while each group in the two High-Profit and two Low Critical-Mass treatments constitutes a single observation, groups in the baseline and price crawl-up treatments are each exposed to two and six prices, respectively. To account for possible arbitrary correlation in the outcomes of these latter groups, we cluster the standard errors by group. Table 6 reports the results.

The estimated coefficient of .097 on the constant term in regression (1) implies that the likelihood of arriving at the efficient equilibrium in the terminal round for a group that did not reach critical mass in round 1 is about 10%. Add to this the highly significant estimate of .886 to obtain a probability of .98 of arriving at the efficient equilibrium for groups that did attain critical mass in round 1. Regression (2) also includes an indicator variable for whether the required critical mass of the game is 6 or 7. The interpretation of the estimated constant term of .221 is now the probability that a group reaches the efficient equilibrium in the terminal round when playing in a market with a critical mass of 3 (in the Low-Price Baseline or Low Critical-Mass treatments) or 1 to 5 (in the Price Crawl-Up treatment). The indicator variable for whether the critical mass is 6 or 7 is negative but not significantly different from 0 (p=.21). The highly significant coefficient of .782 on “Round 1 Critical Mass” implies that attaining critical mass in the first period predicts an additional likelihood of 78% of converging to the efficient equilibrium in the last period.

Table 6: Convergence to the efficient equilibrium and the number of buyers in the final round

Regression	(1)	(2)	(3)	(4)
Dependent Variable / Variable	Efficient equilibrium	Efficient equilibrium	Number of buyers	Number of buyers
Round 1 Critical Mass	.886*** (.055)	.782*** (.115)	5.813*** (0.413)	5.124*** (0.794)
Critical Mass of 6 or 7	________	−.142 (.111)	________	−.942 (.771)
Constant	.097* (.053)	.221* (.119)	1.065*** (0.401)	1.885** (0.817)
R^2	.810	.821	.769	.779
Obs.	88	88	88	88

Notes: 1. Regressions (1) and (2): Linear probability model, dependent measure is a binary variable for whether the group converged to the efficient equilibrium in terminal round.
2. Regressions (3) and (4): OLS regressions, dependent measure is the number of buyers in the terminal round.
3. Independent variables: Round 1 Critical Mass: indicator variable for whether the group attained critical mass in round 1; Critical Mass of 6 or 7: indicator variable for whether the required critical mass for the game was 6 or 7 buyers.
4. Standard errors are clustered to account for any arbitrary correlation at the group level.
5. * 10-percent significance level, ** 5-percent significance level, *** 1-percent significance level.

Regressions (3) and (4) are analogous to regressions (1) and (2), respectively, except that the binary dependent variable for whether the group arrived at the efficient equilibrium in the terminal period is replaced with the actual number of buyers in the last round. The estimated coefficients of 1.065 and 1.885 indicate that the predicted number of buyers in the terminal round when the group does not attain critical mass in round 1 is about one overall, and less than two for groups in markets with a required critical mass less than 6, respectively. Yet, according to both regressions, when the group does achieve critical mass in the first period, the estimated number of buyers approaches the entire group size of 7.

In summary, failure to achieve critical mass in the first round dooms the market to collapse, whereas success practically assures the group will reach the efficient purchasing equilibrium by the final round. Why is the eventual fate of these network-good markets so closely tied to behavior in the very first round of play? The answer lies in the ease with which subjects are able to make inferences and learn to best respond to others in this environment. With full information, symmetric payoffs and feedback about the number of buyers at the end of each round, inference in these games is straightforward. A binary strategy space further simplifies subjects' choice. Strategic uncertainty is the only complicating factor which subjects respond to by purchasing the good if the end-of-round feedback informs them that purchase was profitable in the previous round and by not purchasing if they observe that purchasing led to losses. The result is uniform convergence to one equilibrium or the other, typically within the first several rounds.

5 Conclusions

We introduce a series of experiments to capture some of the salient features facing consumers contemplating the purchase of a network good when it is first introduced into the market. The paradigm involves a seven-person coordination game with two pure-strategy equilibria: one equilibrium entails no one purchasing the network good, while the other Pareto-superior equilibrium obliges everyone to purchase.

We design a number of experimental treatments to determine which factors facilitate and which ones thwart the establishment of a successful network market. In each treatment, the same cohort of seven consumers plays repeatedly. Feedback about subjects' realized profits or losses from buying the network good at the end of each round results in strikingly fast and uniform convergence to one equilibrium in which no one buys the good or the other in which all seven do.

We find the level of the critical mass (namely, the minimum number of purchasers needed to make purchase worthwhile) to be of central importance. When the critical mass requires that six of the seven consumers buy the good, the market collapses. Only a stress test in which the profit potential from purchasing is substantially inflated induces subjects to buy. On the other hand, when the critical mass requires that only three of the seven consumers purchase, everyone does. This result holds even when the potential profit from buying is shrunk to a minimum.

This paper serves as a first step in investigating coordination problems relevant to network goods. Future research could introduce consumers who have heterogeneous values or who proceed sequentially in their decision whether to purchase the good. Also, an active role for the seller raises the possibility of price discrimination, with early adopters and large buyers plausibly being induced to buy through lower prices.

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Appendix

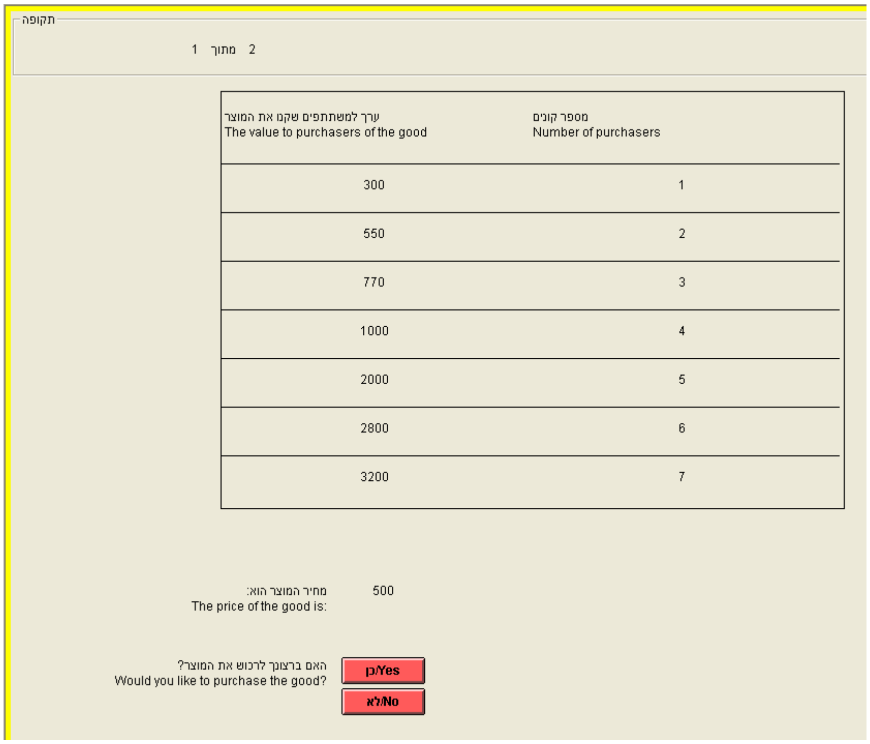
This appendix presents the instructions, translated from Hebrew. We omit below standard preliminaries that request quiet, ask subjects to adhere closely to the instructions, explain the use of the computer mouse and ensure subject anonymity. Note that the numbers that appear in the examples in the instructions are intentionally not those used in the experiment itself.

Instructions

You have been asked to participate in an economics experiment. At the start of the experiment you will receive 15 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.

You are one of seven players taking part in a game. All players are identical, and 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.

When the game starts, you will see a screen that appears as follows (the actual numbers will differ):



Explanation of the chart: The right column indicates the number of participants who purchase the good in this round. The left column indicates the income each purchaser will receive from the purchase. Notice that as the number of purchasers increases, this income grows. Thus, for example, if two players buy the good, each will receive an income of 550 Agorot, and if five purchase, the income will be 2000 Agorot, etc.

The price of the good appears at the bottom of the screen. Note that the effect of the purchase on your account is determined by the difference between the income you earned from purchasing the good and the price of the good. 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. That is, if you do not purchase the good, the balance in your account does not change.

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 decrease.

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 20 times, and then the price will be changed, and remain at its new level for an additional 20 rounds. The change in price will be announced before it occurs.

Are there any questions?