Organizational growth and coordination problems: An experimental study

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Abstract

Coordination problems arise when actors within an organization are only willing to commit resources (effort, time, etc.) if they think others will as well, resulting in strategic uncertainty. This paper considers the connection between this type of coordination problem and organizational size. There is support in both the organizational and economics literatures for the belief that coordination problems become much more difficult as groups increase in size. This implies that solving coordination problems should be a crucial objective of growing organizations. Given the difficulty of coordinating the activity of large groups, however, the question is how to accomplish this.

This paper argues that the growth process itself is a useful tool for solving coordination problems in organizations. As an organization grows, a key aspect to maintaining successful coordination is to grow slowly enough and socialize new members sufficiently so that the established rules for coordinating activity are not overwhelmed by the growth process. The ability to maintain the culture of the organization throughout the growth period is an important determinant of successful coordination. This claim is supported by an example from the airline industry and in laboratory experiments that start with small groups and then show that "growing" the groups at a sufficiently slow rate can lead to successful coordination in large groups – a result impossible to obtain when group size is initially large.

1 Introduction

This paper is about coordination problems in firms, and the special difficulty that growth creates for efficient coordination. While problems associated with obtaining cooperation have received much attention from economists and organizational researchers (Williamson, 1985; Klein, Crawford and Alchian, 1978; Milgrom and Roberts, 1990; Chatman and Barsade, 1995; Bettenhausen and Murnighan, 1991), coordination is as central a problem of organization and one that has received less attention (Heath and Staudenmayer, 1999; Weber, 2000a). Moreover, just as the prisoner's dilemma game models the problems associated with cooperation, coordination can also be represented in a simple game-theoretic way – as the game "stag hunt." (Camerer and Knez, 1997; Cooper, 1999).

Experiments consistently show that large groups miscoordinate more often than small groups in a version of the stag hunt game known as the weak-link coordination game (Van Huyck, Battalio and Beil, 1990; Weber, Camerer, Rottenstreich and Knez, 1998) . If we believe that this game models problems present in organizations (Knez and Simester, 1997; Nanda, 1996; Weber, 2000a), this result suggests that larger firms may have more difficulty coordinating activity efficiently than small firms. This, in turn, implies that as firms grow larger, miscoordination tends to occur. However, no experiments have studied what happens to coordination when small groups grow into large groups by adding members. Perhaps the coordination problems large groups experience can be avoided if the process of growth is managed properly.

This paper argues that the ability of large groups or organizations to coordinate successfully is critically affected by the growth process itself. Specifically, successfully coordinated small organizations have established a set of rules or norms – either tacit or formalized – governing what actions are appropriate. These norms allow the organization to successfully coordinate activity. Therefore, it is crucial that as the organization grows adherence to the norms be maintained despite the entrance of new members. This is particularly true when the rules are not formal and are subject to interpretation. One way to achieve successful coordination through the growth process is to limit the number of new entrants at any time and to have significant socialization procedures in effect. This result has been shown using a formal model of behavior in the weak-link game (Weber, 2000b). Thus, successful growth is obtained by growing slowly and allowing sufficient time between growth periods for the rules not to be overwhelmed by new entrants. The result is a strong organizational culture that allows members to correctly anticipate what is the correct activity to be performed.

This paper complements Weber (2000b) by providing two additional pieces of support for the above argument. First, the argument is illustrated by an example of a firm in the airline industry – Southwest Airlines – in which top management explicitly used a slow approach to growth to solve coordination problems. Southwest's emphasis on culture and slow expansion allowed it to grow successfully in an industry where coordination plays an important role (Knez and Simester, 1997) and avoid problems that plagued other airlines such as People Express. Second, experiments are used to investigate whether this result can be established in the laboratory. The experiments look at whether large groups playing the weak-link coordination game are more efficiently coordinated when they are "grown" – i.e., start off small and have players enter slowly – than when they begin playing at a large size. A second set of experiments examines the behavior of subjects placed in the role of "managers" and allowed to determine the group size. These second experiments are conducted for two reasons. First, it is possible that the managers might discover growth paths that work better than those used in the first experiments. Second, evidence from previous experiments indicates that subjects are not aware of the difficulty in coordinating large groups (Weber, Camerer, Rottenstreich, and Knez, 1998).[1] If this is true, then the managers might grow the groups too quickly, leading to coordination failure.

The next section discusses the type of coordination problem that is the topic of this paper and its prevalence in organizations. Following that, the relationship between size and coordination problems is explored and the growth process is presented as a possible solution. This is then explored in a case study and a simple description of the main result in Weber (2000b). Finally, experiments are used to demonstrate the importance of the growth process in obtaining successful coordination in large groups.

2 Coordination problems in organizations

A fundamental problem of organization is coordination: Suppose there are two sets of activities, A and B, which could be performed simultaneously and efficiency is only achieved if everyone performs the same activity. Thus, everyone wants to perform the same action that everyone else is performing, but they are unsure of what action others will take. This is the basic coordination problem made famous by Schelling (1960). To make the coordination problem more interesting, suppose that A is better for everyone but riskier. Therefore, if

[1] Heath and Staudenmayer (1999) argue that an important problem associated with obtaining coordination is "coordination neglect", or the tendency to ignore the importance or difficulty of obtaining coordination.

everyone performs activity A, then everyone is better off than if they all performed B, but anyone who does A when all others do not would have preferred to have done B. Then the problem of coordination is getting workers to believe that everyone else will do A, in which case they will as well. Coordination problems like this arise when there are complementarities in activities of different workers or corporate divisions, but there is some uncertainty about the action each worker or division will take.

Situations where coordination is important have been discussed by both economists and organizational researchers.[2] For instance, search costs in markets are decreased when buyers and sellers are located near each other (Coase, 1937; Cooper, 1999). There are also several examples of where the best practice to be adopted by a worker or a specialized unit of an organization depends on what is being done elsewhere (Becker and Murphy, 1992; Thompson, 1967; Lawrence and Lorsch, 1967; Milgrom and Roberts, 1992; Baker, Gibbons and Murphy, 1994; Barnett and Freeman, 1997). This may arise often because goals at the organizational level are decomposed into several smaller goals to be performed independently by different units (Malone and Crowston, 1994). To solve these kinds of problems and perform better when coordination is important, several researchers have argued that organizations incorporate coordinators or integrating units into their structure (Lawrence and Lorsch, 1967; Scott, 1998; St. John and Harrison, 1999).[3] To solve problems associated with coordina-

[2]For a survey of several different approaches to the study of coordination, see Malone and Crowstone (1994).

[3]There is also evidence that organizational structure may have an important effect on firm organizational performance in complex tasks or in changing or unstable environments where coordination is important (Shaw, 1981; Leavitt, 1962; Carley, 1992; Ghemawat and Ricart I Costa, 1993).

tion, firms often also rely on communication between units or decision makers (Malone and Crowston, 1994), on formal plans such as schedules (March and Simon, 1958; Lawrence and Lorsch, 1967; Arrow, 1974; Scott, 1998), and on simple, naturally-emerging routines (Cohen and Bacdayan, 1994).. There is also a body of evidence indicating that firms pursuing narrow business strategies outperform firms that diversify into unrelated fields (Rotemberg and Saloner, 1994, Teece, Rumelt, Dosi, and Winter 1994). One possible reason for this is that narrow business strategies make it easier to coordinate activity than trying to diversify into areas consisting of widely unrelated activities. Finally, Kogut and Zadner (1996) argue that the reason firms exist is because they establish group identities that help workers solve coordination problems better than simple market transactions. Central to their argument is the notion that coordination is critical to organizational performance.

There are several industries and areas of organizational behavior where coordinated activity between employees or separate units is crucial. Examples include both civilian and military flight operations (Thompson, 1967; Weick and Roberts, 1993; Knez and Simester, 1997), software development (Kraut and Streeter, 1995; Kiesler, Wholey and Carley, 1994), health care provision (Gittell and Fairfield, 1999; Gittell and Wimbush, 1998), and inter-organizational networks and alliances (Khanna, Gulati and Nohria, 1998; Human and Provan, 1997; Aoki, 1999). However, while coordination plays an important role in these and several other industries, it is often a problem neglected by both managers and organizational researchers (March and Simon, 1958; Lawrence and Lorsch, 1967; Heath and Staudenmayer, 1999).

2.1 Coordination vs. cooperation

While often neglecting problems of "coordination", organizational researchers have often paid attention to problems associated with obtaining "cooperation" and the two terms are often used interchangeably. However coordination is very different than cooperation, another fundamental problem of organization.[4] The contrast between coordination and cooperation can be sharply seen in two simple games: Prisoner's dilemma (PD) and stag hunt (or the assurance game), shown in Table 1.

	Cooperate	Defect
Cooperate	2,2	0,3
Defect	3,0	1,1

	High	Low
High effort	2,2	0,1
Low effort	1,0	1,1

Table 1: Prisoner's dilemma (top) and stag hunt (bottom) games

In the PD game players choose to either *Cooperate* or *Defect*. The latter is a dominant

[4]Examples of problems associated with obtaining cooperation (or problems associated with agency or opportunism) are discussed by Williamson (1985); Klein, Crawford and Alchian (1978); Hart (1995); Milgrom and Roberts (1990); Holmstrom and Tirole (1989); Chatman and Barsade (1995); and Bettenhausen and Murnighan (1991) among others.

strategy because it gives a higher payoff regardless of what the other player does. In the stag hunt game players choose actions *High* or *Low*. Neither strategy is dominant because each can be better depending on what the other player does – the players wish to coordinate their choices because *Low* is the best response to another player choosing *Low* (then they both earn 1) but *High* is a best response if another player chooses *High* (then they both earn 2).[5]

In both games, the outcome which is best for both players is the one in which they both earn 2 (from (*Cooperate*, *Cooperate*) in PD or (*High*, *High*) in stag hunt). The contrast between the two games lies in the reasons why reaching this outcome may difficult. In PD players prefer to not reciprocate cooperation, because if the other player cooperates defection pays 3 while cooperation pays 2. That is, it is not in the players' best interests to select *Cooperate* even though both players end up worse off as a result. In stag hunt, on the other hand, players do prefer to reciprocate *High* (which corresponds to cooperation), because reciprocating pays 2 while choosing *Low* pays 1. However, coordination is difficult because playing *High* results in the worst outcome if the other player plays *Low*, and players are unsure of what others will do when choosing their action.

Applying the games to behavior in organizations yields an insight into two – often confused – distinct problems faced by firms. Thus, "solving" the PD requires an organization

[5]Stag hunt is also called an "assurance" game and is closely related to a threshold or step-level public goods game (in which a public good is provided if enough subjects contribute), also known as the "volunteer's dilemma" (Murnighan, Kim, and Metzger, 1993), and to infinitely-repeated prisoners' dilemma games where trigger strategies create multiple Pareto-ranked equilibria.

to get players to act against their best interests. Defection imposes a negative externality on the other player and if players could somehow be prohibited from doing so, both would be better off. "Solving" stag hunt requires an organization to get players to believe that others will choose High; then they will prefer to choose High and reach the Pareto-optimal payoffs.[6]

Both games imply that rational players may choose strategies which lead to a collectively "irrational" outcome yielding Pareto-inferior payoffs.[7] In PD, this collective inefficiency results because of the conflict between private and collective incentives. However, in stag hunt rational players may end up at the inefficient (Low, Low) equilibrium simply because of strategic uncertainty– they aren't sure what other players will do and there is therefore some risk associated with choosing High.[8]

2.2 Weak-link coordination

In the stag hunt game, a player's payoffs can be decomposed into two elements: A cost from choosing *High*, and a group payoff which depends on whether either player chose *Low*.[9] A

[6]Foss (1998) argues that the central role of leadership in organizations is to provide this type of solution. Having leaders make public announcements about which action everyone should take results in the preferred outcome being common knowledge and, therefore, salient. However, experimental work on coordination games by Van Huyck, Gillette and Battalio (1992) and by Weber, Camerer, Rottenstreich and Knez (1998) shows that the effects of this type of leadership are limited.

[7]A Pareto-inferior outcome is one for which there is another outcome in which all players are beter off.

[8]The rest of this paper deals with a specific type of coordination problem. For a more detailed discussion of the application of game theory to different types of coordination or interdependence problems in organizations see Weber (2000a).

[9]So, for instance, the payoffs in the stag hunt game in Table 1 could be represented by a cost of 1 for choosing *High* and 0 for choosing *Low* and a payoff of either 1 to everyone if either player chose *Low* and 3 to everyone if both players chose *High*.

natural n-person generalization of this game is one in which players choose numbers – or orderable strategies such as effort or contribution levels – and the group payoff depends on the lowest number selected by any player. These are sometimes called "weak-link," or minimum effort, coordination games (because everyone's payoff is a function of the lowest effort selected by any player, or the "weakest link" in the group) and are a special kind of order statistic game.[10] Processes in which the production function has the Leontief form (output depends on the minimum of the factors of production) have the weak-link quality. Some examples include production of chemical compounds, orchestra performances (one false note ruins the whole symphony), some kinds of cooking, and provision of safety in dangerous situations (see Camerer and Knez (1997)).

Camerer and Knez (1997) discuss weak-link coordination problems that can arise when a customer interacts with several different employees of an organization. In some situations (e.g., hotels and restaurants), the impression of the organization the customer is left with might be disproportionately affected by the minimum level of service provided by any of the employees the customer encounters. This same type of problem is discussed by Malone and Crowston (1994) who label the situation one of "shared reputation dependency."

An example of weak-link coordination problems arising from safety requirements is provided by Weick and Roberts (1993). They discuss the critical need for "heedful interrelating"

[10]See Van Huyck, Battalio and Beil (1990 & 1991), Crawford (1995), and Camerer (in progress, Chapter 7)

in preventing accidents in flight operations on aircraft carriers. They describe how even the most basic operations on flight decks involve several groups of people performing different tasks simultaneously and how a mistake in any of these task can lead to a catastrophic outcome.

Groups of firms engaged in illegal or collusive behavior are also often involved in weak-link coordination problems. Suppose that the illegal activity is unlikely to be discovered or proven by regulatory agencies unless one of the firms reveals some information. However, none of the firms has an incentive to provide evidence unless it believes others will as well. Then the firms face a weak-link coordination problem in that they are all better off maintaining silence as long as all the other firms are as well. This was the case in the tobacco industry where, until recently, the top firms were able to maintain secrecy concerning their knowledge of the harmful effects of smoking, making it difficult for the government to take action against them. This changed, however, when the smallest of the big five firms, Liggett Group, provided evidence acknowledging that the industry had known of the effects all along. It is interesting that Liggett did not benefit from providing the evidence and instead the resulting settlements in several lawsuits forced the firm close to bankruptcy.[11]

Organizational change is another area where weak-link problems might arise. There is

[11]In fact, the anecdote often used to illustrate the prisoner's dilemma – of two suspects being questioned and urged to present evidence against the other – is actually often a stag hunt game. If the prosecutors lack sufficient evidence to convict either prisoner if neither confesses, then the best outcome for both is if neither defects and they are both released.

a large body of evidence indicating that firms face difficulties adapting to changes in their environment, as indicated by Hannan and Carroll (1995):

> History readily illustrates the difficulties of adaptation. Few organizations achieve either great longevity or great social power, and virtually none achieves both. In other words, few organizations succeed in solving their adaptive problems for very long in a turbulent world. (p. 24)

One explanation for this is that firms face weak-link problems in implementing many kinds of change. For instance, Hannan and Carroll write about how tacit agreements between members of a group concerning what actions are correct may then infuse these actions with social value. The result is that these actions become understood as the correct way of doing things and become more difficult to change when the need arises. A firm stuck at an inefficient equilibrium – that may once have corresponded to an efficient set of activities but may no longer do so because of changes in the firms' environment – may attempt to implement a change to an optimal set of activities. However, if employees only benefit by attempting to implement the change if everyone else attempts to do so as well, the problem is identical to a weak-link game (Nanda, 1996). The danger, then, is of ending up at an out of equilibrium outcome where some people are performing the old set of activities and others are attempting the new ones. This results in the worst outcome for the firm.[12] Hannan and Freeman

[12] Levinthal (1997) shows that the implementation of change can be modeled for some organizations as

(1984) discuss similar hazards involved with change. They argue that during change there is "a period of time during which existing rules and structures are being dismantled . . . and new ones are being created to replace them" and that "the presence of multiple rules and structures greatly complicates organizational action." (p. 158)

Problems requiring temporal synchronicity also create weak-link coordination problems. In these problems, the key factor is the time at which each of many tasks is performed. For example, assume that workers would like to finish their portions of a project as late as possible – but the entire group would be better off if the project was finished sooner – and that the project is not finished until all the portions are finished and assembled. Then each worker wants to finish just when the slowest worker does (no one wants to finish ahead of the slowest worker since this does not help complete the project any sooner) and everyone wants that time to be soon. This creates a weak-link coordination problem. Examples of this type of problem include assembly lines, projects with strict deadlines (e.g., preparing bids for contracts), assembling chapters of an edited book, or service activities in which customers are forced to wait until all parts of the service are completed. An example of the latter is airline departures – the plane can't leave until the gate crew, ground crew, baggage handlers, and flight crew have all finished their preparations (see Knez and Simester (1997)).

jumping from one peak to another in a multi-peaked environment. In order for change to be successful, it is necessary for all critical units to change in the same manner, resulting in a coordination problem. An example of organizational change where several processes need to be implemented simultaneously is provided in the case of banks replicating practices between branches by Winter and Szulanski (1997).

Weak-link coordination problems are a particularly punishing form of coordination. It only takes one person or factor failing to perform optimally for the outcome to the entire group to be negatively affected. Thus, every element must coordinate efficiently in order for efficient outcomes to be achieved.

It is not unreasonable, therefore, to expect that larger groups of people might have a more difficult time coordinating successfully in weak-link problems as well. Previous experimental research has established this phenomenon.

2.3 Previous studies on weak-link coordination

Weak-link coordination games were first studied experimentally by Van Huyck, Battalio, and Beil (1990) .[13] Most early studies on weak-link games used an abstract version of the game in which players chose numbers and were given a payoff table indicating how their payoff depended on their own number and on the minimum number chosen in their group.

Weber, Camerer, Rottenstreich and Knez (1998) used a decomposed payoff format in which players were told that their earnings were comprised of a group reward (which depended on the minimum number chosen) and a personal fee (which depended on their choice).

[13]These games have also been studied experimentally by Cachon and Camerer (1996), Knez and Camerer (1994) and (1996), Camerer, Knez and Weber (1996), and Weber, Camerer, Rottenstreich and Knez (1998); and theoretically by Anderson, Goeree, and Holt (1996) and Crawford (1995).

To address concerns about how more natural contextual labels might affect behavior, Weber, et al., also included a condition in which players were told that the numbers they chose corresponded to the times at which they finished their portions of a group report.[14]

The instructions read:

> In this experiment, you are one of N members of a project team that is responsible for producing a series of reports. Each report that the team prepares consists of N sections, where each member of the team is responsible for contributing one of the sections. A report is considered complete only after all members of the team contributed their sections. Your team will be responsible for producing a total of T reports. Until a particular report is finished, no member of the team can work on his or her section of the next report.

Subjects then chose how early to contribute their section of the report, from 1 to 7 weeks early. Table 2 shows how each player's payoffs depended on their own choice and on the project completion time (the number of weeks ahead of schedule that the project was finished, which depended on the minimum number chosen by any subject).[15]

[14]Behavior in this natural-label condition was indistinguishable from behavior in the more abstract conditions.

[15]The instructions to subjects actually had them choose a time at which they finished their portion of the report, so the completion time was the maximum of these numbers. The game is described here in terms of minima for comparability to prior research, and so that high numbers correspond to more efficient choices.

	Report completion time						
Player's Time	7 weeks early	6 weeks early	5weeks early	4 weeks early	3 weeks early	2 weeks early	1 week early
7 weeks early	.90	.70	.50	.30	.10	-.10	-.30
6 weeks early		.80	.60	.40	.20	.00	-.20
5 weeks early			.70	.50	.30	.10	-.10
4 weeks early				.60	.40	.20	.00
3 weeks early					.50	.30	.10
2 weeks early						.40	.20
1 weeks early							.30

Table 2: Payoffs (in dollars) for weak-link game

The diagonal cells correspond to outcomes in which the player is choosing the same time as the group minimum. These outcomes, in which everyone chooses the same time and receives the same payoff, are all Nash equilibria since no player would prefer to contribute either earlier (which would increase their personal fee but not affect the completion time or group reward) or later (which would lower their personal fee but would also affect the completion time and lower their reward by even more). Notice, however, that the equilibria are different because those with higher personal fees also yield higher payoffs. The Pareto-dominant (or "efficient") outcome arises when all of the participants select the earliest time, 7 weeks early, and receive $.90. It is in the players' mutual interest to reach this outcome and the players realize this.

However, the efficient outcome may not be easy to achieve because players are faced with strategic uncertainty. Simply being unsure about what others will do may lead different players to take different actions, and when groups are large the minimum completion time may therefore be quite low.

Previous experiments with weak-link games have established clear regularities. Coordination on the efficient equilibrium is impossible for large groups. Of the seven sessions initially conducted by Van Huyck, et al. (1990) (VHBB) with groups of size 14 to 16, after the third period the minimum in all games was the lowest possible choice. For small groups (n = 2) coordination on the efficient equilibrium was much easier – it was reached in 12 of 14 (86%) of the groups studied (a result replicated by Knez and Camerer (1996)). Table 3 summarizes the distribution of fifth-period minima in several different experiments, all using the VHBB game in which subjects choose integers from 1 to 7 and choosing 7 is efficient.

1	2	3	4	5	6	7	Group Size	N	Source
9	0	0	0	0	0	91	2	28	VHBB, 1990; Knez & Camerer 1996
37	15	15	11	0	4	18	3	60	Knez & Camerer 1994, 1996
80	10	10	0	0	0	0	6	114	Knez & Camerer 1994
100	0	0	0	0	0	0	9	18	Cachon & Camerer 1996
100	0	0	0	0	0	0	14-16	104	VHBB, 1990

Table 3: Fifth period minimums (by %) in various 7-action weak-link studies (1 = inefficient; 7 = efficient)

The effect of group size could hardly be stronger. Subjects in a group of size 2 are almost assured to coordinate on the efficient outcome. Subjects in larger groups (six or more) are almost assured to converge to the least efficient outcome.[16] Thus, there is a strong negative relationship between the size of a group and the ability of its members to coordinate efficiently.[17]

This increased difficulty of coordination associated with larger group sizes has also been recognized by organizational researchers. For instance, Thompson (1967) writes that because the costs of achieving tacit coordination, or coordination by mutual adjustment, are expensive and "increase as the number of positions involved increases, we would expect organizations facing reciprocal interdependence to fashion the smallest possible groups." (p. 58) Lawrence and Lorsch (1967) argue that large organizations will be the ones that are able to solve the coordination problems arising from simultaneous differentiation and integration. If firms are not able to solve these coordination problems, on the other hand, it will be impossible for them to efficiently grow. In addition, it has also been argued that there is a connection between the size of inter-organizational networks and their effectiveness and longevity and that these may be related to coordination costs (Human and Provan, 1998; Phillips, 1960).

There exists a similar relation between size and successfully coordinated change in organizations. It is often argued that larger organizations are more likely to exhibit organizational

[16]Once these groups reached the inefficient outcome, they were not able to subsequently increase the minimum.

[17]This result has also been replicated using slightly different versions of the game and in experiments in which the task is framed as a realistic group project rather than an abstract game (Weber, Camerer, Rottenstreich and Knez, 1998).

inertia.[18] Recalling Nanda's (1996) argument that organizational change involves solving a problem essentially identical to the weak-link game, one interpretation of the above experimental result is immediate: larger organizations are more subject to inertia because they find it more difficult to solve the weak-link coordination problems associated with change.

Given the relationship between weak-link coordination games and coordination problems faced by firms, it becomes important to identify how large groups can coordinate successfully. This paper is part of a larger general program of research concerned with identifying mechanisms for resolving large group coordination failure in weak-link problems, which the previous section argues correspond to a naturally-occurring organizational phenomenon.[19]

3 Coordination and growth

3.1 Coordination problems and organizational size

The weak-link game provides a way to test the connection between growth and coordination experimentally. While it is well- established in weak-link experiments that large groups coordinate poorly, and small groups coordinate well, no previous research has tied these phenomena together by exploring behavior in small groups as they grow larger by adding members. Interest in the effects of growth was motivated by two observations, one from the

[18]See Hannan and Freeman (1984) for a discussion of this proposition.

[19]See Knez and Camerer (1994) and Weber, Camerer, Rottenstreich and Knez (1998).

laboratory and one from the field.

The laboratory observation motivating this work was that 3-person groups usually do not reach efficiency in weak-link games, unless they were created by adding a third person to a successful 2-person group, in which case they almost always reach efficiency. This phenomenon suggests that, in principle, arbitrarily large groups could be created which coordinate efficiently in the weak-link game, if they start small enough and grow slowly enough.

The field observation is the apparent contradiction between two firmly-held beliefs in organizations. The first belief is that firms must grow to achieve scale economies or critical mass. The second belief is that firms can grow too rapidly and end up suffering as a result. One possibility for this failure is that as coordination costs increase with size they become unmanageable for a previously effective organizational form. This possiblity has been discussed by organizational researchers.[20] Scott (1998) states that coordinating activity is one of the main achievements of formal structure. He also argues that:

> As information-processing needs increase up to a certain point, hierarchies can be of benefit, reducing transmission costs and ensuring coordination. But as information- processing needs continue to increase, hierarchies become overloaded. . . Such increased demands . . . encourage the creation of more

[20] See, for instance, Starbuck (1965), Scott (1998).

> decentralized structures. (Scott, 1998, p. 161)

Thus, centralized decision making is suitable for coordinating activity where communication and information- processing are manageable, but the ability of a centralized unit to achieve this is dramatically reduced with size.

The possibility that failure due to growth may be the result of coordination failure has also been stated by March and Simon (1958): "As the size of organization increases . . . the coordination costs become larger" (p. 29) and similarly by Chandler (1962), who wrote:

> . . . growth without structural adjustment can lead only to economic inefficiency. Unless new structures are developed to meet new administrative needs which result from an expansion of a firm's activities into new areas, functions, or product lines, the technological, financial, and personnel economies of growth and size cannot be realized. (p. 176)

Thus, simply increasing the size of a successfully coordinated group may be enough to result in coordination failure. Taken to an extreme, the result that large, efficiently coordinated groups are <u>never</u> produced in the laboratory implies that growing organizations is a treacherous process which is almost certain to fail due to miscoordination. However, given that large, efficiently coordinated organizations are not uncommon, it must be that firms solve this problem somehow. One way they do this is to implement changes in the organization that alleviate the difficulty of solving the interdependence problem. These are the "structural adjustments" that Chandler writes about.[21] Therefore, as a firm grows, it can create decentralized units with limited interdependence between them, increase communication between units that are interdependent, and create positions for specialized teams of integrators responsible for coordinating activity between units.[22]

While the above changes to a firm's structure can help alleviate coordination problems resulting from size, they are not the only way to accomplish successful growth. A second way can be described by analyzing the approach to growth of a particular organization.

[21] As another possible solution, Thompson points to the importance of communication and repeated interaction of the same group members (or coordination by mutual adjustment) in solving problems of interdependence. He discusses as an example of a group where coordinated action is important small bomber crews where "communication had to be rapid, direct, and unambiguous" and "holding the same ten individuals as one team – crew integrity – was a high priority policy." (p. 62)

[22] An example of this can be found in Microsoft's 1999 reorganization into decentralized units. This change, resulting in separate divisions with unprecedented levels of autonomy, was implemented largely to solve problems arising from a large bureaucracy ill suited to cope with the firm's size and from the competitive pressures exerted by a rapidly changing environment. In Microsoft president Steven Ballmer's words, the change was implemented because "we needed to give people a beacon that they could follow when they were having a tough time with prioritization, leadership, where to go, what hills to take" (Moeller, Hamm and Mullaney, 1999, p. 106). Thus, solving coordination problems was a large part of the purpose of the reorganization.

3.2 Southwest Airlines

The approach to growth of Southwest Airlines provides an interesting case study in how the growth process itself can be used to grow a large, efficiently coordinated organization. Southwest began as a low-cost, no-frills airline flying short hauls from secondary airports (such as Love Field in Dallas) .[23] The corporate culture emphasized friendly service by employees who were cross-utilized (performed different jobs), given a lot of freedom to determine their job responsibilities and expected to pitch in spontaneously (e.g., pilots sometimes checked in luggage), and paid less than at other major airlines. Success of the strategy depended on having lower costs than major carriers and attracting price-sensitive fliers who might have not flown at all, but instead taken an alternative method of transportation such as driving.

Southwest's basic strategy was described plainly by executive vice president Colleen Barrett: "We've always seen our competition as the car. We've got to offer better, more convenient service at a price that makes it worthwhile to leave your car at home and fly us instead." Their "luv service" and an emphasis on making a flight fun and simple were an important departure from the industry norms. This approach was successful as Southwest remained profitable for 24 consecutive years (through 1996) and was the only airline to earn a profit in 1992. The ability of Southwest to attract qualified employees willing to work for less was due largely to the team spirit that routinely led Southwest to be ranked as one of the best places to work.

[23]Unless otherwise noted, the information on Southwest Airlines and People Express is from Harvard Business School cases.

What is particularly interesting about the Southwest case, however, is that the airline grew at a very slow rate and regularly passed over opportunities to enter profitable markets. Rather than expand rapidly to achieve a national base – an approach used regularly in the airline industry (for instance, by People Express) – Southwest grew very slowly by comparison and after a quarter of a century of operation had not yet entered markets in the Northeast.

This slow approach to growth was specifically intended to maintain the successful coordination – largely reflected in Southwest's culture – that the airline achieved as a small local carrier. This was accomplished by creating a unique culture in which employees were highly motivated, close to management, and shared a common objective of making customers happy and getting planes in and out on time at low cost. The airline business is an obstacle course of coordination problems, many of which have weak- link structure. This was particularly true for Southwest, which stressed on time service as one of its performance criteria.[24] In addition, on the short-haul routes usually used by Southwest, planes often make several trips a day, so if a plane is late on one haul, it affects the entire system and has a multiplier effect on disgruntled passengers all down the line. The culture worked well at solving this coordination problem when the airline was small. However, maintaining this culture which achieved coordination by stressing personal responsibility and a sense of community (rather than by command and control) could be easily strained by rapid growth.[25] In fact,

[24] Recall that Knez and Simester (1997) argue that flight departures constitute an important weak-link coordination problem between several employees.

[25] As an example of where this happened, consider the case of People Express (PE). PE was initially very

Southwest's approach to growth was specifically motivated by a desire to maintain its culture.

Southwest was able to avoid the coordination failure often resulting from growth by growing more slowly and taking great pains to ensure that new employees were socialized into the culture. Rather than expand into new markets, Southwest stressed growth within the current route system and added new routes slowly. According to Southwest director of schedule planning, Peter McGlade, "controlled growth is essential" because "we want to make sure that the way we conduct business in a city we enter will be consistent with the way we conduct business throughout our system. . . We have to feel that we can hire Southwest-type people." McGlade also stressed that Southwest would "possibly pass over a city if it could not retain the Southwest 'luv' culture." For example, there were concerns about adding flights to Baltimore because "many feared that the airline would be unable to find Southwest-type employees on the East Coast."[26]

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similar to Southwest in that it offered low-cost, no frills service over short hauls, using primarily secondary airports (such as Newark). PE founder Donald Burr also stressed a similar culture to Southwest's and initially this proved very successful. In fact, PE was widely held as a model of a successful management approach in the early 80's (Chen and Meindl, 1991).

However, PE's approach to growth differed significantly from Southwest's. After a brief period of initial success, PE grew at a remarkable rate. Between 1981 and 1984, the number of employees increased 12 times, making PE the fastest growing airline in history. This rapid growth created problems, however, as customer service suffered, flights were regularly delayed and overbooked, baggage was routinely mishandled, and employees complained of confusion – leading the airline to be renamed "People's Distress" by customers. In addition, the acquisition of Frontier Airlines in 1985 led to a sharp clash between PE's culture and that of Frontier, which operated more like a mainstream airline.

That PE's difficulties resulted from coordination problems is evident in the steps management took to solve the performance problems. After problems began to surface, operations were split up into small groups "intended to recreate the sense of being on a team, the direct communication, and the personal control that was being lost in the total company" and "where everyone knew everyone." Thus, by attempting to recreate small groups where coordination problems are easier to solve and communication is improved, management revealed their belief that coordination failure was largely responsible for the performance decline.

[26]It is worth noting that Southwest dropped from first place in the annual Airline Quality Rating (a survey conducted of passengers' experiences with areas such as baggage handling, on-time arrivals, denied boardings

In addition, slower growth enabled the airline to choose "Southwest-types" more carefully, and to guarantee that new employees became immersed in the system more effectively. As additional means to maintain successful coordination on the "luv" culture, Southwest encouraged employee referrals of friends and family and required new employees to attend one of two "People Universities." In fact, this reliance on culture to create a large, efficiently operating organization is noted by Herb Kelleher, Southwest's founder and CEO. Colvin (1997) writes of a conversation he had with Kelleher:

> Once . . . I tried telling Herb that his culture wasn't all that important. "I can explain Southwest's success," I said. "You fly one type of aircraft, serve no meals, transfer no luggage, give no assigned seats, fly mostly on short hauls, and always charge the lowest fares on your routes. There's the formula. What's culture got to do with it?" Perhaps steam did not actually shoot out of his ears, but it looked as if it would. He slammed the table and said, "Culture has everything to do with it – because everything you said our competitors could copy tomorrow. But they can't copy the culture, and they know it." (p. 300)

Colvin goes on to note that some airlines, most notably United, have recently attempted to

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and customer service) – a place it held for several years – to fifth in 1998. This coincides with a year in which Southwest grew rapidly and added service to several East Coast cities (Wichita State University News Release, April 19, 1999).

copy the things he mentioned, but have met with only limited success.

The above case study presents a convincing picture that Southwest's success throughout a period of growth is due largely to the approach to growth itself. By adding employees and markets slowly, training and socializing new employees carefully, and by stressing the importance of maintaining the firm's culture for uniting action, the airline was able to reduce the coordination problems that are usually associated with growth.

An interesting question then is whether this approach to growth can yield similar results for other organizations. Weber (2000b) presents a formal model of behavior in weak-link coordination games that implies this is the case. By starting off with a small, efficiently coordinated group and then growing the group slowly enough and exposing new entrants to the group's history, the model predicts that large groups can be "grown" that are more efficiently coordinated than groups that begin at a large size. The intuition behind this result is simple. Players in a weak-link game are initially unsure of what action others will take (and, therefore, what the optimal response will be). Taking players first period choices as exogenous and independent of group size,[27] this uncertainty leads to choice error, represented by an exogenous error term which is added to players' choices. Since the expected value of the minimum is determined by the distribution of first period strategies and by the variance of the error term, if this variance is positive and sufficiently small the expected value of the

[27] In experiments using the weak-link game, the distribution of first period choices is similar across group sizes, indicating that players are not aware of the group size effect (see Weber, et al., 1998).

minimum choice in small groups may be the action corresponding to the efficient equilibrium, while the expected value of the minimum in large enough groups may be considerably lower. If players adjust their choices towards the previous minimum and the variance of the error term decreases with repeated play, small groups can remain efficiently coordinated while large groups collapse toward the inefficient equilibrium.[28] What Weber (2000b) shows is that a growth process that starts off with two-player groups, allows them sufficient time to coordinate successfully, and then adds players at a slow enough rate created large groups that are coordinated at higher levels of efficiency in expected value than groups that start off large.[29]

Taken together, the examination of Southwest's approach to growth and this formal model provide convincing support for the belief that growth may alleviate coordination problems associated with large group sizes. However, since it is often beneficial to discipline theory by testing its implications, it seems worthwhile to test the predictions of the model. One way to do so is with controlled laboratory experiments that look at whether or not slow growth produces more efficiently coordinated large groups. This is ideal since the laboratory provides a controlled environment in which to directly test the model. This test is performed in the next section.

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[28]Crawford (1995) uses this type of model to explain the laboratory result that small groups coordinate successfully while large groups do not.

[29]A key assumption underlying this result is that future entrants to the game who are allowed to watch the outcomes of the group actually playing the game will experience a similar decline in the variance of their error term to those actually playing the game. From an organizational perspective, this implies that it is not only important that new employees enter the firm slowly, but that they also be made aware of the firm's history and culture and that this "training" affect their behavior.

4 Experiments on growing efficient coordination

The previous section discussed the problem of large group coordination failure and explored possible solutions. Previously discussed approaches include improved communication and more suitable organizational forms. As this paper notes, however, the growth process itself can be used to manage coordination problems. Support for this hypothesis includes a case study and an adaptive model of behavior in weak-link games. Both indicate that growing groups carefully – starting off with a small group size and adding players slowly – can lead to more efficiently coordinated large groups.

This section tests this hypothesis using experiments. The experiments are conducted similarly to previous experiments by Van Huyck, et al.. (1990) and Weber, et al. (1998). The goal of these experiments is simply to test the claim from the previous section that "grown" groups are likely to be more efficiently coordinated than groups that start off at a large group size.

Two sets of almost identical experiments were conducted. In the first experiments, the rate of growth was determined by the experimenter prior to the experiment. These experiments were intended to test whether growth paths that satisfy several desirable criteria can produce large groups coordinated at higher levels of efficiency than control groups. A second set of experiments was also conducted in which a participant not playing the weak-link game determined the size of the group. In these experiments, groups were again grown as before, but the rate of growth was endogenous and not determined until the experiment. The goal of both experiments is to test whether or not growth can create more efficiently coordinated large groups. Each experiment will first be discussed separately, and then the aggregate results of both growth experiments will be used to test the hypothesis that slow growth can help solve large group coordination failure.

4.1 Experimental Design

Since large groups of ten or more subjects have never consistently coordinated efficiently in previous experiments – in fact, they almost always end up at the least efficient outcome – this first set of experiments was designed to explore whether a slow, controlled growth rate determined by the experimenter could create large groups that coordinated efficiently. In the experiments, groups of 12 Stanford and UC Santa Cruz students were assembled in one room. The game was presented in the context of a report completion as in Weber, et al. (1998), and as described earlier in this paper. Subjects were paid their earnings in cash at the end of the experiment. Instructions were read aloud and subjects answered several questions to check their comprehension of the instructions.[30]

[30]Instructions are available from the author.

In each experimental session, subjects were anonymously assigned participant numbers. Each session consisted of 22 periods. In the first several periods, only participants 1 and 2 played the weak-link game while the other subjects sat quietly. Participants were told that they would receive a fixed positive amount for rounds in which they were not playing the game, but that the exact amount would not be revealed until the end of the experiment. [31] In each period, participating subjects recorded a number from 1 to 7 (indicating the contribution time for their section of the report) on a piece of paper and handed it to the experimenter.[32]

At various preannounced and commonly known points, other participants joined the group of those actively playing the game. For each session, there was a schedule of such additions that was handed to all subjects at the beginning of the experiment. These schedules will be referred to as *growth paths*. For example, in one of the growth paths a third participant was added in period 7, joining the first two participants who continued to participate. Subjects all knew the predetermined growth path which explained when they began to participate, and they knew that earlier participants always continued to participate.[33] At the end of each period, the report completion time (minimum) was announced to all the subjects, including those who were not actively participating yet. In all growth paths, all 12

[31] This was done because of the concern that announcing the amount they earn per period could create a focal point which might influence participants' choices

[32] To prevent players from knowing which others were participating, all players handed in slips of paper; non-participants simply checked a box saying they were not participating.

[33] In addition, at the beginning of each period the experimenter announced which participants would actively participate in that round.

subjects were participating by the last few periods.

This design is intended to model behavior in a small firm which consists of only two "founders" and slowly adds employees who know the entire history of the firm's outcomes. There is no turnover (no employees "leave") because simultaneously studying the effects of turnover would complicate the conclusions that can be drawn concerning the effects of growth.

One possible criticism of the design is that the resulting "large" groups of 12 subjects are still relatively small by organizational standards. In a firm with 12 employees, for example, coordination would typically be achieved easily through direct communication and personal contact. However, by not allowing any communication between subjects – other than through their strategy choices in the game – the complexity of the coordination problem faced by each group resembles the complexity of coordinating activity in much larger groups in real organizations. Therefore, the two-person game without communication might be more analogous to a small office with less than 20 employees who do communicate and meet regularly. The 12 person groups without communication, on the other hand, are more likely to resemble firms with several hundred employees that do have limited communication channels available than they are to resemble 12 person groups in real organizations – particularly given the difficulty previously observed with achieving coordination in laboratory groups larger than ten. This point is made by Weick (1965), who argues:

> As size increases, several things happen: subgroups form, communication is more difficult, and hierarchies grow taller and more explicit. To reproduce a "large" organization, one or more of these three characteristics can be added to the experimental situation. Although these three characteristics do not exhaust the accompaniments of size, they are representative, manipulable, and common in existing definitions of organization. Thus, they increase the correspondence between experimental and field conditions. (Weick, 1965, p.210)

Another reason for dismissing the above criticism is that the experiments are intended to address whether growth is a means for solving large group coordination failure. In order to answer this question, the experiments need to identify one group size where coordination is not difficult and one where it always fails. Then the experiments need only address whether efficient coordination is improved in the large groups when they are grown relative to when they start at a large size. The results reported in Table 3 show that the group sizes used in this experiment do, in fact, satisfy that criterion. Therefore, as long as there are parallels between the coordination problem in the experiments and problems faced by organizations, the success in groups that began at a size of 2 and were subsequently grown to a size of 12 in the experiments provides an insight into how large firms might solve their coordination problems through growth.

In addition, the experiments are deliberately oversimplified. The goal is not to create a rich lifelike replication of growing firms, but instead to strip away all the inessential details to focus on the strategic uncertainty facing employees in such firms when new members come in, and everyone desires to coordinate but choosing high effort actions is risky.[34] Moreover, the experiments are intended to build on previous research on weak-link games. In order to do so, it is necessary to change only a few design variables at a time – in this case, introducing growth. Finally, simple experiments provide a necessary baseline to which other features can be added in further research.

Another possible criticism of the design is that the only mechanism helping a group coordinate as it grows is the growth process itself. Therefore, the experiments ignore the usefulness of communication (March and Simon, 1958; Thompson, 1967; Heath and Staudenmeyer, 1999), different organizational forms (Leavitt, 1962; Chandler, 1962; Scott, 1998), and specialized integrating units or employees (Lawrence and Lorsch, 1967) in improving coordination as a firm grows. There are several reasons why these alternative mechanisms were not included in the experiments and why they might not always work in real organizations.

First, as mentioned above, the experiments were intended to study only the effects of growth. In order to do this, it is necessary to hold as much possible constant except for the growth treatment variable. Therefore, while implementing several changes aimed at improv-

[34]Weick (1965) provides similar and additional reasons for why experiments on organizations often require a very simplified version of the real situation.

ing coordination at the same time might more realistically reflect the practices of growing firms, this would make it difficult to isolate the effects of managing the growth process alone.

A second and more important reason is that some of the mechanisms may be too costly to attempt. For instance, it is difficult if not impossible to successfully implement large changes in the structure of an existing organization. Similarly, it may be very costly to conduct a large-scale implementation of new forms of communication or to create entirely new positions aimed at coordinating activity. All of these changes would require extensive employee re-training and may present coordination problems themselves if some employees persist in doing things the old way.

A related reason why the alternative mechanisms might not be used is that they may not always be effective. For instance, there is experimental evidence that one-way communication only partially improves efficient coordination in simple stag hunt games (Cooper, DeJong, Forsythe and Ross, 1993) and that it does not improve coordination in large groups playing the weak-link game at all (Weber, Camerer, Rottenstreich and Knez, 1998). The benefits of communication can also be limited by problems of interpretation (Heath and Staudenmeyer, 1999). In order for communication to be effective, there has to be a well understood common language regarding what is meant by different statements. If this is not satisfied, then interpreting communication itself becomes a coordination problem. Communication is not the only one of these mechanisms that may prove ineffective. Structural adjustmenst such as having subjects play the weak-link game in a circular arrangement in which each subject interacts locally with only two other people rather than the whole group (thereby segmenting the group into several small overlapping groups) do not improve coordination on the efficient equilibrium (Keser, Berninghaus and Ehrhart, 1998). Therefore, while growing firms do often use some of these other mechanisms to reduce coordination problems, the fact that they are costly, difficult to implement, and do not always work makes it worthwhile to study the effects of growth separately.

In addition to the above experiments in which the growth path was pre-determined, a second set of experiments was conducted in which one participant was randomly selected to act as a "manager" and determine the growth path. This subject was placed in a separate room from the remaining subjects and an experimenter carried information between the two rooms. The game that the other participants would be playing was described to the manager (again framed in the context of a project completion), who was instructed that he or she would be responsible for selecting the size of the group for all periods after the first. In the first period, the group size was fixed at 2 and this was the smallest size that the manager was allowed to pick in any period. These experiments lasted 35 periods to give the managers plenty of time to experiment with growth. The manager was told that his or her earnings in each period would be determined by the number of active participants and by the group minimum (completion time). Table 4 describes the possible earnings for the manager.[35] Note

[35] The earnings are determined according to the following formula (rounded to the nearest cent if necessary):

that, for any group size, the manager is better off when the group coordinates efficiently. Also, the manager's payoff is higher when efficiently coordinated groups are larger, but the opposite is true for inefficient groups. Therefore, the manager has an incentive to create a large group, but only if it is coordinated successfully.

Number of	Completion Time (weeks early)						
participants	1	2	3	4	5	6	7
2	0.00	0.02	0.04	0.06	0.08	0.10	0.12
3	-0.03	0.01	0.04	0.07	0.10	0.13	0.16
4	-0.05	-0.01	0.03	0.07	0.11	0.15	0.19
5	-0.08	-0.03	0.03	0.08	0.13	0.18	0.23
6	-0.10	-0.04	0.02	0.08	0.14	0.20	0.26
7	-0.13	-0.06	0.02	0.09	0.16	0.23	0.30
8	-0.15	-0.07	0.01	0.09	0.17	0.25	0.33
9	-0.18	-0.09	0.01	0.10	0.19	0.28	0.37
10	-0.20	-0.10	0.00	0.10	0.20	0.30	0.40
11	-0.23	-0.12	-0.01	0.11	0.22	0.33	0.44
12	-0.25	-0.13	-0.01	0.11	0.23	0.35	1.00

Table 4: Manager's payoffs (in dollars)

Following the manager's determination of the group size in each period, a group of up to 12 subjects played the game in the same format as in the other experiments. The instructions for these subjects were the same as before, except that they were now informed that the number of active participants would be determined at the beginning of each period by

$$\pi = \frac{n(min - 3.5)}{100} + 0.05$$

except for the payoff when the group size is 12 and the minimum is 7. Since the goal was for managers to attempt to reach this outcome, a large bonus was awarded for achieving it.

the manager. The manager would select a number, and then the participants whose numbers were 1 through that number would play the game.[36]

In addition to addressing the main hypothesis of the paper, these experiments also allow a test of whether the subjects randomly assigned the role of managers are aware of the need for slow, controlled growth.[37] In addition, the growth paths generated by the managers allow us to further investigate the effectiveness of varying growth paths. These experiments were conducted between June and October at the California Institute of Technology. Subjects were graduate and undergraduate students with little or no formal training in game theory. The experiments lasted about 2 hours.

Finally, four control sessions were conducted to ensure replication of previous results. In these sessions, 12 groups of subjects played the game for 12 periods. The game was similarly framed in the context of a project completion and personal contribution times. However, no mention was made of growth or of participants not actively participating in any rounds.

[36]The one other difference with experiment 1 was that the manager was given the option, at the beginning of each period, to randomly reassign participant numbers. This was intended to allow the manager to "restart" the group in case the first few participants became stuck at a bad equilibrium. Previous results indicate that this does occasionally happen (though rarely) in small groups (see Table 3).

[37]Note that these experiments are also subject intensive and financially costly since 13 subjects are required to obtain one data point: a manager's success or failure. One possible solution to this is to study the managers separately, giving them feedback that is either artificially constructed by the experimenter or determined according to some model developed from the data from the experiments with pre-determined growth paths. Economists are typically opposed to using deception in experiments, though, so the first option can be ruled out. The second option requires large amounts of data to be able to determine feedback in all contingencies. However, this is a possibility for future work. Particularly since several simulation programs already exist (usually used as part of the MBA curriculum) in which students "grow" companies (see, for instance, Graham, Morecroft, Senge, and Sterman, 1992).

The results for these control sessions will be presented first, since it is important that they replicate the large group coordination failure previously found. Subsequently, the sessions for each of the two types of growth experiments will first be discussed separately and finally the aggregate results will be analyzed.

4.2 Results

4.2.1 Control sessions

Four control sessions (n = 48) were conducted using undergraduates at both Stanford (2 sessions) and the California Institute of Technology (2 sessions) between February and December 1998. The results of these experiments are reported in Figure 1, which presents the minimum choice across all 12 periods for each session. In addition, the solid line indicates the average of the minima in all four control sessions.

(Figure 1 about here)

Overall, the results replicate previous experimental results on large groups playing weak-link coordination games. The minimum converges to 1 in all four control groups. The solid line in Figure 1 indicates the average of the session minima and the average of all subjects' choices is also given. Note that both the average choice and the average of the minima consistently decrease and end up at or near one by the final periods. Note also that the average choice is initially high, indicating that many subjects are initially selecting high effort levels but that the minimum is nonetheless low since it is sensitive to outliers.

The results of the control sessions indicate that the expected result of coordination failure in large groups is obtained. Thus, if the growth sessions establish more successful coordination (minima greater than one), the main hypothesis that controlled growth can lead to less large group coordination failure will be supported.

4.2.2 Pre-determined growth paths

Seven sessions with pre-determined growth paths (n = 84) were conducted between January and March 1998. Four sessions were conducted at Stanford using graduate and undergraduate students and three sessions were conducted at UC Santa Cruz using undergraduate students. It is important to note that each session of 12 subjects making 22 choices represents one data point, since the group either succeeds in coordinating efficiently or fails. While a thorough statistical analysis of the results will be done in a later section, there are clear regularities that can be observed by examining the individual session data and from which initial conclusions can be drawn. Thus, in this section the behavior in individual sessions will be analyzed and subsequently the aggregate results of both types of experiments will be statistically examined to firmly establish results.

The goal of these experiments was to explore the possibility that growth can lead to more efficiently coordinated large groups. Therefore, each of the growth paths used was selected with hopes that it would be slow enough to create a large group that behaved more efficiently than large groups had in earlier experiments and in the control sessions. The principles driving the choice of this path were based on the results of the formal model in Weber (2000b), which showed that slower growth stochastically improves coordination. According to this model, slow growth can be implemented by adding only a few players at a time and by allowing more time between growth periods or "spurts", particularly initially. Therefore, the growth paths were designed to first establish repeated successful coordination in the group of size two (by allowing them to play several periods before adding more participants) and then to add players in a slow and regular manner. Thus, with one exception (the last two players added in growth path 3), the growth paths add only one player at a time. Figure 2 shows the three growth paths used in these experiments.[38]

(Figure 2 about here)

Figures 3 through 5 present the minimum choices for sessions 1 through 7. Each figure also presents the corresponding growth path.[39]

[38]Note that growth paths 2 and 3 differ only in period 18.

[39]The choices in the final two periods (21 and 22) are not reported here because there is often a strong end of experiment effect in these games, in which subjects change their choices in the final period (perhaps to punish or do better that others, or perhaps because they believe that others will do so – in which case doing so is a best response). While this phenomenon is interesting, this paper is not concerned with what occurs in the final rounds (after growth is completed), but rather with coordination during and immediately after growth.

Both sessions 1 and 2 (growth path 1) began with six periods in which only participants 1 and 2 played. As predicted based on earlier results, these two-person groups reached efficiency (in both sessions, the minimum was 7 in periods 5-6). However, when a third participant was added in period 7, the minimum dipped below 7 in both sessions. In session 1, the minimum was 6 in periods 7-8. When a fourth participant was added, in period 9, the minimum fell further to 5 and stayed there in period 10. When a fifth participant was added, in period 11, the minimum fell to 4. This pattern suggests an interesting conjecture. Earlier research showed that precedents often matter dramatically, in the sense that a group expects the minimum in one period to be the minimum in an upcoming period. That is, the previous choice establishes a strong precedent that is reinforced by subsequent actions. In session 3, however, players seem to be inferring a precedent from the relation between changes in structure (group size) and changes in behavior. The fact that the minimum fell by one when group size increased from 2 to 3, and from 3 to 4, seems to create a precedent that "when we grow the minimum falls by 1," which is self-fulfilling in later periods.[40]

(Figures 3 - 5 about here)

Behavior in session 2, however, shows a different pattern. In that session the minimum was 7 in the two-person group in periods 5-6, but the minimum fell to 5 when a third player

[40]Notice that while the minimum falls to 1 (inefficiency), the collapse is slow and regular. This contrasts with previous results and the control data where the collapse is typically much more rapid.

was added in round 7. The minimum rose to 6 in the next round, which indicates a possible recovery to an efficient minimum of 7, but a fourth player was added in round 9 and the minimum fell back to 5, where it remained – even when the group reached a size of 12. Note that while the minimum is not at the maximum of 7, a minimum of 5 is still much more efficient than the usually observed minimum of 1 in large groups. Thus, the fact that the minimum for a 12 person group is 5 in session 2 provides support for the hypothesis that growth can lead to successful coordination.

Because the first transition lowered the minimum from 7 to 5 in session 2, but then the minimum recovered to 6 in the next period, the question arose of whether full efficiency (a minimum of 7) could be reached by allowing the three-person group to recover by playing more periods before growing further. This was explored in growth path 2, which begins with five periods of 2-person play, followed by four periods of 3-person play, to give the 3-person group more time to recover from any drop in the minimum after the 2-to-3 group size transition.

Sessions 3 and 4 used this growth path. In session 3, the minimum in the two-person group is reliably 7 for all five periods, then drops to 5 when the third person is added, and stays there. When more players are added, the minimum stays at 5 until period 17, when the 10th player enters and chooses 1. While the minimum falls to 1 when the group reaches a size of 10, the fact that it remains at 5 until then provides some additional (though modest) support for the successful controlled growth hypothesis. In session 4, the two-person group was again able to coordinate efficiently. In this session, however, when the third person was added the minimum continued at 7 and remained there through the entire growth path. Efficient coordination was obtained in all periods and an efficient group of size 12 was obtained. The results of this session provide strong evidence of successful growth.

Sessions 5 through 7 were conducted at UC Santa Cruz. These sessions used growth path 3 which is identical to growth path 2 except that participant 12 enters at the same time as participant 11.[41] In session 5, the two-person group coordinated efficiently in periods 3-5. Efficient coordination continued until period 14, when the seventh participant entered and the minimum fell to 4 and then 3 the next period, where it remained. While a drop in efficiency occurred when group size reached 7, the minimum did not fall the whole way to 1. This again provides some evidence that more efficient coordination in large groups can be obtained using growth. Behavior in session 6 was initially very similar. The minimum was 7 through period 13 when 6 subjects were participating. When the seventh participant was added, the minimum fell to 5. It then continued to fall by one every period. While the minimum eventually reached 1, the decline was much more regular and gradual than in the control data. In session 7, the two person group was not able to coordinate on the efficient equilibrium. Instead, the minimum was 6 for all first five periods. The minimum continued to be 6 through period 12. In period 13, the sixth participant entered and selected

[41] This modification was made because of the concern that selecting one individual to be the last entrant might create greater incentives for this participant to want to punish other players.

1, lowering the minimum. The minimum then went up to 4 and remained there through the 18th period, when the final two participants entered. It then dropped in the next two periods to 1. Thus, while efficient coordination was not maintained through all the periods, a large group with a minimum higher than one was obtained.

This first part of the analysis, though mainly a casual examination of behavior in individual sessions, nonetheless helps shed light on several behavioral regularities. First, while efficient coordination does not occur in all cases, efficiency (measured by the value of the minimum) is higher for large groups than in previous experiments. In only three of the seven sessions is the minimum initially 1 for the groups of size 12 – after having already played several periods in large groups (of size 11, 10, etc.). In the other four sessions the minima are 3, 4, 5 and 7. In the following period, efficiency declines in only one of the sessions (the minimum falls from 4 to 3 in session 7).

In addition, in all the sessions that end up at a minimum of 1, the minimum is higher at least through a group size of 9. This higher level of efficiency for groups of size 9 (the minima are 2, 5, 5, 7, 3, 3, and 4) is surprising in light of the fact that the minimum was always 1 for the large groups (nine or larger) in Table 3.[42] Thus, there is support for the hypothesis that starting with a 2- person group, which reliably reaches efficiency, and adding players slowly enough, enables much better coordination than starting with large groups.[43]

[42]While Table 3 reports the fifth period minima, the minima in the first period were not as high as in the sessions reported here and there was never a minimum of 7.

[43]In addition, the results of the experiments by Knez and Camerer (1994) which showed that "merging"

Second, it appears that early experience with growth is important in determining subsequent success. In sessions 2 through 7, the minimum did not drop when the fourth person was added compared to what it was when the third participant entered. In these groups, the minimum was 5 or greater through at least period 12, indicating that subjects may have learned that controlled growth was possible (at least for a while). In session 1, however, the minimum dropped both of the initial times the group grew and continued to drop with growth, indicating that the initial experience with growth led subjects to believe that the group could not grow successfully.

Third, the results of session 1, in which efficiency declined steadily, suggest that players may form "higher-order" precedents based on not just levels of previous play (e.g., expect the previous minimum to be the minimum again), but also on the relation between levels of previous play and group sizes or transitions. The fact that the minimum falls by one unit when a third person is added, and falls again by that same amount when a fourth person is added, seems to create a belief that adding a person leads the minimum to fall by one (which is self-fulfilled when the fifth, seventh, ninth and tenth people are added, though not when the sixth and eighth are added). This kind of behavior had not been observed in previous work because nobody had changed structural variables repeatedly from period to period, in

two three person groups leads to coordination failure (the minimum fell to 1 80 percent of the time) indicate that growth can be too rapid. This provides additional evidence that controlled growth can play an important role in obtaining successful coordination in large groups. Note that the minimum for a group of size 6 was 1 in only one of the seven sessions in experiment 1.

a way which allows formation of higher-order relational precedents. However, it is impossible to make any generalizations based on the results of this session alone.[44]

The results of these sessions indicate that controlled growth can help solve the problem of large group coordination failure. However, the growth paths used do not always succeed in creating large, efficiently coordinated groups and, in fact, in only one of the sessions did the minimum remain at 7 throughout. Given the difficulty of obtaining successful growth, an interesting question is whether subjects are aware of the need for slow, regular growth paths and, if so, whether they can discover more effective growth paths than those used in these experiments. A second set of experiments addresses this question by endogenizing the growth path.

4.2.3 Endogenously determined growth paths

For the experiments in which the growth path is determined by a manager, four sessions were conducted using 52 subjects. These experiments were conducted at the California Institute of Technology. While the number of sessions provides data on the choices of only four managers, the results provide interesting insights into the managers' cognition of the need for controlled growth as well as further evidence supporting the main growth hypothesis. Again, the results will first be examined by looking at behavior in individual sessions. In the

[44] There is even more convincing evidence of this result, however, in experiment 2.

next section, the aggregate results of both experiments will be analyzed more rigorously.

The growth paths employed by the four managers (sessions E1 through E4) are presented in Figure 6. The important thing to note is that all four managers initially grew the groups quickly. In the first period, managers were constrained to a group size of two, but in the next period, all of them added at least three new players. It is also worthwhile to note that two of the four managers (sessions E1 and E4) subsequently implemented much slower growth paths. In order to more closely analyze the behavior of individual managers, it is worthwhile to examine the individual session data. Figures 7 through 10 report the results (growth path and minima) for each of the endogenous growth sessions.

(Figures 6 - 8 about here)

Figure 7 presents the results for session E1. The minimum choice in the first period was 6, which represents a high level of efficiency. In the second period, the first period in which the manager determined the group size, the manager raised the group size to 6. The minimum remained at 6, but then dropped to 5 when the manager increased group size to 9 in the next period. While group size remained at 9 in period 4, the minimum fell to 4 and remained there for several periods while the manager varied the group size between 8 and 12. At a minimum of 4, the manager earned \$0.11 per period for a group of size 12, but this is less than he could earn by having a group of size 2 coordinating efficiently. The manager then proceeded to "fire" several participants and start over with a group of size 2.

This succeeded in raising the minimum back up to 6. The manager then added one more participant, which did not reduce the minimum, and remained at a group size of 3 for 4 periods. He then increased the group size by one every period until reaching a group size of 12 in period 25. The minimum remained at 6 through the remaining periods.[45] Thus, while the manager initially failed to realize the need for controlled growth and added participants too quickly, he started over with a group size of 2 and proceeded to add participants at a slow enough rate to create a large group playing a minimum of 6.

In session E2 (Figure 8), the first two participants coordinated efficiently on 7 in the first period. When the manager increased the group size to 5 in the next period the minimum remained at 7, but it then fell to 6 when the manager added 5 more participants in the next period. The manager then tried to raise the minimum by varying the group size (between 8 and 12) and reassigning participant numbers in the next few periods. However, while the minimum initially remained at 6, it fell to 1 in period 8 (when group size increased from 10 to 12). The manager then decreased the group size to 8 and the minimum went back up to 5. During the remaining periods, the manager tried to increase the minimum by varying the group size. Although the smallest size he then selected was 4 (until the last period), when he did so the group almost always recovered to a minimum of 6. However, the manager did not let the group remain at a size of 4 for more than one period and tried to increase the group immediately by adding at least 2 more participants. This resulted in a drop in the

[45]The minimum fell to 1 in the final period. This was the result of one participant's choice and is an example of the end game effect discussed earlier.

minimum every time. The manager continued to vary the group size (with a resulting effect on the minimum) for the remaining periods, but was unable to find a growth path allowing him to create a large, efficiently coordinated group.

The results of session E3 (Figure 9) are similar. In this session, the minimum was 3 in the first period. Rather than allowing the two first participants time to coordinate, however, the manager immediately increased the group size to 7 and the minimum remained at 3. He decreased group size to 2 in period 4 – increasing the minimum to 6 – but then proceeded to add participants right away, leading to a drop in the minimum. Similarly to the manager in session E2, this manager varied the group size (between 3 and 10) in the remaining periods, increasing the group size too quickly after any increase in the minimum.

(Figures 9 & 10 about here)

The behavior of the manager in session E4 was like that of the manager in session E1 in that he also grew the group too quickly initially, but then subsequently used slower growth successfully. The minimum was 6 for the group of size 2 in the first period. The manager then tried to grow the group too quickly (increasing the size to 10) and the minimum fell to 1 in the next period. The minimum remained at 1 while the manager tried group sizes of 12, 7, and 5 unsuccessfully, and then moved up to 3 when he set group size at 3. The manager then increased the group size by one and allowed the group of size 4 enough time to raise the minimum to 6. When group size again increased by one, the minimum again fell to 3, but then rose to 7 as group size remained the same for several periods. For the remainder of the experiment, the manager always added only one or two participants at a time and the minimum fell to either 3, 4, or 5 every time the group grew. However, after the initial drop following growth, the minimum increased by exactly 1 in every period in which the group size remained the same. This continued until period 33, when the entire group of 12 participants coordinated successfully on 7. Thus, after initially growing too quickly, the manager in session E4 discovered a growth path slow enough to lead to efficient coordination.

The results of session E4 also point to an interesting phenomenon similar to the reaction to growth in session 1 of the first experiments, in which the minimum fell exactly by one when the group grew. In all periods after period 7, the group reacted in the same manner to growth. Every time the group grew, the minimum fell, but then increased by exactly one for every period that the group did not grow. Thus, similarly to session 1, a self- enforcing norm was established concerning how the group would react to growth.

While there are only four sessions, it is again possible to draw some preliminary conclusions based on an examination of the data. First, in all four sessions the subjects participating in the role of manager initially grew the groups too quickly, resulting in coordination failure. This points to a lack of cognition of both the difficulty of coordinating large groups – which is consistent with previous research (see Weber, et al., 1998) – and the need for controlled growth to solve coordination failure.[46]

Following this initial failure, however, there is evidence that some subjects learned to grow using a slower and more regular approach. While two of the managers failed to realize this and continued to grow too quickly, the other two started over with small groups and then grew slowly (never adding more than 2 participants at a time) to create large groups coordinated on minima of 6 and 7. The two managers that started over and grew slowly had higher earnings than the managers that did not (managers in sessions E1 and E4 earned \$7.39 and \$7.37, respectively, while the managers in sessions E2 and E3 earned \$4.28 and \$2.54).[47] It is interesting to note that the growth path used by the manager in session E1 is very similar to the growth paths used in the sessions with pre-determined growth paths.

There is also further support in these experiments for the hypothesis that slow, regular growth can lead to successful coordination in large groups. In the two sessions in which the managers started over at a small size and grew slowly (sessions E1 and E4), the result was

[46]It should be noted that though the managers in these experiments are students and not professional managers, students at Caltech are not a representative student population in that they are well above average in quantitative and analytical skills. In addition, many of them go on to fill important management positions and start high-tech firms shortly after leaving Caltech. Therefore, while it would be interesting to examine whether this result extends to a population of professional managers or MBA students (which is a possibility for future research – particularly if it is possible to conduct the one subject experiments discussed earlier), the use of this population allows for claims of at least some external validity.

[47]While the managers in sessions E2 and E3 did "poorly" in that they tried to grow the groups too quickly and therefore failed, they still made positive profits because they were always able to decrease the size of the group which usually led to improved coordination (or at least less negative earnings). In fact, while the average per period earnings of both the successful managers was \$0.211, this number was \$0.097 for the other two managers. The latter number is close to the average per period earnings (\$0.087) that would have resulted if the payoffs in Table 4 had been applied to the results from experiment 1 (in which the experimenter served as manager). That these two numbers are close is surprising since in experiment 1 the group was constrained to grow even if the minimum fell to one and this was not true in experiment 2.

large groups that coordinated on high minima. In addition, the failure to succeed of the other two managers indicates that the rate of growth is important in obtaining efficient large group coordination.

Finally, the results of session E4 provide strong additional support for the previously mentioned conjecture that experience with growth plays an important role in subsequent reactions to growth. In this session, as in session 1, subjects responded not just to the previous minimum, but to what happened to the minimum as the group grew. Therefore, a precedent was established indicating that every time the group grew, the minimum fell, but that in every period that the group did not grow, the minimum went up by exactly one. The strength of this precedent and the extent to which it was a self-reinforcing belief held by <u>all</u> players is evident in the last few episodes of growth. When the group grew to a group size of 10, the minimum fell to 5. In the next two periods, all 10 players played first 6 and then 7. When the group grew again to a size of 12, the minimum fell to 4.[48] In the next three periods, all 12 players played first 5, then 6, and then 7. This points to a strong coordinating effect of previous experience with growth.

The above examination of behavior in the two experiments supports the notion that growth can lead to higher efficiency in large groups and points to additional interesting re-

[48]Since this was the first time that the group had grown successfully by more than one, there was noticeable agitation (e.g., fidgeting, longer response time) by several participants in the experiment. This points to the importance of the precedent since players were nervous because they had never experienced this kind of growth before and were therefore uncertain about what the outcome would be. As a result, the minimum fell below (to 4) what it had fallen the last few times the group grew (to 5).

sults. However, in order to establish more conclusively that growth works, the aggregate results must be examined more carefully.

4.2.4 Aggregate Results

In order to test the main hypothesis of the paper – that groups that are grown slowly are more efficiently coordinated than groups that start off at a large group size – it is necessary to look at the aggregate data. The sessions with pre-determined growth paths are all examples of 12 person groups that were grown slowly since they started off at small group sizes (2) and grew in size by only adding one or two players at a time to a large size (12). In addition to these sessions, however, two of the sessions with endogenous growth paths also provide data on groups that were grown slowly. In both sessions E1 and E4, following initial unsuccessful rapid growth, the managers started the groups over at small sizes (2 and 3, respectively) and then grew the groups slowly – never adding more than two players at a time – until reaching a group size of 12. Therefore, these two sessions are pooled together with the results of the first experiments in Table 5.

Table 5 presents the growth paths (number of active participants) and minimum choices by period for each of the grown groups. For each of the five growth paths used (two of which were determined by the managers in experiment 2), the results of groups growing at that rate are presented.[49] Of the resulting nine 12 person groups, two were successfully coordinated

[49] All of the periods are not included in the table for sessions E1 and E4 since these experiments lasted

on 7 for more than one period (though the final two periods for session E4 in which all 12 players selected 7 are not included in the table). There was one 12-person group in which the minimum was 6, another in which it was 5, and another in which it was 3. In another group, the minimum at size 12 was initially 4, but it then fell to 3 and then 1. In the remaining three groups, the minimum was 1 by the time group size reached 12 and it remained there. While a majority of the groups are not efficiently coordinated, the fact that two are playing minima of 7 and another three are coordinated at levels of efficiency higher than 1 indicates that growth does work, even if only limitedly. In addition, as mentioned before, the majority of groups are also playing higher minima at intermediate group sizes (such as 9) than they did in previous experiments.

A better test of whether growth works or not can be obtained by comparing the distribution of choices between the grown groups and the control sessions, in which group size was constant at 12. In order to make this comparison, however, it is necessary to decide on a valid comparison period. The control groups played as large groups for 12 periods. The grown groups all started off at small sizes and did not reach a group size of 12 for several periods. The earliest period in which a grown group reached the maximum size was period 18. Also, the grown groups did not all reach that size in the same period. The key question, then, is when the comparison should be made. A reasonable comparison is to compare the

longer and the focus is on what occurred when the groups reached larger sizes. The complete data for these sessions is available in Figures 12 and 18.

	Period																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Growth path 1	2	2	2	2	2	2	3	3	4	4	5	6	7	8	9	10	11	12	12	12
Session 1	7	7	7	7	7	7	6	6	5	5	4	4	3	3	2	1	1	1	1	1
Session 2	6	5	7	6	7	7	5	6	5	6	5	5	5	5	5	5	5	5	5	5
Growth path 2	2	2	2	2	2	3	3	3	3	4	4	5	6	7	8	9	10	11	12	12
Session 3	7	7	7	7	7	5	5	5	5	5	5	5	5	5	5	5	1	1	1	1
Session 4	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Growth path 3	2	2	2	2	2	3	3	3	3	4	4	5	6	7	8	9	10	12	12	12
Session 5	6	6	7	7	7	7	7	7	7	7	7	7	7	4	3	3	3	3	3	3
Session 6	7	7	7	7	7	7	7	7	7	7	7	7	7	5	4	3	2	1	1	1
Session 7	6	6	6	6	6	6	6	6	6	6	6	6	1	4	4	4	4	4	3	1
Growth path E1		2	3	3	3	3	4	5	6	7	8	9	10	11	12	12	12	12	12	12
Session E1		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Growth path E4		5	6	6	6	6	7	7	8	8	8	9	9	10	10	10	12	12	12	12
Session E4		5	4	5	6	7	5	6	5	6	7	5	6	5	6	7	4	5	6	7

Table 5: Minimum choices by period for "slow growth" sessions

control groups in period t with the t-th period in which the grown groups played as groups of size 12. In this case, subjects in both treatments have $t-1$ periods of play in 12-person groups and therefore share a similar history. This is still not a perfect comparison since the grown groups have a much longer history that includes the periods spent growing, and the question remains about when the comparison should be made (i.e., what the value of t should be). Should the first period of play in the control groups be compared to the first period in which the grown groups reached the maximum size? Another issue has to do with how many periods as 12-person groups there is data for in the grown groups. Since the maximum number of periods (after reaching a size of 12) in which there is data for all the grown groups is four, and since by period 4 the majority of 12-person groups have coordinated on some equilibrium, this was decided upon as the appropriate comparison point. Table 6, therefore, compares the distribution of subject choices in the four control sessions and the nine growth sessions in the fourth period in which participants played at a group size of 12.

		Control		Growth	
Choice	7	2	(4.2 %)	20	(18.5 %)
	6	0	(0.0 %)	15	(13.9 %)
	5	5	(10.4 %)	13	(12.0 %)
	4	16	(33.3 %)	8	(7.4 %)
	3	5	(10.4 %)	10	(9.3 %)
	2	9	(18.8 %)	9	(8.3 %)
	1	11	(22.9 %)	33	(30.6 %)
Total		48		108	
Minima		1,1,1,4		1,1,1,1,3,4,5,6,7	

Table 6: Distribution of subject choice in fourth period as 12-person groups

The first thing to note is that the number of subjects choosing 1 is high in both conditions (11 of 48 in the control sessions and 33 of 108 in the growth sessions). While this number is higher for the growth sessions, this is not surprising since in three of the nine grown groups the minimum was 1 even before the group reached a size of 12. In these groups, therefore, there were more previous periods for subjects' choices to converge towards the inefficient equilibrium than in the control treatment.

Just as interesting, however, is the difference in the distribution of high choices (6 or 7) between the two treatments. In the control sessions, only 2 of 48 subjects (4.2%) played either a 6 or a 7, while this is true of 35 of 108 subjects (32.4%). Therefore, the number of subjects playing the two highest strategies is much higher in the grown groups than in the control sessions.

The distributions of choices in Table 6 are significantly different when compared using a Chi-Square test ($\chi^2_{(6)} = 29.97$, $p < 0.001$). In addition, when the cumulative choice frequencies (which can be derived from Table 6) are compared, the null hypothesis that the distributions are the same can be rejected in favor of higher choices in the grown groups at the $p < 0.01$ level (Kolmogorov-Smirnoff one-tailed, $\chi^2_{(2)} = 11.85$) .[50] Some additional support for the hypothesis that growth leads to greater efficiency can be found in a comparison of the minima in the fourth period after growth. These minima are reported in the final row of Table 6. Note that the minimum in all but one of the control sessions is 1 and that while the minimum in four of the growth session is also 1, the minimum is greater than 1 in the remaining five session and there are grown groups with minima of 6 and 7. A Mann-Whitney U test of the minima yields the test statistic $z = 1.09$. While the corresponding p-value of 0.13 is greater than the usual significance levels, it must be noted that this test and p-value are extremely conservative since they treat each group of twelve subjects as just one observation.

As the results of the above tests indicate, choices in the fourth period as a group of size twelve tend to be higher in the grown groups than in control groups. When each subject's

[50]Both of these tests, however, rely on the assumption that all the observations in each treatment are independent. In this case (as in much of experimental data) this assumption is not satisfied since the choices of all of the subjects in a session in a particular period are affected by the common history shared by these subjects. Therefore, the level of significance reported by the statistics is exaggerated.

choice is treated as an independent observation, the difference is highly significant. However, this significance is exaggerated as the assumption of complete independence between subjects' choices is most likely unreasonable for subjects with a shared history in the same group. Therefore, as the last test indicates, when each session is treated as only one observation, the results are not quite significant. However, this extreme assumption of complete lack of independence results in a test that is too conservative and underestimates the true significance level.

A better test of the difference between the two conditions has to control for the lack of independence between subjects' choices, but also has to recognize that this dependence is limited. Therefore, the test should control for the within session subject dependence without treating all subjects within a group as one observation. This interdependence in subject choices arises because of the shared history that the subjects in a session have jointly observed in previous periods. Therefore, one possible test is to consider the difference between subject choices by treatment in a period while controlling for dependence arising from shared history, recognizing that subjects' choices are conditionally independent once the effect of shared history is removed. Using Crawford's (1995) dynamic model of behavior in weak link games allows for the inclusion of this dependence. In Crawford's model, a player i's choice in period t (x_{it}) can be described as a partial adjustment between her own previous choice (x_{it-1}) and the minimum in the previous round (y_{t-1}), along with a drift parameter

(α_t) and an idiosyncratic error term (ϵ_{it}):[51]

$$x_{it} = \alpha_t + \beta_t y_{t-1} + (1 - \beta_t) x_{it-1} + \epsilon_{it} \quad (1)$$

Subjects' choices in period 4 after growth (period 4') are not independent because players have jointly observed all the previous minima with other players in their session. However, controlling for all the prior common information within a session, subjects' choices are conditionally independent. Therefore, one way to control for lack of independence in period 4' choices is to include the effect of the previous minima (for periods 1' through 3'). In the growth sessions there are periods before period 1' (since period 1' is actually the first period at a group size of 12) and interdependence in subject choices may arise due to shared history in these prior periods, However, most of the effect of this interdependence on period 4' choices can be captured in subjects' period 1' choices. Therefore, the lack of within-session independence in subjects period 4' choices is controlled for in a regression of period 4' choice on a treatment dummy variable and on the three previous minima as well as on choice in period 1'. This model was estimated using ordinary least squares. The estimated coefficient for the treatment dummy variable (growth = 1) was 0.496 and was significantly greater than zero ($t = 2.199$, $p < 0.03$) indicating that subject choices were higher in the growth

[51] Crawford's model is used rather than the model from the previous section, because Crawford's model is a more complete description of behavior in order-statistic coordination games. Since the goal here is to test the difference between the two treatments while controlling for non-treatment sources of variation, the more descriptively complete model is used. For the purpose of this section, the only difference between the two models lies in the drift parameter. Omitting it from the analysis does not change the results.

treatment, even after controlling for the shared history.

Taken together, the above analysis convincingly indicates a positive effect of the growth treatment on subject choices. While the lack of independence between subject choices within sessions complicates the analysis, the result persists when controlling for this interdependence.

There is also evidence that the rate of growth mattered. All four of the managers in experiment 2 encountered problems after growing the groups too quickly. The two successful managers (sessions E1 and E4) were able to grow efficiently coordinated groups only by starting over at a small size and then growing slowly. The other two managers did not attempt to do so – but instead continued to try to grow quickly – and subsequently failed. The correlation between change in group size (number of players added or dropped) and change in the minimum in experiment 2 is -0.497, indicating that the minimum decreased when group size increased by a large amount.[52]

The above tests support the result that grown groups are more efficiently coordinated than groups that start off large. Even without examining the aggregate results, however, the fact that two 12-person groups were able to successfully coordinate on the efficient equilibrium (a result never previously obtained) shows that growth can work to help solve large

[52]This correlation is -0.166 for experiment 1.

group coordination failure.

5 Discussion

Coordination problems have been recognized as an important issue for firms. The weak-link coordination game models the most punishing forms of coordination – where the lowest level of any input has a strong effect on efficiency. This coordination problem is one frequently encountered by firms. Efficient coordination in this game becomes much more difficult as the number of players grows, indicating that increased coordination may become a more important problem as organizations grow. Previous experimental results indicate that it is impossible for large groups to coordinate on the efficient equilibrium.

Motivated by the observation from the business world that firms are often said to "grow too fast," by an example of a firm that grew slowly specifically to solve coordination problems, and by a model suggesting that slow growth may work to solve large group coordination failure in the weak-link game, this paper has argued that the growth process itself can be managed to alleviate large-group coordination problems. Experiments were conducted to test this hypothesis. Evidence from the experiments indicates that growth may play an important role in determining the ability of large groups to coordinate efficiently. Starting with small groups that play efficiently and adding players slowly enough resulted in groups of size 12 at efficiency levels above the usually observed minimum. In fact, some of the minima in large groups reached the highest levels of efficiency. This was true for groups starting out small and growing slowly both by growth paths determined by the experimenter and by growth paths determined by a subject in the role of manager. The endogenous growth experiments also indicated that slow growth may be critical, as all four managers initially grew too fast and met with failure. However, some of the managers learned to grow slowly from experience. In addition, there is evidence that subjects' initial experiences with growth may be critical for determining subsequent success with growth and that previous experiences with growth may set precedents concerning what will happen the next time a group grows.

While the results of the experiments indicate that growth plays an important role in determining success or failure in large group coordination problems, the generalization of these findings to organizations must be taken with caution. The laboratory is an artificial environment and subjects participating in simple experiments do not correspond directly to actors in complex organizations. In order to establish a connection, evidence must be found in the functioning of real organizations. The example of Southwest Airlines provides a convincing case in which the growth process itself appears to have been successfully manipulated to avoid coordination problems. However, this is just one case and a more exhaustive empirical study would greatly complement the results of this paper. For instance, a more complete analysis might involve comparing the growth strategies of several firms across industries in which the importance of coordination varies. One conjecture is that growth paths would matter more (in determining success or failure) in industries where coordination plays a more central role, such as the airline industry.

It is also important to remember that controlled growth is just one of the means by which organizations avoid coordination problems due to size. Recall that in addition to growing slowly, Southwest also expended great effort on ensuring that new employees would fit well within the culture. Thus, socialization mechanisms for new entrants can play an important role in determining the ability of the organization to coordinate activity successfully. This is noted by Weick and Roberts (1993) who argue that "The quality of collective mind is heavily dependent on the way insiders interact with newcomers." (p. 368) In fact, in the experiments above, an important element of the design is that future entrants to the game are sitting in the same room as those currently playing and this is commonly known by all. If these entrants are not aware of the history of outcomes (or if the current players are not aware that the entrants know the history), the strength of the socialization process is weakened and growth is likely to be less successful.

Aside from socialization and training, better communication can help members of an organization remain successfully coordinated as the organization grows. Heath and Staudenmeyer (1999) stress the importance of direct physical communication in helping groups solve coordination problems. However, since the best way to achieve this is to place people in the same location, it is not always possible throughout the growth process. Therefore, it may also be necessary to implement better long- distance communication technology. Recent work has examined how decision making is affected by different forms of communication (Kiesler and Sproull, 1992; Hinds and Kiesler, 1995). Allowing varying forms of communication in the above experiments might also yield important insights into how the ability of an organization to coordinate successfully is affected by different modes of communication and information transmission. This becomes particularly important as firms expand geographically.

In spite of these caveats and the need to conduct additional studies to address the above questions, the contribution of this paper is obvious: there exists at least one clear solution for large group coordination failure. This solution is a careful planning of the growth process itself.

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Figure 1. Choices in Control Treatment

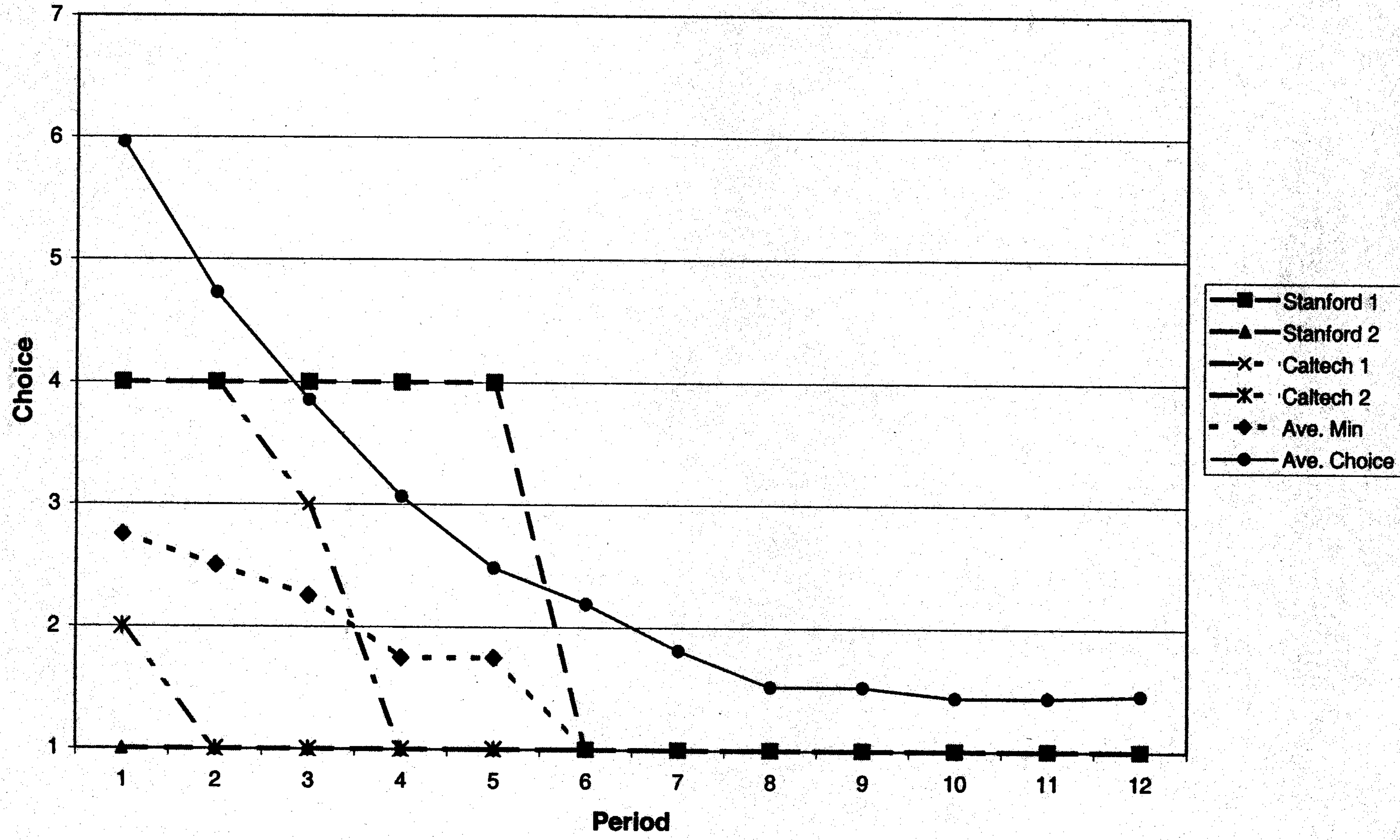

Figure 2. Pre-determined growth paths

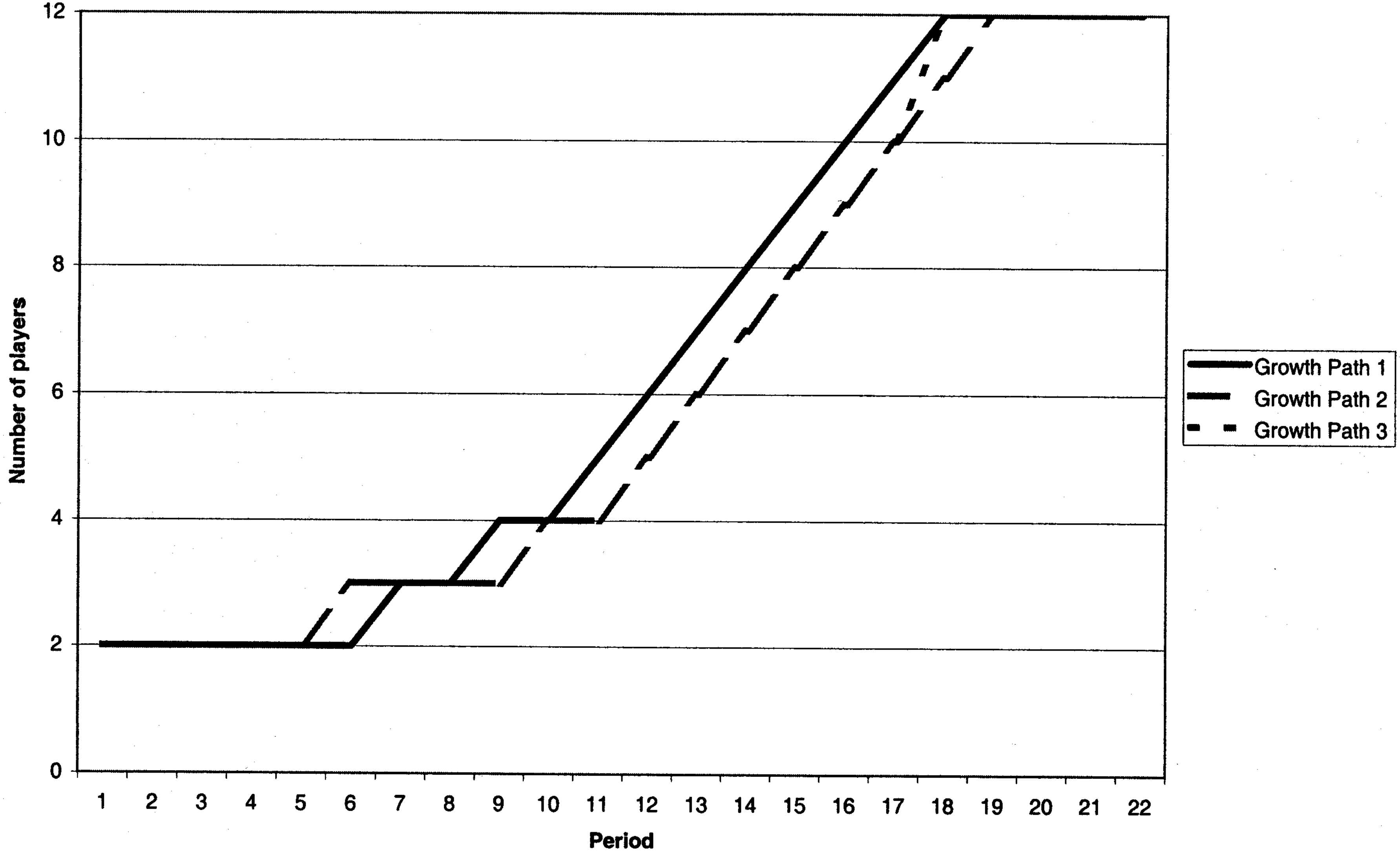

Fig 3. Growth path and minimum choice for sessions 1 & 2

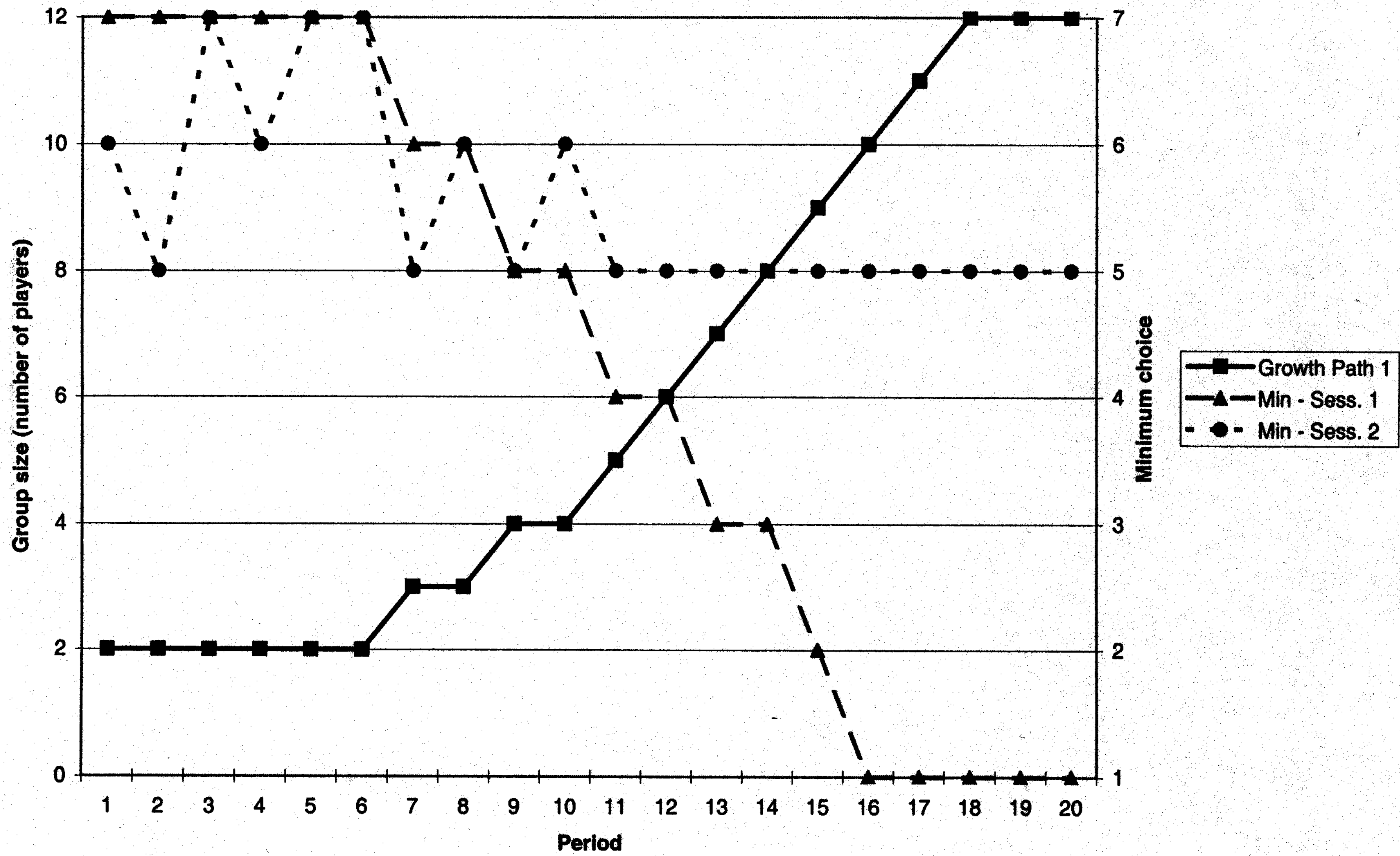

Fig 4. Growth path and minimum choice for sessions 3 & 4

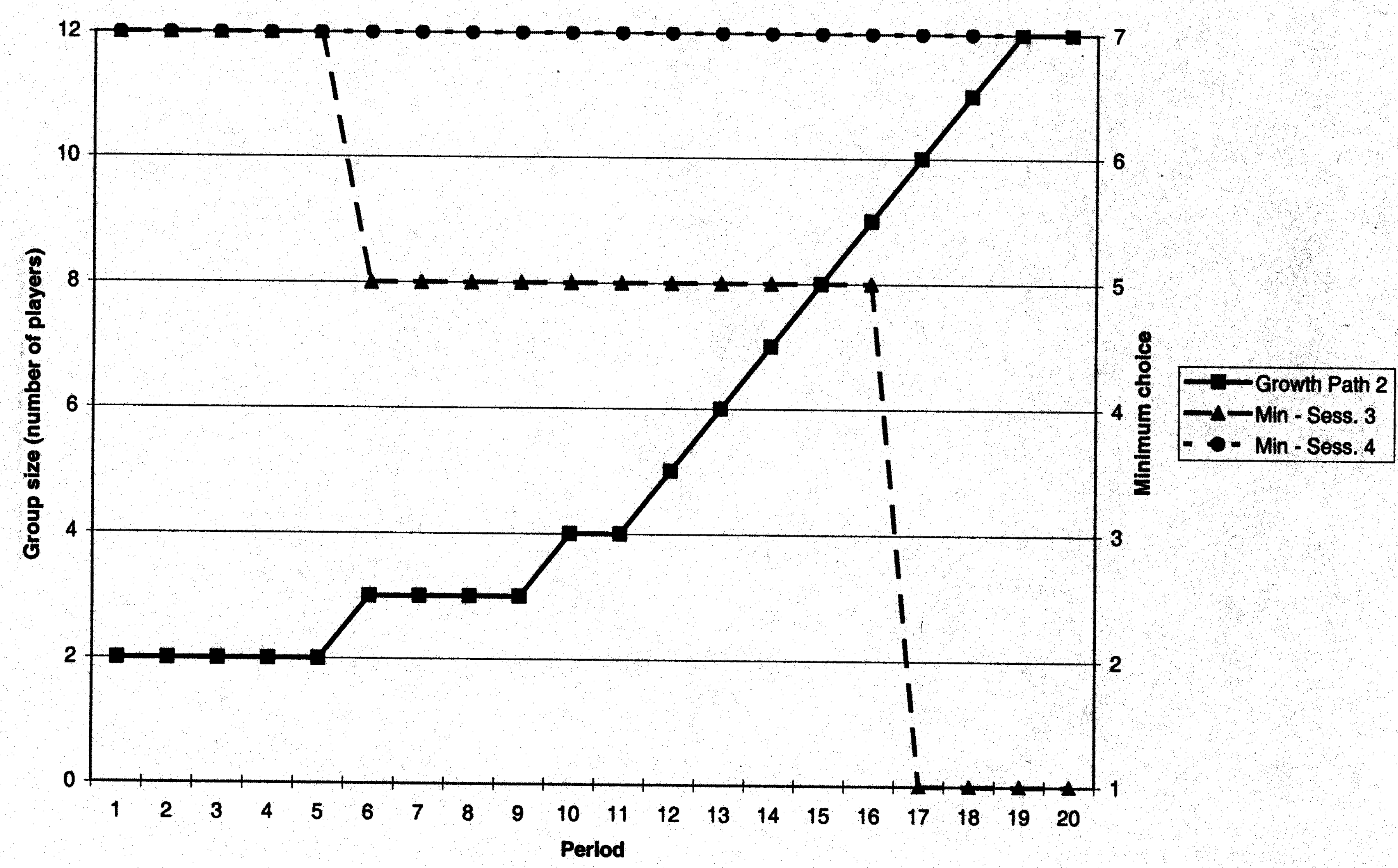

Fig 5. Growth path and minimum choice for sessions 5 - 7

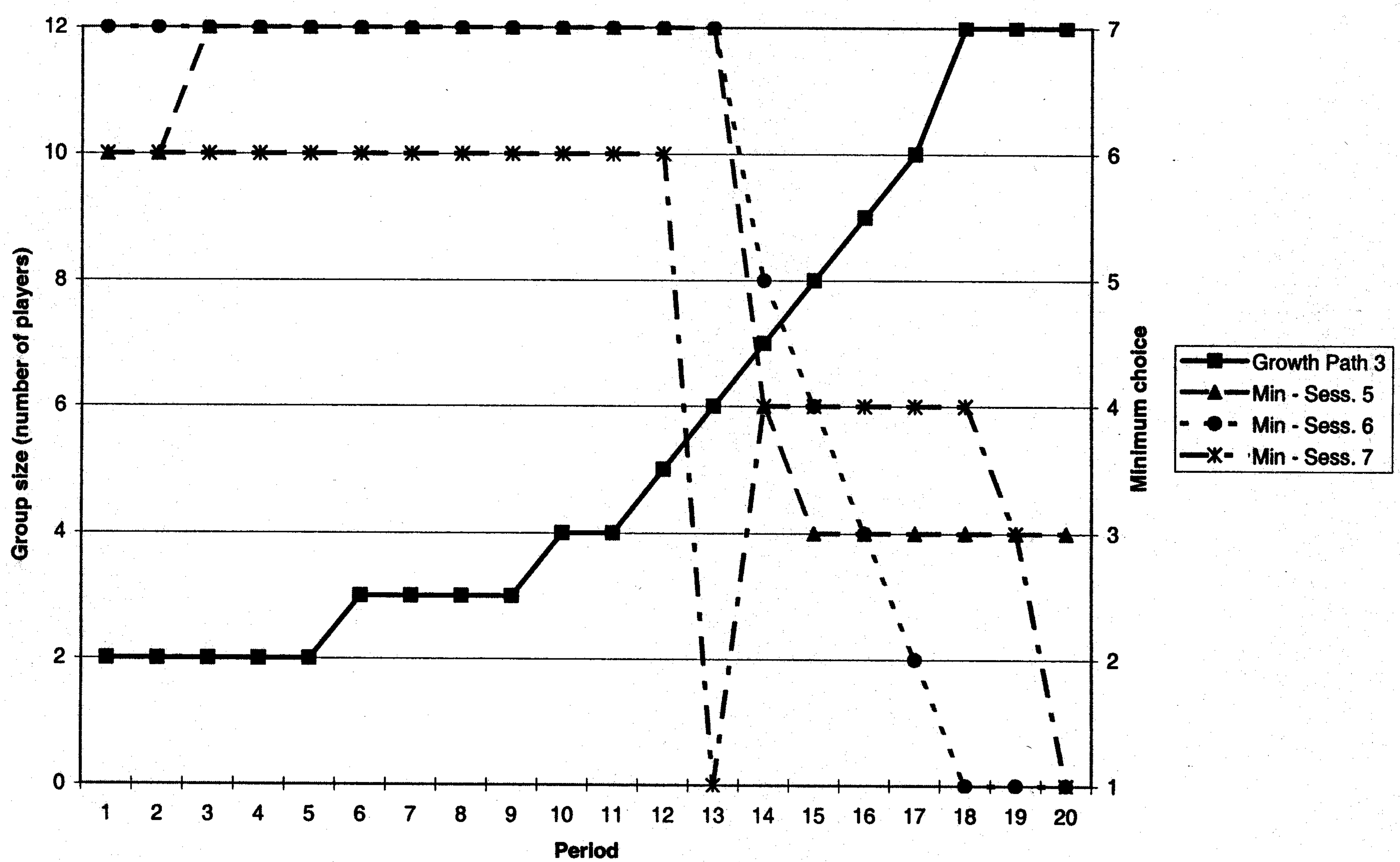

Figure 6. Endogenously determined growth paths

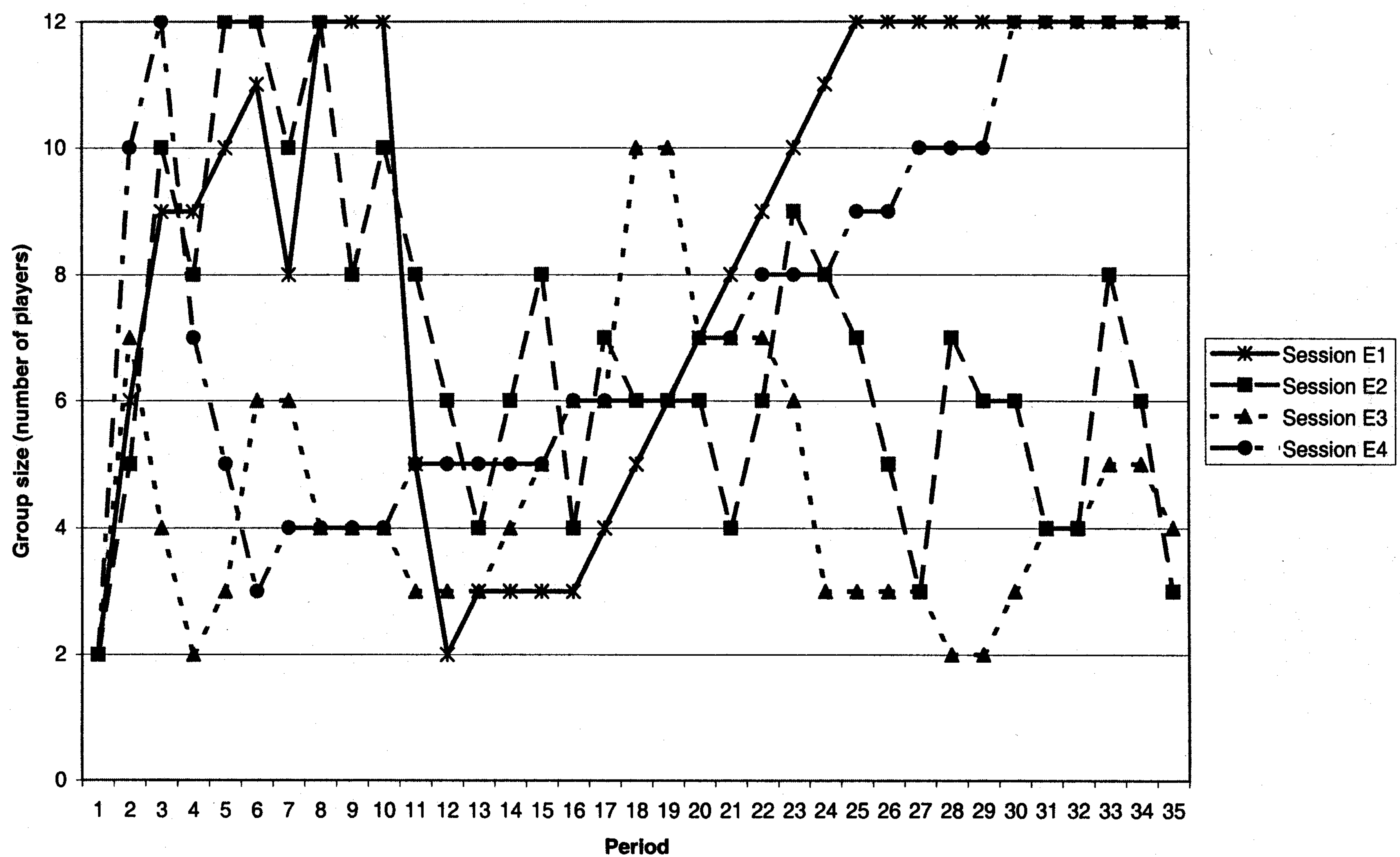

Figure 7. Endogenous growth path and minimum choices in Session E1

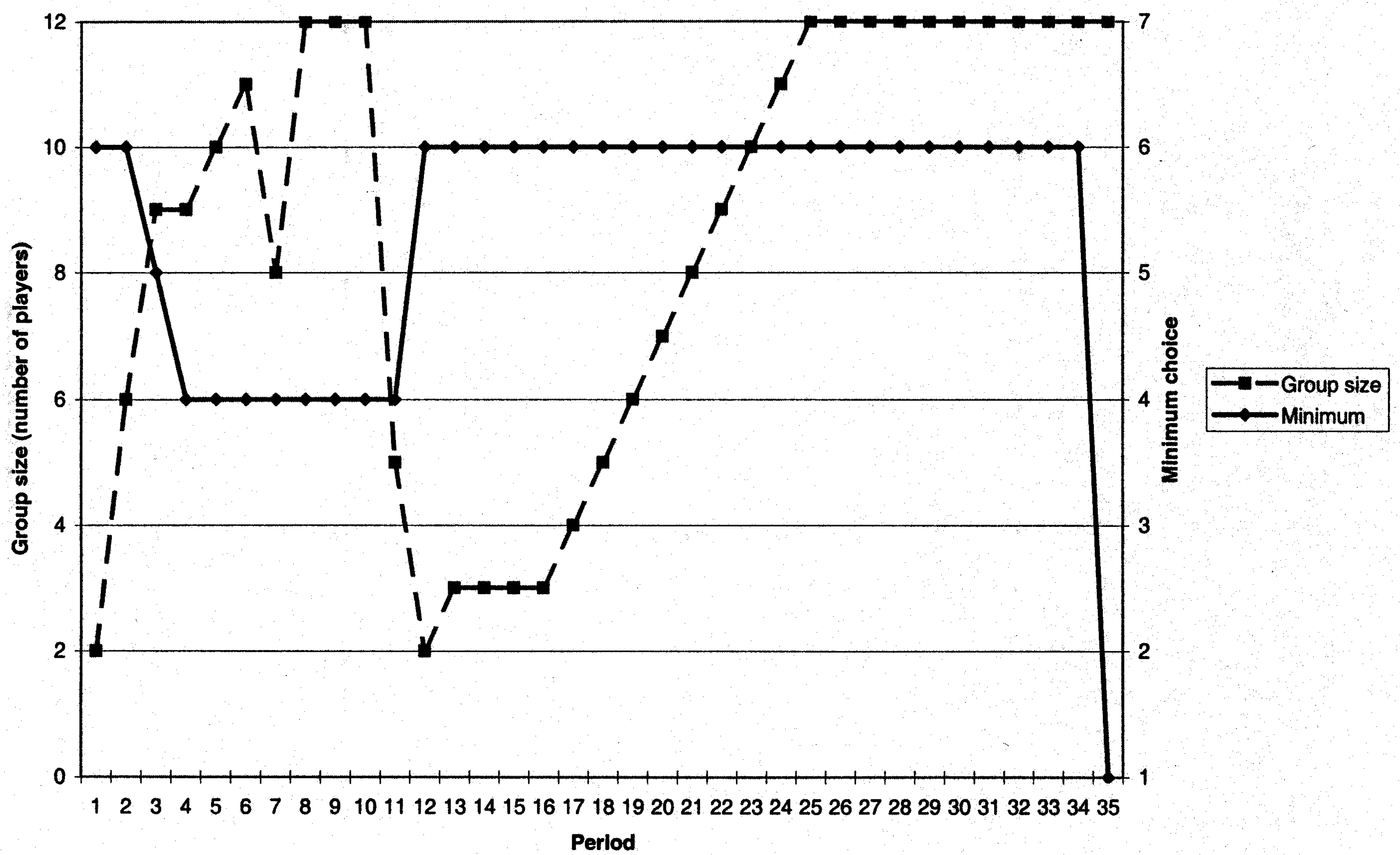

Figure 8. Endogenous growth path and minimum choices in Session E2

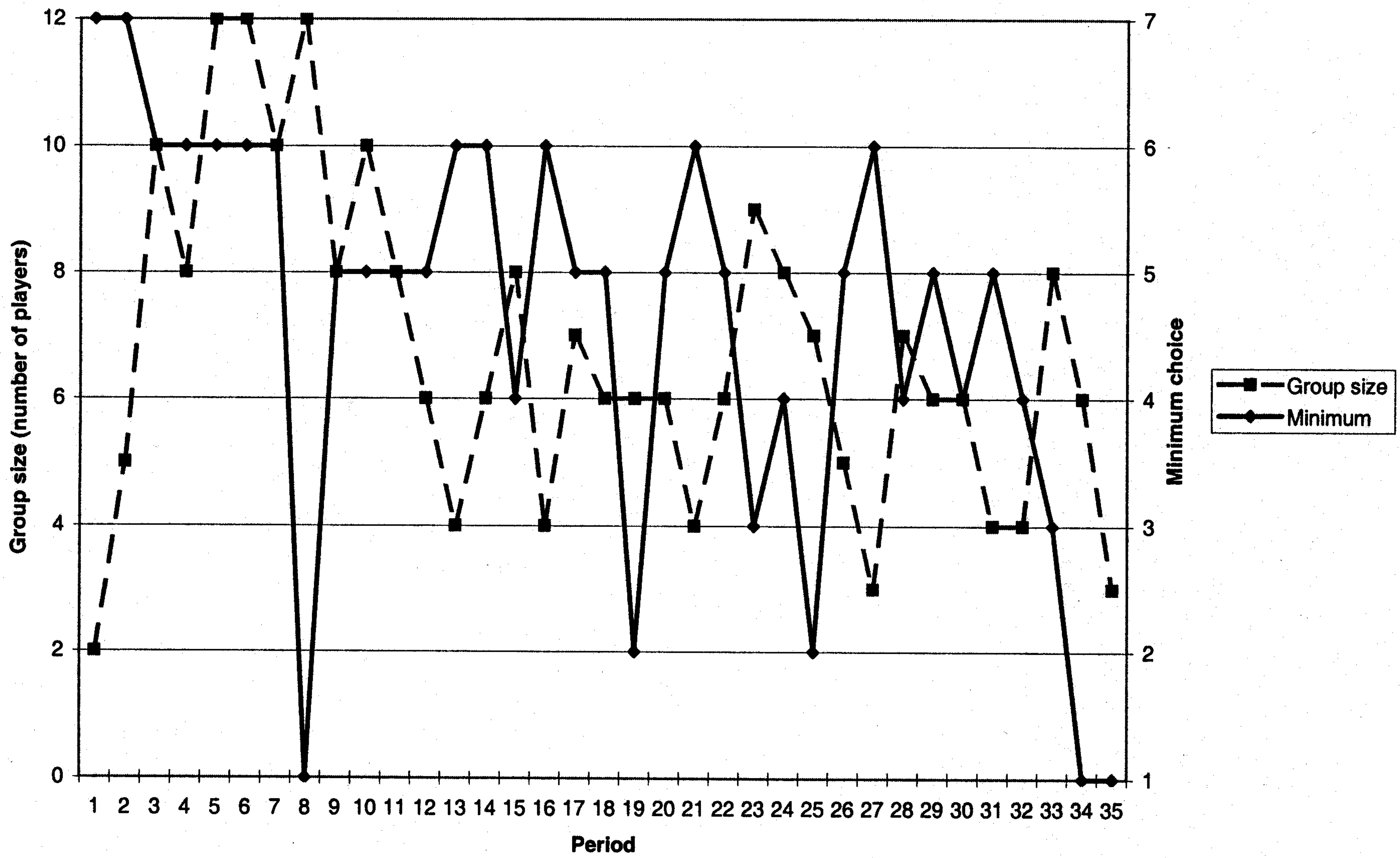

Figure 9. Endogenous growth path and minimum choices in Session E3

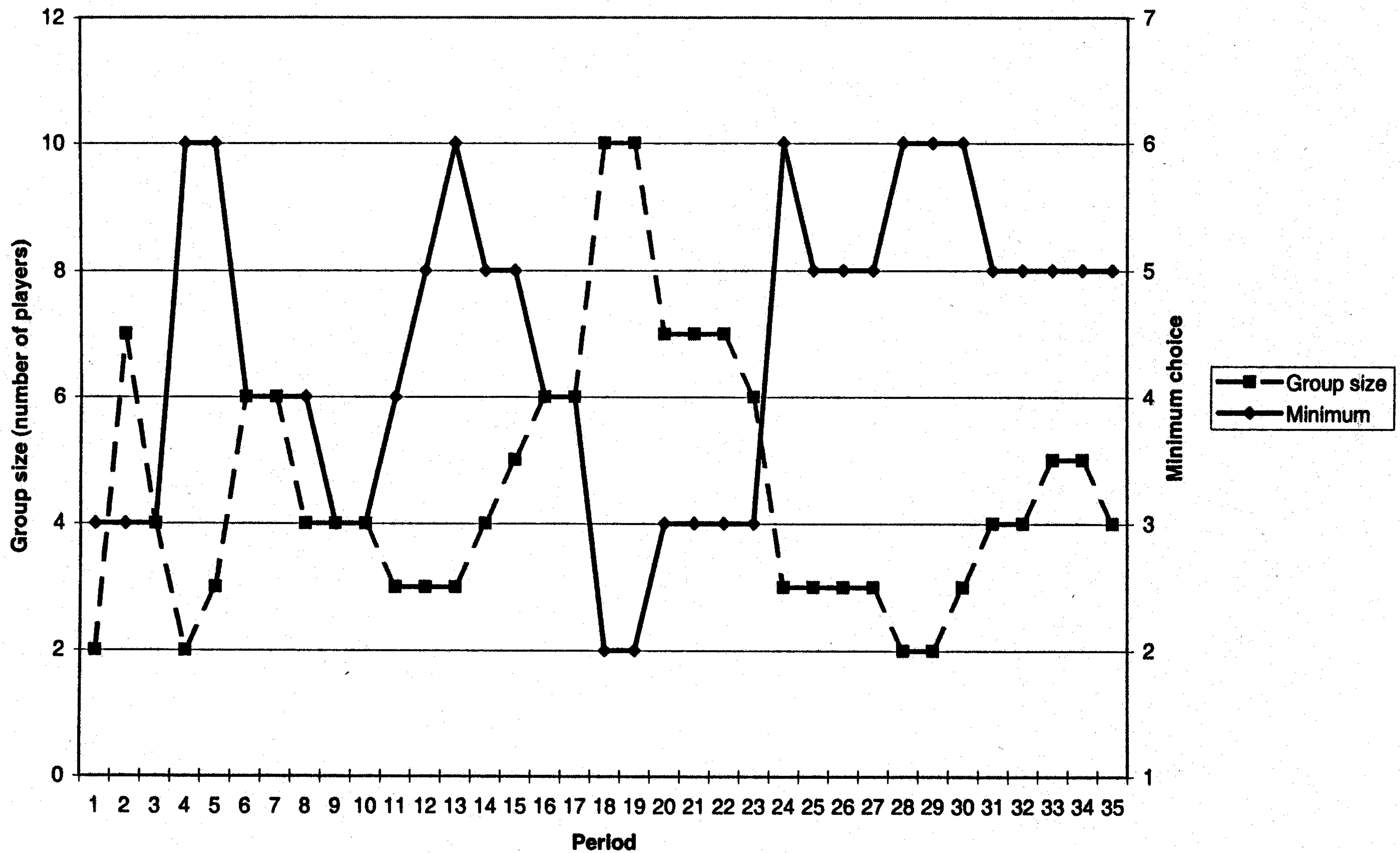

Figure 10. Endogenous growth path and minimum choices in Session E4