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ECONOMIC MODELING TRIGGERS MORE EFFICIENT PLANNING: AN EXPERIMENTAL JUSTIFICATION*

ABSTRACT. Consider a firm as an organization that needs to efficiently coordinate several specialized departments in an uncertain environment. Decision making involves collective planning sessions and decentralized operational processes. In this setting this paper explores the role of economic modeling through an experimental game. Results support the idea that economic modeling favors higher performance. Economic modeling facilitates the emergence of common knowledge and the decomposition of a group decision problem into individual decision problems that are meaningfully interrelated.

KEY WORDS: economic modeling, interactive rationality, planning, organizational learning.

JEL CLASSIFICATIONS: D83, L2, M21.

1. INTRODUCTION

The formalization of decision making in organizations has been strongly influenced by the work of March and Simon (1958). Rational behavior covers two distinct activities: search activity and routinized behaviors. The first one consists in framing the problem and discovering alternatives, while the second one is quite similar to a computer routine.

Another important characteristic of decision making in organizations is that agents are interdependent. The very nature of the firm consists in having several specialized and

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complementary departments generate a joint output (Alchian and Demsetz, 1972). Decision making in firms reflects this dual form of interdependence. It repeatedly involves both collective sessions, presumably to elaborate some coordination, and decentralized processes, within which each specialized department proceeds on its own. Planning and budgeting are representative of collective sessions while operations management are of decentralized processes. It would seem that the collective sessions be the natural time and space where the members of the organization could involve into a search activity. Decentralized decision making, while not excluding completely search activities, would be more typical of routinized behaviors.

This paper explores the role of economic modeling in the collective sessions. How is the eventual search activity of these sessions affected by economic modeling? How is the knowledge elaborated in the planning sessions incorporated in the routinized behaviors that go along decentralized decision making? Does the use of formalization generate a more efficient search that is, routinized behaviors leading to higher performance? A secondary question that is addressed concerns the learning ability of the organization. Does the fact that the organization relies on a formal device to generate its strategy influence its learning ability in face of a changing environment? These questions are investigated through an experimental game. The results globally support a positive answer regarding the link between formalization and efficiency and a more qualified answer regarding formalization and organizational learning.

These questions are related to the group decision making literature as such and to the more general literature on planning.

Consider first the group decision making literature. Munier (2003, in particular Section 4) reviews some important aspects of bounded rationality specific to this context as opposed to purely individual decision making. In the latter there are quite many experiments designed to support the bounded rationality assumption (such as the dependence to the menu question). In the former, the research focuses on the role of social interactions to generate the simplifying assumptions embedded into the decentralized routinized behaviors. The distinction seems to have been well perceived by Simon (1947) who was the first to coin the term "interactive" to specifically refer to bounded rationality in a group decision making context. With this distinction in mind, the routines now need to deal with expectations about the behavior of others, and may restrict one's own behavior considerably. It becomes important to know the origins of these mutual expectations, how this knowledge is stored in the organization and how the organization as such may eventually learn (Argyris and Schon, 1978). The notion of common knowledge elaborated by game theorists (Aumann, 1976) is helpful in this regard: it formalizes the degree to which A knows that B knows that A knows, etc. Common knowledge facilitates communication by allowing the decomposability of the group decision problem into separable interrelated mono-agent problems (Egidi, 1996). A number of experiments may be used to illustrate these ideas. Egidi, *opus cited*, develops an interesting card game in this regard, there are also many pure coordination matrix games that may be used (see Crawford and Haller, 1990 for further references) or many informal classroom examples around focal points (Shelling, 1960). The experimental game used in this paper has some distinctive features that make the analysis original and interesting: its theoretical solution can be interpreted as an economically meaningful decomposition of the group problem into individual ones. Yet this decomposition is complex enough so that it cannot be arrived at without some joint search activity. Thus the role of economic modeling to facilitate a relevant and efficient search activity can be easily traced. The fact that the experimental game involves several periods in a changing environment provides further insights about the learning process at work among the subjects.

As regards the more general planning literature, a widely accepted fact is that excessive formalization is detrimental to efficient planning (Mintzberg, 1994). Concerns may arise about the lack of credibility of the data to derive the optimal strategy, the dependence of this strategy on the selected data set, the lack of involvement of operational managers for an optimization process they may not understand and, finally, many decisions are eventually made outside the plan. However, as also noted by Mintzberg *opus cited* (p. 384), some degree of formalization may be helpful. A good formal system can "structure discussions" and act as "a tool to facilitate organizational learning". Such systems explicitly leave the operational managers in charge of the process while the strategist operates only as a catalyst. Johnson and Kaplan (1987) have also emphasized the progressive lack of relevance of traditional formal control systems. These systems based on accounting figures and mostly in the hands of controllers, progressively lost their connections with the physical operations of the firm. They focus on local and incremental approaches, while reactivity to external changes requires continual coordinated responses of the firm. The current orientation of the management control literature recognizes these pitfalls and proposes approaches to bypass them such as: a re-connection of physical and financial flows, an involvement of operations managers in the monitoring of management control systems, and tools facilitating internal communication. The general concept of interactive control systems developed by Simons (1995) builds on these ideas. Simons distinguishes "interactive control systems" from more traditional "diagnostic control systems". The former ones are relatively simple and technologically unsophisticated, but they receive continuous attention of the hierarchical structure to provide guidance and stimulate learning.

There is a limited overlap between the group decision making and the planning literatures. Ponssard and Tanguy (1993) have described an interactive system at work in a detailed case study and have explicitly related its features to the interactive rationality approach. Munier (2001) also elaborated a decision aid in that perspective. There some mutual formalization should be viewed as a way to enhance cognitive coordination rather than as a tool to identify the right decision in a prescriptive sense. This paper follows this line of thought and provides a laboratory experiment that can be used to test these important considerations in a somewhat realistic context.

Altogether this paper demonstrates the relevance of interactivity to interpret planning and decentralized decision making in firms. This conceptual framework, originally introduced by Simon, is characterized by search activities and routinized behaviors. This is made explicit in our experimental game through a form of economic modeling in which common knowledge plays the major role. It is shown that the level of common knowledge directly triggers the efficiency of the group decision process. This also explains why organizational learning may be incrementally easy but structurally difficult. These results have important normative implications for the design of planning and control systems.

The paper is organized as follows. Section 2 gives the empirical background and the practical issues that motivated the experimental game. The experimental set up is described in Section 3. Section 4 details the research methodology. This methodology relies on the theoretical solution of the game (Section 5) and on associated computer programs (Section 6) to be used to benchmark the observed behaviors. This analysis is carried on in Section 7 and the main research conclusions are discussed in Section 8. Section 9 concludes.

2. EMPIRICAL BACKGROUND OF THE EXPERIMENTAL GAME

The experimental game reproduces a standard business situation faced by firms when they move from a favorable to a less favorable environment. In a favorable environment the internal coordination problem can be solved under loose constraints: errors are mitigated by growth. In a less favorable environment, purchasing, production and sales have to be monitored more closely and errors may be quite costly.

Chandler's analysis of the Du Pont company is a well known example of such a situation (Chandler, 1962). In 1907, Du Pont was organized along strong functional lines and the professionalism of each specialized department was seen as a keystone of its success. However, when sales became less predictable due to the partial loss of the market of the Defense Department, the company took quite some time to re-coordinate its internal operations: sales dropped while the purchasing department kept buying much nitrate because of bargain prices. This coordination failure almost led to bankruptcy. Du Pont addressed this question by introducing some formalization in its planning system designed to limit the initiatives of each department. In 1920, Du Pont again had to face an important change in its environment with the definitive decline of its military sales and the failure of its diversification strategy. At that time, the re-coordination of its activities took the more drastic form of an organizational move towards the multi-divisional structure.

Similar situations appear constantly in firms. They are openly discussed in the business press (see for instance the recent report on Nokia by Reinhardt in Business Week, 2002). The case study described in Ponssard and Tanguy (1993) is another example. This company operated in the Champagne sector. It had experienced rapid growth until increased competition on the market place put the company at risk and required much more coordination of its activities. Some features of this context have been used to elaborate the experimental game.[1]

This discussion points out that the decision making process addressed in this paper is more closely related to operational planning than to strategic planning seen as portfolio management with capital budgeting, acquisitions or sales of assets.

3. THE EXPERIMENTAL GAME: DESCRIPTION AND SET UP

The firm consists of two specialized departments: on the one hand purchasing and production, on the other hand sales. It is managed by a team of two players, a *buyer* and a *seller* operating each department respectively. There are neither financial nor planning departments as such.

3.1. *Physical and financial flows*

Time is discrete and divided into periods. At each period, the firm buys some quantity of input at some input price, and uses it to produce some quantity of output which is available for sale at the next period. One unit of input generates one unit of output. At each period the firm sells some quantity from its inventory at some output price. There are production and inventory costs that are known to the firm. Prices are uncertain, they do not depend on the behavior of the firm. They are announced sequentially one period after the other. The firm cannot borrow. There are no dividends paid. The accumulated cash can only be reinvested in the firm.

3.2. *The group decision process*

It consists of two distinct processes: collective sessions and decentralized operations management. The two managers openly discuss their policy during the planning session but they do not know at that time the input and output prices of the ongoing period. Once the planning session is closed, no communication can take place between the two managers. The input price is revealed to the buyer and he or she decides the input quantity. Simultaneously, the output price is revealed to the seller and he or she decides the quantity of output to be sold.

Once the decentralized decisions have been made, the firm financial statement is automatically issued. The next period starts with a new planning session. Past financial results and the future policy may be discussed.

The game is played over 15 periods, labeled as 2001–2015 or as 1 to 15.

3.3. *The objective function of the firm*

The economic value of the firm is defined by adding the cash at hand and the current inventory valued at the output price averaged out over the latest five periods. A team is assumed to maximize the final value of the firm at period 15. There is no discounting. The economic value of the firm at period 0 is 5 252. To encourage growth and put some pressure on the teams, it is written down that the "stockholders" expect 15% as an average growth rate in the economic value of the firm.

Bankruptcy at any period introduces exogenous moves at the next period: no input is bought and all inventory is sold whatever the prices. Then the bankrupt team may proceed as usual.

3.4. *Information given to all the participants*

The game is played using an Excel spreadsheet which has been preprogrammed to generate the financial statements from the physical flows, the inventory and the cash at hand. The players have access to the formula so that they know exactly how it works. This is particularly important for the cost figures. The players also receive the financial statements of the firm completed over the five periods that preceded their arrival at the head of the company. This past information is reproduced Table I.

It is important to note that the production cost exhibits increasing returns to scale: let Q_i denote the input, the total production cost is given by the formula $120Q_i^{1/2}$ (which can be directly read in the Excel sheet), for $Q_i = 100$ the unit cost is 12. With an average selling price of 25 and an average purchasing price of 10 this leaves quite some room for profit. For $Q_i = 400$ the unit cost drops to 6.

It can be seen that the past prices are quite variables, some correlation may also be noted. There is no information whatsoever regarding future prices or trends regarding these prices.

It will be apparent that many players do not make all these inferences from the data given to them.

TABLE I

Financial statements over the five periods preceding the beginning of the game

Period		1996	1997	1998	1999	2000
Physical flows	Quantity of input purchased	100	124	180	140	140
	Quantity of output sold	100	95	129	125	145
	Inventory at the end of period	0	5	0	55	50
Prices	Input price	8,9	11,8	13,9	8,7	7,3
	Output price	21,8	29,5	34,0	22,3	18,9
Financial flows	Sales	2,180	2,803	4,386	2,788	2,741
	Purchasing cost	890	1,436	2,502	1,218	1,022
	Production cost	1,200	1,336	1,610	1,420	1,420
	Inventory cost	0	10	0	110	100
	Profit or loss (incl.30 for SG & A)	60	−37	244	10	169
	Cash at the end of period	60	23	267	277	445
Scorecard	Capital employed	950	1,545	2,769	1,973	1,832
	ROCE		−4	16%	0%	0
	Economic value of the firm	2,590	3,287	4,821	5,210	5,252

3.5. *Further information on prices disclosed progressively to the participants*

The complete sequence of prices is reproduced Figure 1. While the input price remains in the same range, the output price deteriorates. It will be more and more difficult to make profit unless the firm can operate at high volumes, which means that it grew quite strongly at the earlier periods. But growth implies some coordination to avoid bankruptcy.

3.6. *Experimental setting*

The rules of the games are distributed to the participants. A standardized oral presentation is made to explain the use of the Excel spreadsheet. Participants are encouraged to use the spreadsheet for simulations if they wish to do so. Participants in the experiment were not paid, they were students in managerial economics courses taught by the authors either in engineering or business schools during the 1999 and 2000

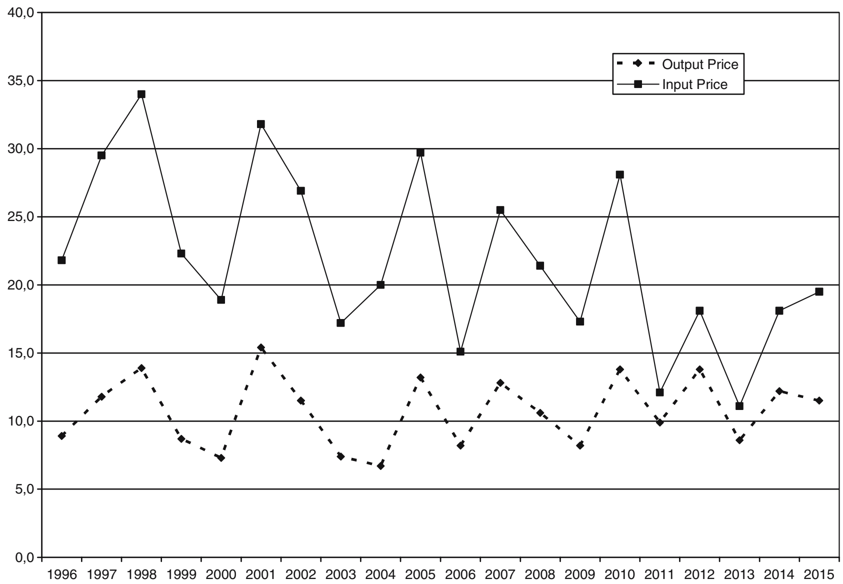


Figure 1. Sequence of input and output prices.

academic years. A Champagne bottle was offered to the winning team, excluding those teams who went into bankruptcy; a typical play would take three hours, each team playing at its own pace. The experiment has been run over a population of 108 teams labeled from team 1 to team 108.

3.7. *Retrieved information from the experiment*

The completed Excel spreadsheets are collected so that the decisions taken at each period can be analyzed.

Each team is also asked to answer an open questionnaire. This questionnaire has three parts. The subjects have to provide answers after the initial planning session, at the end of period 10 and at the end of play. The initial question is "Do you have a strategy and can you describe it?" The mid term question is "Do you want to change your strategy and why?" The question at the end is "Given what you know at this point, if you could replay the game, would you play differently?"

While the spreadsheets provide hard data, the open questionnaires are not so easy to quantify. Still they are important to distinguish between teams that have a strategy to those who don't and, if there is one, to have some ideas on how that strategy is formalized. It also provides some information on the learning process that takes place during the play. A more formalized questionnaire could have provided hints on what is at stake.

4. METHODOLOGY

The analysis is done in the context of interactive rationality as discussed in the introduction. The behaviors of the seller and the buyer during the decentralized operational processes are to be interpreted as routinized behaviors. These routinized behaviors will rely on a decomposition of the group decision problem into individual interrelated decision problems. The decomposition is based on the amount of common knowledge elaborated during the planning sessions. This is now made precise. A theoretical analysis of the experimental game is carried out. It will be shown that the Nash equilibrium may indeed be interpreted as a decomposition procedure which involves a high degree of common knowledge. Computer programs suggested by this procedure are designed and can be used to benchmark the observed routinized behaviors.

Much simpler computer programs may also be designed in which the players take a more myopic view of the game that is with no elaborated common knowledge.

The comparison between actual behaviors and these computer programs (both sophisticated and simple) shows that the interactive rationality framework applies. It is thus possible to analyze the experimental results by comparing the level of formalization during the search collective sessions. This will be used to test our major assumption: does economic modeling go with higher scores?

The theoretical analysis of the game is also useful to address our secondary question namely, the adaptation of the behaviors in face of a changing environment. As a matter of fact, as the game proceeds, the Nash equilibrium path radically changes in its construction at some point in time. Such a radical change is quite different from a simple revision of the parameters of a computer program. When discussing the observed behaviors over the 15 periods of play these two forms of learning can be easily distinguished. In the terminology elaborated by Argyris and Schön (1978) the radical change may be qualified as "double loop" learning while a simple adaptation of the behaviors, illustrated as a change in the parameters of a given computer routine, would be qualified as "single loop" learning. Our discussion will differentiate between these two levels of learning and will elaborate on its implication for planning in firms.

5. THEORETICAL ANALYSIS OF THE EXPERIMENTAL GAME

The game may be seen as a team consisting of two players, each player having some private information. As such it belongs to the class of team games introduced by Marschack and Radner (1972). This class of games has already been used to formalize the role of the organizational structure for decision making in firms (Aoki, 1986; Crémer, 1980).

Here, the time dimension makes the game stochastic, then bankruptcy may be seen as an absorbing state. Such a game may be solved through Markov strategies, with cash and inventory as the state variables. This solution is quite complex.

A simplified version of this game has been solved analytically (Ponssard et al., 2002). In this version the game involves only one period, there is no correlation in the prices, the cost function is reduced to a fixed cost in case of production, prior probability distributions on prices are uniform over two different fixed ranges, the objective is to maximize the economic value of the firm under a given constraint for the probability of bankruptcy. The game is solved for all values of the state variables. The results are now summarized (for convenience the results are expressed directly in the format of the experimental game to avoid unnecessary confusion).

5.1. *Notations, objective function and constraints*

- Q_i and Q_o refer to the input and output quantities, respectively,
- P_i and P_o refer to the random input and output prices, respectively, and P_i^* and P_o^* refer to the input and output prices privately observed, respectively, by the buyer and the seller, denote $\mathrm{E}(\mathrm{P_i})$ the expected value of P_i,
- $C(Q_\mathrm{i}) = 120Q_\mathrm{i}^{1/2} + 30$ is the total production cost including a fixed administrative cost,
- S stands for the initial inventory, so that $Q_\mathrm{o} \leq S$,
- T stands for the initial cash,
- S and T may be seen as state variables,

– The values of the state variables after one period of play are respectively:

  - $S' = S - Q_o + Q_i$
  - $T' = T - P_i^* Q_i - C(Q_i) + P_o^* Q_o$.

– Let $\varepsilon > 0$ be the bankruptcy risk, the objective function for the team is to maximize the expected value of $V(Q_i, Q_o, P_i, P_o)$, where $V(Q_i, Q_o, P_i^*, P_o^*) = T' + E(P_i)S'$ under the constraint Prob $(T' < 0) \leq \varepsilon$.

There is a family of Nash equilibria in this game that may be characterized as follows:

– Let θ be a positive parameter to be interpreted as the minimal amount of cash expected from the sales,
– There exist two triggering prices $P_i(\theta)$ and $P_o(\theta)$ that can be used to characterize the equilibrium strategies,

  - if $P_i^* \leq P_i(\theta)$ the buyer selects the maximal Q_i under the constraint Prob$(T - P*_i\ Q_i - C(Q_i) + \theta < 0) \leq \varepsilon$,
  - if $P_i^* > P_i(\theta)$ the buyer selects $Q_i = 0$,
  - if $P_o^* < P_o(\theta)$ the seller selects Q_o so as to satisfy $P_o^* Q_o = \theta$,
  - $P_o^* \geq P_o(\theta)$ the seller selects $Q_o = S$.

– Depending on the ranges for the input and output prices, the highest value for the team is obtained either for $\theta = P_o^{\min} S$ or $\theta = 0$.
– At period 1, the best equilibrium path should be initiated with $\theta = P_o^{\min} S$ and, from period 10 on, with $\theta = 0$.

5.2. *Interpretation of the Nash equilibria as a decomposition procedure*

Start with a simple idea. Independently of the bankruptcy constraint, the players would face a standard decision problem under uncertainty: the buyer should either keep the cash for future use or invest it all in purchases, the seller should sell everything now at the current price or keep it on inventory expecting a higher price. The interdependence between the players comes from the fact that current sales generate some cash that can be immediately used by the buyer to reduce the unit production cost, this may be extremely profitable due to the increasing returns assumption. An unjustified high expectation of sales on part of the buyer may easily lead to bankruptcy. Some coordination in strategies is appropriate. That this coordination problem can be completely solved through the parameter θ is a remarkable property of this game. Once the buyer and the seller have a joint expectation about the minimal amount of cash to be generated from the sales, a coordinated decomposition of the global maximization problem into two local problems is feasible. It makes the mathematical analysis transparent and accessible to an economic interpretation.

The equilibrium associated to $\theta = P_o^{\min} S$ corresponds to selling all inventory, or keeping some but without endangering the cash expectation on part of the buyer, and using the expected cash to reduce the unit cost. Note that if $P_o^* < P_o(\theta)$, the lower P_o^* the more the seller sells so as not to put the company at risk. This is not so intuitive and illustrates the high degree of common knowledge that goes with this equilibrium.

The equilibrium associated with $\theta = 0$ should be preferred when the initial conditions make less important the role of increasing returns as opposed to selling when output price is high and buying when input price is low. After a few periods, this equilibrium will necessarily lead to a "bang bang" policy: either the firm has only cash and waits until a favorable input price to buy or the company has only inventory and waits until a favorable output price to sell (or selling just enough to cover the inventory cost). Again, such a strategy involves a very deep understanding of the game and relies on a high degree of common knowledge, even if no bankruptcy may incur.

The former equilibrium shall be referred to as a *coordinated growth policy* while the latter one will be to as a *coordinated speculation policy*.

6. COMPUTER PROGRAMS DESIGNED TO PLAY THE GAME

As announced Section 4, computer programs based on this theoretical analysis are now designed. These programs range from sophisticated to myopic ones. The sophisticated programs are directly based on the preceding analysis, in particular on the coordinated growth policy. Similarly as the Nash equilibrium, they explicitly decompose the joint coordination decision program into two individual decision programs, but in a simplified way. The myopic ones are based on a limited and local understanding of the rules of the game, in particular the benefit associated with cost reduction through a joint monitoring of the bankruptcy issue is not addressed.

6.1. *Sophisticated programs*

These programs are based on a constant parameter k related to the risk that is assumed by the firm and a minimal selling price P_o^{min} updated period after period. Two cases shall be considered to define P_o^{min}.

- Case 1: without exploiting the observed correlation in the prices

P_o^{min} = Mean (P_o | latest five periods) – k Standard Deviation (P_o| past observations).

- Case 2: using the observed correlation in the prices

$P_o^{min} = P_i^*$ (Mean (P_o/P_i| latest five periods) – k Standard Deviation (P_o/P_i| past observations)).

In both cases the buyer and seller programs are, respectively:

- the buyer always selects the maximal Q_i under the constraint $T + P_o^{min} S - P_i Q_i - C(Q_i) \geq 0$
- the seller always selects $Q_o = S$.

6.2. *Myopic programs*

These programs combine a constant growth policy and a limited range for speculation. No explicit consideration is associated with the cash constraint. Let r and R be two parameters, $Q_{i,0}$ a parameter to initialize the growing sequence of input quantities. Let n be used to index the quantity decisions or the prices on the period. The idea is that a growth trend is constructed from $Q_{i,0}$ and r. At a given period n, some limited reaction is made to the observed prices: in case of a low price the buyer will buy in excess of the trend by some percentage R and in case of high price the buyer will reduce the purchased quantity by a similar percentage R. Similarly, the seller will either sell all inventory at hand in case of a high price and only some percentage of it in case of a low price. Then:

- if $P_{i,n} <$ Mean ($P_i|$ latest five periods), $Q_{i,n} = (1 + R)\ Q_{i,0} (1 + r)^n$,
- if $P_{i,n} \geq$ Mean ($P_i|$ latest five periods), $Q_{i,n} = (1 - R)\ Q_{i,0} (1 + r)^n$,
- if $P_{o,n} <$ Mean ($P_i|$ latest five periods), $Q_{o,n} = (1 - R)S$,
- $P_{o,n} \geq$ Mean ($P_i|$ latest five periods), $Q_{o,n} = S$.

These myopic programs involve some speculation but in a very different way as in the coordinated speculation policy. Here the speculation will be limited and the increasing returns assumption is completely ignored. These programs replicate a naïve approach that focuses on local adaptations to two disjoint problems seen as standard decision problems under uncertainty.

Table II provides the economic values at the end of period 15 when these computer programs are played using different plausible values for the parameters.

TABLE II

Value achieved with the different computer programs

Computer programs		Value achieved at period 15 (in 000's)
Sophisticated programs		
No correlation	$k=2$	228
	$k=1.8$	337
	$k=1.5$	Bankrupt at period 3
With correlation	$k=3.5$	700
	$k=3$	853
	$k=2.5$	Bankrupt at period 6
Myopic programs		
No growth ($Q_{i,0}=119, r=0\%$)	$R=10\%$	2.9
	$R=15\%$	3.4
Growth ($Q_{i,0}=190, r=15\%$)	$R=10\%$	38

7. ANALYSIS OF EXPERIMENTAL RESULTS

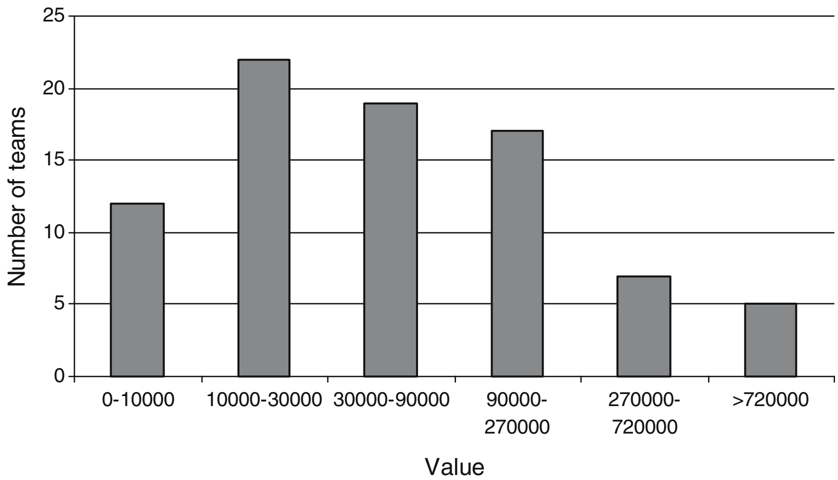
The statistical distribution of scores is extremely large (see Table III).

This distribution can only be explained by completely different behaviors. The analysis proceeds as follows:

- Is the team aware that there is a joint coordination problem? The hard data provided by the completed spreadsheets can be used to test whether the actual behaviors of the seller and the buyer indeed exhibit some coordination? This provides a classification under which to discuss more meaningfully the actual behaviors.
- Using this classification, the decisions actually made are compared with the decisions obtained from the computer programs described in Section 6. Similarities and differences are discussed using the additional information provided by the open questionnaires in order to further validate the relevance of the use of the computer programs as benchmarks.

TABLE III

Distribution of the values obtained by the teams that avoided bankruptcy



- Special attention is given to the learning aspect. Once the behavior of a team has been characterized, does it change over time? Both the hard data provided by the spreadsheets and the qualitative data provided by the questionnaires will be used.

Two preliminary qualifying comments about the data are in order. First, among the 108 teams, only one team (n°42) played a coordinated speculation strategy. This strategy can easily be identified from the spreadsheet and the corresponding team is eliminated from the sample. Second, 26 teams did go bankrupt. Parts 1 and 2 of the analysis only cover the 81 teams that did not go bankrupt. Point 3 concerns all teams.

7.1. *Classification of the empirical results*

Instead of testing directly the behaviors of the 108 teams against our computer programs, a preliminary classification is made. The role of this classification is to indirectly infer from the decisions actually made by a team whether or not they rely on a high level of common knowledge. The classification is based on the answers to two questions:

- do the subjects perceive that there are economies of scale so that coordinated growth will increase the value, selling today provides some cash which should be immediately invested into purchases (anticipation)?
- do the subjects recognize that speculation on part of the seller may be in contradiction with the coordinated growth strategy (speculation)?

The answers are obtained from the actual play of the game through two tests:

- Test 1 (anticipation of sales by the buyer): if the current sales were zero at anyone period, is the buying policy such that the firm would go bankrupt at that period? And if yes, does this occur at least six times over the first 10 periods? (The reason to limit the test to the first 10 periods is to eliminate end play perturbations, since quite a few teams limit their ambitions in the latter part of the game);
- Test 2 (reactivity of the seller to the output price to speculate): is the final inventory strictly positive for at least six periods over the 15 periods? (The speculation behavior should not be affected by endplay).

The computer programs can be tested and the results can be used to label the different classes depending on the answers (see Table IV derived from Appendix A). A positive answer to test 2 (speculation) corresponds to a myopic program either with constant growth (positive answer to test 1) or no growth (negative answer to test 1). No speculation (test 2) and anticipation (test 1) corresponds to a sophisticated (growth) program either with correlation or without correlation.

The global results of the test of the 81 teams are detailed in Table V. Note that only three teams fall outside the three classes identified, they are labeled as question marks. For the three other classes the mean values of the scores are sufficiently apart to suggest that the underlying behaviors are

TABLE IV
Results of the test of the computer programs

Test 1	Test 2	
	No speculation	Speculation
Anticipation	Sophisticated programs (No correlation and With correlation)	Myopic programs – Growth ($Q_{i,0} = 190$, $r = 15\%$)
No. anticipation		Myopic programs – No growth, ($Q_{i,0} = 119$, $r = 0\%$)

TABLE V
Test of the experimental results

Test 1	Test 2	
	No speculation	Speculation
Anticipation	Coordinated growth Number of teams: 18 Mean of terminal values: 382	Myopic with growth Number of teams: 33 Mean of terminal values: 90
No anticipation	Question marks Number of teams: 3 Mean of terminal values: 49	Pure Myopic Number of teams: 27 Mean of terminal values: 21

different. As expected these scores are increasing with the degree of common knowledge.

7.2. *Comparison between the actual behaviors and the computer programs within each class*

The difference in actual behaviors is now further investigated by means of the computer programs. Within each class does a particular computer program provide a reasonably good approximation of the actual behaviors of the corresponding teams? The fit appears better for high or low scores, rather

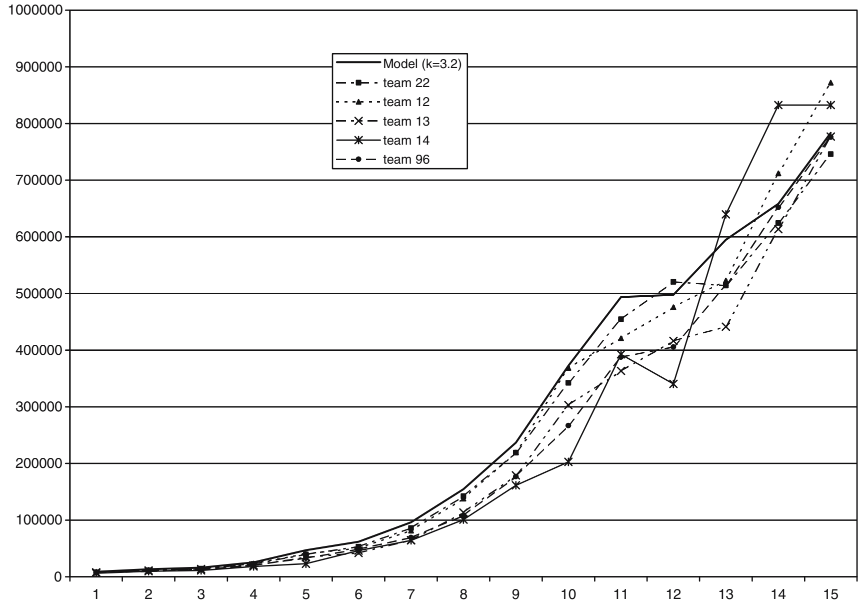


Figure 2. Comparison between the values of teams 12, 14, 13, 22, 96 and sophisticated program with correlation ($k = 3.2$).

than medium ones. The analysis reported here is limited to these extreme outcomes.

7.3. *Growth with correlation: teams 12, 13, 14, 22, 96*

Figure 2 allows for a direct comparison of the observed experimental values obtained over the 15 periods with the values obtained using the sophisticated computer program using the correlation in the prices (with $k = 3.2$). Still does it mean that these teams did actually use a reasoning close to the one corresponding to our computer program?

The answer to the open questionnaire of team 22 provides the following elements of appreciation. Team 22 went through a long initial search activity, followed by more limited ones, to generate a behavior for operational decisions characterized by:

- Decide that the seller always sells everything, $Q_{o,n} = S$,
- Select some parameter to be used to predict the output price from the observed input price, denote λ this parameter so

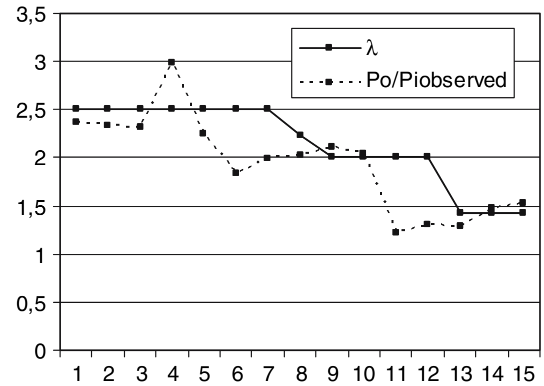


Figure 3. Regression coefficient used by team 22.

TABLE VI
Cash reserve used by team 22

Input price	Period 1–5	Period 6–15
Low	8%	20%
Medium	20%	30%
High	50%	50%

that $P_o = \lambda\, P_i$, observe from Figure 3 that the past observations are used to update the parameter λ but that this updating operates with some lag that puts the firm at risk,

- Determine the total cash available given that $Q_{o,n} = S$ and that P_i may be used to estimate that $P_o = \lambda\, P_i$,
- Put a fraction of this cash on reserve using Table VI, that fraction depending on the actual value of the firm at the end of the preceding period and on the observed input price, note that the fraction on reserve increases with P_i and from periods 1–5 to periods 6–15,
- Determine the input quantity Q_i using the cash that remains.

This actual behavior was formalized through a computer program (which is easy given the availability of the spreadsheet). The correspondence between a routinized behavior and a computer program is clear, even if some adaptation took place in a non formal way (change in the parameter λ and in the amount of cash reserve).

Other teams such as team 12 did not go through such a highly formalized modeling activity. An intuitive percentage of the cash is put aside as a reserve, this percentage is jointly discussed in the planning sessions and numbers are rounded when the buyer makes his or her decision. Team 14 introduced another element of reasoning not used at all by other teams in this group. Namely, they decided no to buy in case the input price is higher than 13. This is consistent with the idea of economies of scale, but it is unclear how the number 13 was arrived at.

7.4. *Growth without correlation: teams 106, 52, 17, 35, 58, 15, 40, 38, 62, 67, 108, 44, 68*

A reasonable good fit of these experimental outcomes can be obtained using the computer program based on growth without correlation using three possible parameters that is, $k = 1.8$ (teams 52, 17, 35, 106, see Figure 4), $k = 2.05$ (teams 58, 15, 40, 38 see Figure 5) and $k = 2.3$ (team 62). For teams 67, 108, 44, 68, which correspond to the lower results, there is no value of k that would generate a good fit. This is not surprising since the corresponding scores are the lowest ones in that class.

A typical approach used by these teams is to remain at zero inventory at all periods and to set a minimal selling price P_o^{min} to determine the available budget for the buyer. The numerical value used for P_o^{min} is intuitive and eventually updated during the play. The major difference between these teams and the ones discussed earlier concerns the correlation. After the fact some teams were amazed they had missed to infer it from the data. Others reported that they had recognized the correlation in prices but that they would not trust that this correlation would last.

This discussion suggests that all these teams indeed framed their approach to the problem by assuming that they should anticipate cash from current sales and then not induce

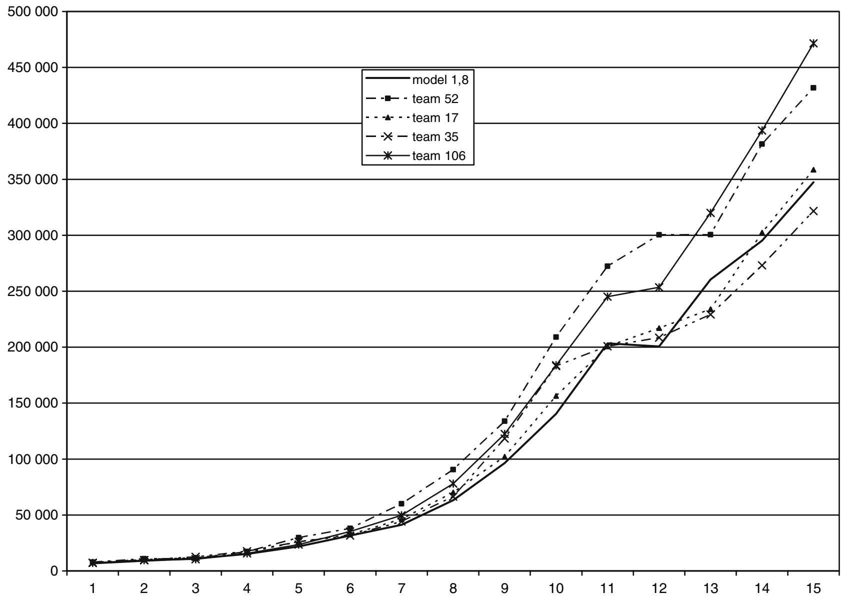


Figure 4. Comparison between the values of teams 52, 17, 35, 106 and sophisticated program without correlation ($k = 1.8$).

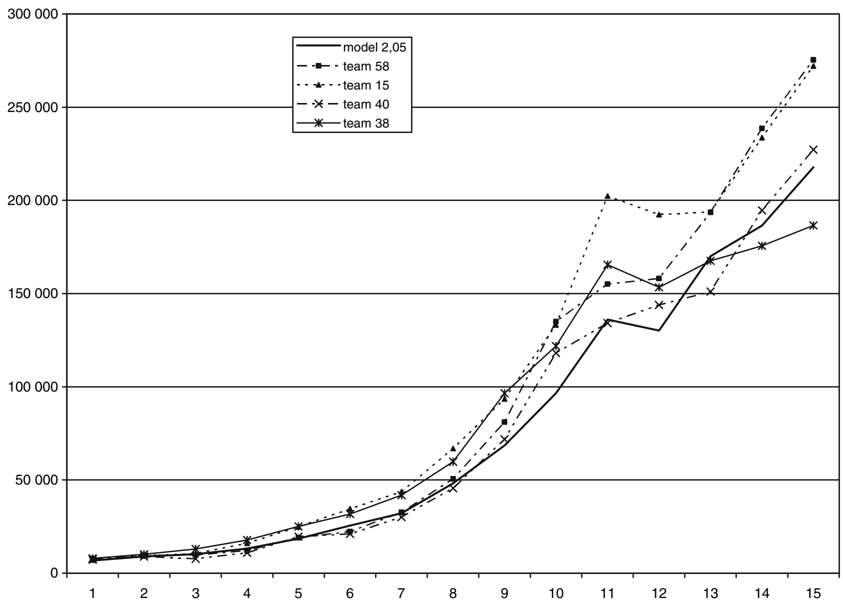


Figure 5. Comparison between the values of teams 58, 15, 40, 38 and sophisticated program without correlation ($k = 2.05$).

speculation on part of the seller. Then they used more or less formalized approaches to determine what risk to assume when the buyer makes his or her decision. The fact that they based these approaches on the correlation or not explains well the difference in the scores.

The information provided by the open questionnaire filled by team 17 shows that the minimal selling price P_o^{min} may sometimes be determined in dubious ways. This team selected a minimal selling price P_o^{min} equal to the current average accounting cost. Observe that this generates an implicit function, which can only be solved through a numerical simulation (which is easy given the availability of the spreadsheet). The actual outcomes are very close to the one obtained through our growth model with $k = 1.8$. The fit is good but the underlying rationales are far apart!

7.5. *Myopic behavior: teams 83, 54, 2, 18, 55, 6, 74, 77, 78, 46, 5, 56*

Only the 12 lowest scores shall be analyzed. The answers to the open questionnaire show that such teams did not have a clear strategy when they start the game. They devoted much less time to the initial planning session. Then, when they individually faced operational decisions, they adopted routines quite similar to the myopic programs described Section 6.

A direct comparison of the prices with the actual decisions made by the buyer and the seller respectively shows the major role of local speculation. The correlation coefficients are given Table VII. In most cases, one can observe a negative correlation between input quantities and input prices and a positive correlation between output quantities and output prices. This observation does not apply for only two teams (6 and 5) which can be analysed as a misunderstanding of the game.

This speculation is illustrated by the results of team 2. Observe (Figure 6) that input quantities almost always go in the inversed direction as the input price (only exception is at periods 4 and 15). For output quantities and output prices there is no exception (Figure 7). From Appendix B it can be

TABLE VII

Correlation coefficient between quantities and prices for the 12 teams that obtained the lowest scores

Team	Input quantity vs input price		Output quantity vs output price	
	Regression coefficient	R^2	Regression coefficient	R^2
83	−0.016	0.28	0.007	0.01
54	−0.009	0.07	0.036	0.24
2	−0.027	0.50	0.049	0.54
18	−0.012	0.31	0.010	0.03
55	−0.006	0.09	0.009	0.03
6	−0.004	0.02	−0.008	0.02
74	−0.014	0.13	0.050	0.38
77	−0.023	0.66	0.034	0.28
78	−0.012	0.27	0.026	0.23
46	−0.025	0.49	0.042	0.30
5	0.017	0.28	0.030	0.13
56	−0.019	0.19	0.040	0.11

seen that the anticipation test gives 7 "no anticipation" out of the 10 first periods. That means that in the other three periods the firm would have been bankrupt if the seller had sold nothing. But the seller indeed sold nothing at period 6! Still the team did not recognize this risk and the behaviors did not coordinate (go to no anticipation or always sell some minimal amount). There seems to be no learning whatsoever in such a team.

8. DISCUSSION OF THE TWO RESEARCH QUESTIONS

The comparative analysis carried on in the preceding section demonstrates the relevance of the bounded rationality framework to analyze the decisions made by the subjects. An outside observer that would have access only to the operational decisions could infer that the actual behaviors have strong

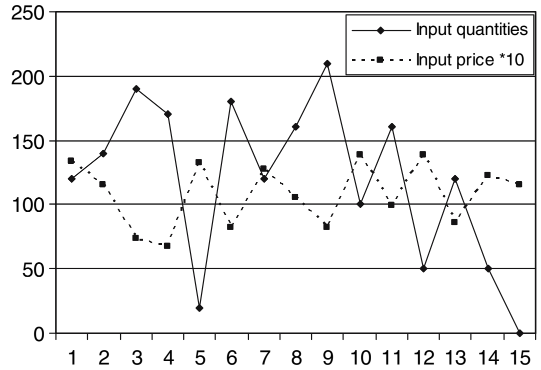


Figure 6. Example of myopic speculation – input quantities versus input price for team 2.

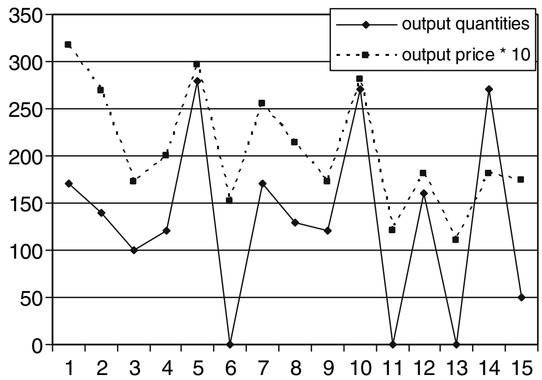


Figure 7. Example of myopic speculation – output quantities versus output price for team 2.

similarities with computer routines. Indeed such routines can be constructed and the fit appears quite good.

Building on this first result, our research methodology allows to investigate further questions related to the origin of these routinized behaviors. We have been able to link these routines to the search activities that take place during the planning sessions and in particular to the degree of common knowledge used to decompose a group decision problem into individual decision problems. This decomposition process has been stressed as a major component of interactive rationality defined as a refinement of bounded rationality for group decision problem.

The two more specific research questions of the paper are now discussed.

8.1. *Economic modeling and efficiency*

The empirical results show that economic modeling goes with higher scores. This economic modeling has some striking features. It is mostly elaborated during the search activity that takes place during the very first planning session rather than incrementally in the successive ones. How this economic modeling is used to decompose the joint decision problem into two individual decision problems has been detailed. This approach may, on one hand, miss some minor optimality features (the correlation in prices, the rigidity in the seller policy) and, on the other hand, imbed some ad hoc elements (in the construction of a cash reserve). It constructs consistent mutual anticipations in the behaviors of each member of the team, rather than local optimizations of individual independent decision problems. The model is first a communication device and only second a way to arrive to an optimal decision. This explains why the economic modeling observed in the experiment remains quite simple, after all.

In contrast, teams that did not use economic modeling used an implicit rather than explicit decomposition of the problem. That implicit decomposition misses important considerations related to the anticipation of cash from current sales and the induced constraint to limit the natural propensity of the seller to speculate. It appears as a simple juxtaposition of naïve local optimizations of individual independent decision problems. This explains why they lose in efficiency.

8.2. *Economic modeling and learning*

An advantage of the use of economic modeling is that it allows incremental adaptation as the environment is changing. This is easily captured through the updating of the parameters

TABLE VIII
Proportion of the teams that went bankrupt

Test 1	Test 2	
	No speculation	Speculation
Anticipation	29%	27%
No anticipation	NS	26%

such as the minimal selling price or the cash reserve. Typically the teams that used economic modeling adapted their behaviors accordingly (single loop learning, Argyris and Schön, 1978).

In this section a more practical issue about efficiency is also addressed. Does the adoption of economic modeling enhance the capacity of the firm to survive a major downturn in the environment? The empirical observations discussed in the introduction were about this issue. A pure statistical analysis of the results of the experiment depending on the classification introduced Section 7 gives a negative answer to that question (the classification of teams that went bankrupt is defined in Appendix C). The results are detailed Table VIII. The bankruptcy rate does not depend on the class under consideration. The teams in the coordinated growth policy class went into bankruptcy with approximately the same probability as the firms classified in the other two classes. The use of economic modeling and the induced capacity to update the behavior in face of a changing environment did not prevent them from the bankruptcy risk.

The theoretical analysis of the game provides an interesting benchmark to analyze this point further. The optimal strategy is to change from a coordinated growth policy to a coordinated speculation policy as the firm gets into a tougher environment. This radical change represents "double loop" learning. One would not expect that double loop learning would occur without going back in a major search activity during one of the planning sessions regularly opened by the rules of the game. The question is now the following one:

does the use of economic modeling generated in the initial learning activity provides some help to get into another search activity when the environment is clearly changing as it is in the game?

The answers to the open questionnaires demonstrate that this is not the case. The teams that are classified as using a growth policy did not consider that the change in the environment was radical enough to induce a change in their strategy. They would play the game again exactly the same way if they had to. They seem to have framed the problem once and for all and were not aware that a new search activity could be worthwhile. Even the teams that used a coordinated growth policy and went bankrupt did not consider a radical change in their policy.

It may very well be the case that some of the teams associated with medium scores did go into a double loop learning activity. A qualitative analysis of the input and output decisions of team 59 shows for instance that it may qualify for double loop learning. Figure 8 demonstrates the move towards the coordinated speculation strategy initiated at period 5. It is among these teams that the answers to the questionnaires contains assessments such as "yes we changed our strategy but it was too late" or "yes we would play the game quite differently if we had to". However such assessments may illustrate a late formalization of a strategy rather than double loop learning.

9. CONCLUDING COMMENTS

This paper explores the ability to coordinate in teams. Subjects face a group decision problem. The main originality of the experimental setting is to repeatedly allow collective sessions followed by individual operational decisions without any communication. There are uncertainties that are not known at the collective sessions but that are revealed privately when individual decisions are made. This setting captures well the overall decision process at work in firms.

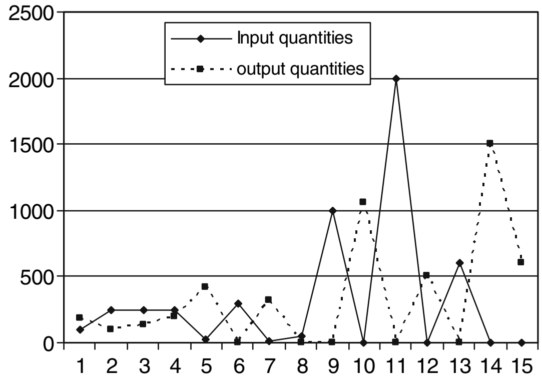


Figure 8. Double loop learning (team 59).

The observed decision making process involves search activity and routinized behaviors. This may be interpreted in the general theory of bounded rationality and, in particular, in the framework of interactive rationality typical of group decision making. The role of common knowledge to decompose the problem into individual interrelated decision problems is critical. That these ideas can be illustrated and precisely discussed in this experimental setting is interesting since most of the empirical work that has been published so far concerns quite abstract games.

The more specific results demonstrated in the paper are twofold: economic modeling improves performance precisely because it facilitates the emergence of relevant common knowledge, however it does not necessarily induce a higher learning capability. While incremental single loop learning is observed, it does not enhance the capability of the organization to revisit the way the problem has been framed (double loop learning). This latter result adds a confirmation of the inertia of decision making in organizations (Hall, 1984).

These results should be confirmed through further experimental studies. It would be interesting to know if the ability to coordinate depends on such aspects as the homogeneity of the team (ability to use economic reasoning), the availability of softwares such as excel spreadsheets (so important to draw business plans), time pressure ... The participants in this experiment were fairly homogenous, the teams were not made at random, the time pressure was not very strong. It seems also clear that the duration of the game, here 15 periods, is quite short and that longer games may be more appropriate to refine our results.

These theoretical results provide interesting insights about the practical use of economic modeling in planning. They indeed explain when and how formal planning may be successful and at the same time why it may also limit the adaptability of the firm. As a consequence, they suggest some specific directions to improve the potential benefit of planning. According to our results, good planning should be viewed more as a coordination device than as a forecasting exercise. Then the benefit associated through improved internal coordination should not obliterate the ability to remain attentive to external changes and eventually to reframe the problem. Due to organizational inertia, it is worth paying special attention to this perverse aspect of economic modeling.

ACKNOWLEDGEMENTS

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APPENDICES

These appendices provide the detailed results of the two tests for the computer programs (Appendix A), for teams that did not go bankrupt (Appendix B) and for those which went bankrupt (Appendix C).

Test 1: If number of no anticipation (10 first periods) ≥ 6 then “no anticipation” from buyer.

Test 2: If number of inventory non zero (15 periods) ≥ 6 then “speculation” from seller.

APPENDIX A: COMPUTER PROGRAMS

Program	Coordinated Growth	Myopic with growth	Question marks	Pure myopic (no growth)	Terminal value	Nb Inventory > 0	Nb no anticipation	Nb cash< 0
Sophisticated programs								
No correlation	Ant.+				227 899	0	0	0
k = 2	No Spec.							
No correlation	Ant.+				337 765	0	0	0
k = 1.8	No Spec.							
With correlation	Ant.+				699 826	0	0	0
k = 3.5	No Spec.							
With correlation	Ant.+				853 182	0	0	0
k = 3	No Spec.							

Myopic programs						
No growth ($Q_{i,0} = 119$, $r = 0\%$, $R = 10\%$)		No Ant. + Spec.	2 927	9	9	0
No growth ($Q_{i,0} = 119$, $r = 0\%$, $R = 15\%$)		No Ant. + Spec.	3 384	9	9	0
Growth ($Q_{i,0} = 190$, $r = 15\%$, $R = 10\%$)	Ant.+ Spec.		38 101	9	3	0
Growth ($Q_{i,0} = 190$, $r = 15\%$, $R = 15\%$)	Ant.+ Spec.		40 338	9	3	0

APPENDIX B: TEAMS THAT AVOIDED BANKRUPTCY

Team	Joint speculation	Growth	Myopic with growth	Question marks	Pure myopic	Terminal value	Nb inventory > 0	Nb no anticipation	Nb of cash <0
12		Ant.+ No Spec.				872 025	0	0	0
14		Ant.+ No Spec.				832 380	0	1	0
13		Ant.+ No Spec.				777 116	0	0	0
96		Ant.+ No Spec.				776 094	0	2	0
22		Ant.+ No Spec.				745 820	0	0	0
106		Ant.+ No Spec.				471 644	2	2	0
104			Ant.+Spec			468 250	9	1	0
52		Ant.+ No Spec.				431 864	0	0	0
17		Ant.+ No Spec.				358 664	0	0	0
35		Ant.+ No Spec.				321 617	2	1	0

58		Ant.+ No Spec.			275 361	0	0	0
15		Ant.+ No Spec.			272 078	4	4	0
87			Ant.+ Spec.		251 697	11	0	0
10			Ant.+ Spec.		250 571	6	2	0
42	Joint spec.				227 631	1	1	0
40		Ant.+ No Spec.			227 173	2	0	0
38		Ant.+ No Spec.			186 512	3	3	0
11			Ant.+ Spec.		155 904	14	2	0
69			Ant.+ Spec.		150 653	7	1	0
103			Ant.+ Spec.		147 143	9	5	0
84			Ant.+ Spec.		147 031	6	4	0
92			Ant.+ Spec.		141 606	11	0	0
16			Ant.+ Spec.		135 961	8	0	0
62		Ant. No Spec.			131 074	4	2	0
19			Ant.+ Spec.		129 473	10	1	0
89			Ant.+ Spec.		113 624	7	4	0
97			Ant.+ Spec.		110 353	13	0	0
9			Ant.+ Spec.		99 408	10	5	0
39			Ant.+ Spec.		93 422	8	2	0
37				No ant.+spec	79 579	11	8	0
91			Ant.+ Spec.		77 294	8	4	0

APPENDIX B: (continued)

Team	Joint speculation	Growth	Myopic with growth	Question marks	Pure myopic	Terminal value	Nb inventory > 0	Nb no anticipation	Nb of cash <0
101				No ant.+ No spec.		71 864	4	6	0
7			Ant.+ Spec.			69 791	6	5	0
67		Ant.+ No Spec.				64 422	0	5	0
80			Ant.+ Spec.			59 140	6	4	0
81				No ant.+ No spec.		55 028	2	7	0
98			Ant.+ Spec.			53 851	11	2	0
107			Ant.+ Spec.			50 433	9	2	0
73					No ant.+ spec	49 516	6	8	0
4			Ant.+ Spec.			47 464	12	0	0
108		Ant.+ No Spec.				45 108	3	2	0
44		Ant.+ No Spec.				44 044	4	5	0
49			Ant.+ Spec.			44 043	7	5	0
59					No ant.+ spec	36 976	8	6	0

68	Ant.+ No Spec.			36 373	3	3	0	
47				No ant.+ spec	35 910	7	8	0
102				No ant.+ spec	31 119	12	6	0
53		Ant.+ Spec.			30 401	15	1	0
90				No ant.+ spec	29 044	6	7	0
8				No ant.+ spec	28 031	7	8	0
70				No ant.+ spec	26 526	8	7	0
76				No ant.+ spec	26 526	8	7	0
36		Ant.+ Spec.			26 496	13	2	0
50				No ant.+ spec	22 047	11	6	0
3		Ant.+ Spec.			20 110	10	1	0
61				No ant.+ spec	19 182	12	6	0
64			No ant.+ No spec.		19 025	3	7	0
72		Ant.+ Spec.			17 999	12	5	0
71		Ant.+ Spec.			17 046	9	5	0
21				No ant.+ spec	16 225	7	6	0
57		Ant.+ Spec.			15 569	14	5	0
99		Ant.+ Spec.			14 313	12	3	0
85				No ant.+ spec	14 056	12	7	0
63				No ant.+ spec	13 865	12	7	0
1				No ant.+ spec	13 187	6	7	0
93		Ant.+ Spec.			13 014	14	4	0
88				No ant.+ spec	11 952	12	7	0

APPENDIX B: (continued)

Team	Joint speculation	Growth	Myopic with growth	Question marks	Pure myopic	Terminal value	Nb inventory > 0	Nb no anticipation	Nb of cash <0
20					No ant.+ spec	11 566	10	7	0
66					No ant.+ spec	11 508	14	6	0
82					No ant.+ spec	10 121	10	7	0
83					No ant.+ spec	9 934	15	7	0
54					No ant.+ spec	9 813	12	6	0
2					No ant.+ spec	9 588	10	7	0
18					No ant.+ spec	9 520	14	6	0
55					No ant.+ spec	9 227	14	6	0
6					No ant.+ spec	7 400	14	9	0
74			Ant.+ Spec.			7 224	14	5	0
77					No ant.+ spec	6 661	12	8	0
78			Ant.+ Spec.			6 276	12	3	0
46					No ant.+ spec	5 558	14	8	0
5			Ant.+ Spec.			3 406	13	0	0
56			Ant.+ Spec.			1 043	14	4	0

APPENDIX C: TEAMS THAT WENT BANKRUPT

Team	Joint speculation	Growth	myopic with growth	Question marks	Pure myopic	Terminal value	Value at period 11	Nb inventory > 0	Nb no anticipation	Nb of cash<0
23		Ant.+ No Spec.				2 040 486	683 723	0	1	4
30		Ant.+ No Spec.					606 732	4	0	1
34		Ant.+ No Spec.				1 166 360	444 581	1	1	2
29		Ant.+ No Spec.				857 154	322 743	0	0	1
27			Ant.+ Spec.				276 590	9	0	1
95		Ant.+ No Spec.				329 430	265 813	1	2	1
26					No ant.+ spec	451 459	248 813	5	2	5
31			Ant.+ Spec.			336 900	204 534	12	0	4
32		Ant.+ No Spec.				289 763	122 487	1	2	1
28					No ant.+ spec	70 457	42 036	9	7	1
24			Ant.+ Spec.			40 090	37 925	7	1	1
79			Ant.+ Spec.				32 245	12	3	1

APPENDIX C: (Continued)

Team	Joint speculation	Growth	myopic with growth	Question marks	Pure myopic	Terminal value	Value at period 11	Nb inventory > 0	Nb no anticipation	Nb of cash<0
51		Ant.+ No Spec.				25 152	24 742	3	3	1
75					No ant.+ spec	31 961	24 499	9	6	1
48			Ant.+ Spec.			27 923	20 261	8	5	1
100			Ant.+ Spec.				19 703	12	1	1
65					No ant.+ spec	14 550	17 796	9	7	1
45			Ant.+ Spec.			9 450	15 203	14	5	1
43			Ant.+ Spec.			9 233	14 538	14	3	2
25					No ant.+ spec	10 242	14 154	12	6	1
41					No ant.+ spec	11 083	13 109	13	6	2
60			Ant.+ Spec.			4 671	8 293	6	1	1
105					No ant.+ spec	3 841	7 091	10	6	1
33					No ant.+ spec		6 681	9	8	1
86*								15	0	1
94*								9	1	1

*These two teams cannot be classified because they went bankrupt during the first periods and stopped playing afterwards

NOTES

1. This game was originally designed to emphasize the benefits of interactive control systems in managerial economics classes (de Jaegere and Ponssard, 1990). The complete pedagogical set may be obtained from the authors upon request.

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