The Way out of the Trap Experiments on Dynamic Coordination Games

Jordi Brandts

Institut d'Anàlisi Econòmica (CSIC)
Campus UAB
08193 Bellaterra (Barcelona)
Spain

jordi.brandts@uab.es

Ágnes Pintér

Universitat Autònoma de Barcelona
Dept. d'Economia i Història Econòmica
Edifici B, Campus UAB
08193 Bellaterra (Barcelona)
Spain

apinter@idea.uab.es

Abstract

Underdevelopment is often seen as the result of coordination failure between different parts of the economy. Positive agglomeration economies may imply that no one sector of the economy can develop alone; instead, coordinated development of many economic activities is required for a country to achieve greater prosperity. We present experiments from dynamic coordination games in which moving between a traditional and a modern sector has a fix cost, and the returns to modernization only arise with some delay. Both complete stagnation as well as immediate development are equilibria of the dynamic game independently of the cost and delay. However, our results show that coordinated development does depend on both factors, the cost structure and the presence of delay.

Acknowledgement 1 *The scholarship Beca de Postgrado para la Formación de Profesorado Universitario del Ministerio de Educación, Cultura y Deporte (Ref.: AP2001-0923) is gratefully acknowledged.*

1 Introduction

The Nash equilibrium solution concept for noncooperative games may generate multiple outcomes, and selecting the final outcome is a difficult and complex issue. Even if the equilibrium outcomes can be Pareto ranked, the decision of agents is not obvious, hence we can not ensure that concepts of efficiency will predict the final outcome accurately. In order to reach the payoff dominant outcome, these situations require the coordination of the agents. Coordination games characterize strategic interactions in many fields of economics and real life. Schelling (1960) provides an overview of social environments where these games naturally arise. In economics, games with multiple equilibria are also of great interest. They are present for example in models on industrial organization (models of double moral hazard; network externalities, and team production) and macroeconomic models[1] (models of imperfect competition and search).

In international trade and in development models there has been a growing interest in the analysis of market economies in the presence of externalities, and studies on this field show that there may exist multiple Pareto-ranked equilibria.[2] One of the first studies along these lines of investigation is the one of Paul Rosenstein-Rodan (1943). More recently Murphy, Shleifer and Vishny (1989) have formalized some aspects of the point of view of Rosenstein-Rodan making precise the conditions for multiplicity of equilibria in this setting.

Facing the equilibrium selection problem, numerous investigators examine the role and use of historical factors in predicting the resulting equilibrium. Ethier (1982) and Panagariya (1986) showed how history affects the long-run outcomes in dynamic two-sector models with externalities. They use an adjustment process in which the reallocation of factors takes place at a rate determined by the difference between the current returns in the two sectors; but this type of behavior is generally inconsistent with perfect foresight.

Once the assumption of perfect foresight is made, history alone may not be enough to dictate the long-run behavior of the economy with externalities.[3] The assumption of perfect foresight may help to answer for a central question posed by Rosenstein-Rodan: how does an economy move from a bad to a

[1] For a survey on the use of coordination games in modeling macroeconomic phenomena see Cooper and John (1988), and also Bryant (1993), Chatterjee and Cooper (1989) or Cooper (1999).

[2] International trade has a wide literature on the analysis of externalities and multiple equilibria in a static framework. For a survey see Helpman (1984). For dynamic models see for example Mortensen (1988).

[3] See for example Krugman (1991) and Fukao, Benabou (1993).

good equilibrium? However, this question may result problematic to answer. In pure coordination games, where is the role of history or perfect foresight? Why would an initial coordination failure transmit itself or persist over time? This question, as well as the distinction of history versus expectations is of particular importance in the context of development. As Matsuyama points out: [4] "The diversity of per capita income levels across countries suggests the presence of some sort of multiplicity. The idea of history determining the long-run position of the economy than implies that many countries may be in underdevelopment traps. (...) The active state intervention may be called for in order to break a vicious cycle of poverty." On the other hand, if the problem is caused by the coordination failure of agents' expectations, the role of government should be limited to promoting the optimism.

Matsuyama (1991) and Krugman (1991) use a two-sectors model of sectorial adjustment to show the role of discounting in the generation of ahistorical equilibria. They demonstrate that if discounting rates are close enough to zero, generally there exist multiple perfect foresight paths, leading to equilibria that are able to break free of initial conditions. On the other hand, if discounting rates are high, then initial conditions determine migratory flows, and the economy will be trapped in the "state of preindustrialization".

Adserà and Ray (1998) use a similar model to the above mentioned ones, with an important distinction. They assume that positive agglomeration externalities manifest themselves with a time lag (that can be vanishingly small).[5] They find that in their model, if relocation costs are constant or depend negatively on the number of agents in the destination sector and are independent of the intersectoral allocation of agents, the final outcome of any perfect foresight equilibrium depends exclusively on initial conditions, and the equilibrium path is the same as if agents were short-sighted (independently of the size of discounting).

Although in the experimental literature there exists a large number of studies concerned with equilibrium selection problems, these experiments focus on static situations. These papers report evidence on the accuracy of predictions of the different equilibrium selection principles and of the suggested focal points with or without communication.[6] Generally they study

[4] Matsuyama (1991).

[5] For empirical literature on lags see Henderson (1994). For theoretical studies about the role of time lags in dynamic (investment) models see Chamley and Gale (1994), and Gale (1995).

[6] For experimental results on coordination games with pre-play communication see e.g. Cooper et al. (1989, 1992); and Duffy and Feltovich (2002). For results without communication see e.g. Van Huyck, Battlio and Beil (1990); Cooper, DeJong, Forsythe and Ross (1990); Straub (1995) or Camerer (2003).

the role of risk dominance, group size and of repeated game in the selection of the equilibrium outcome. They suggest that the often observed coordination failure results from strategic uncertainty (risk dominance): some players conclude that it is "too risky" to choose the payoff dominant action. In situations, where pre-play communication is allowed, experimental results show that in practice communication usually improves coordination, but rarely leads to full efficiency.

We designed three treatments to examine agents' behavior in a dynamic two-sector investment (or migration[7]) situation in a controlled experimental environment. The design of the treatments is a particular parameterization of the model used by Adsereà and Ray. Our main concern is to answer the following questions: First, whether agents succeed to make the economy get out of the bad state under the assumptions of the model, or - as predicted by the general model - they will get trapped in the Pareto inferior equilibrium. The other question we pose is strongly related to the previous one. We want to study, whether the decisions of the agents are lead by myopic tatonnement (that is, if they choices are based on the current discrepancies in the rates of return) or by long-run expectations. As we mentioned earlier, it does not make much sense to pose these questions in a static framework, but our dynamic design allows us to deal with these rather complicated issues.

Our experimental data suggest that behavior in the games is ambiguous. In all three treatments there are economies that get trapped in the initial Pareto inferior Nash outcome, but also there is a significant number of economies which are able to reach the socially desirable outcome and make the economy break free of the initial conditions. Even so, there are important differences in the results of the different treatments, due to the parameter settings. In particular, in the two treatments where investment changes are costly, results are bipolar, and final outcomes are reached relatively quickly and result to be stable. On the other hand, when moving between investment sectors is costless, behavior is less stable, but most of the experimental economies manage to reach at least a "medium level" outcome. We use a probit regression to explain the motives that are behind our experimental data on individual decisions, and we see that the different individual decision behaviors are lead by different motives when making the choices.

The rest of this paper is organized as follows. In the next section we describe our model and give some examples of symmetric pure strategy equilibria for the three games we examine; in Section 3 we describe the design

[7]The model can be interpreted in both ways. In the paper by Adserà and Ray they introduce it as a migration model, we refer to it as investment model to keep the harmony in wording with the one used in the experiments.

of the experiment; then in Section 4 we report our experimental results; and the last section concludes.

2 The Theoretical Model[8]

We have constructed three experimental treatments (CNL, NCL, CL)[9], all of them based on a simple, two-sector dynamic investment model. In the economy there are two sectors, a traditional one (sector 1) and a modern one (sector 2). At date 0 the total capital endowment is situated in the traditional sector. The capital invested in the traditional sector yields a fixed return (R_1) that we set at 6% in our treatments. The rate of return in the modern sector (R_2) depends positively on the number of agents in this sector. This means, that if there are N agents in the economy, from which n invests in the modern sector, the corresponding return is: $R_2 = f(n)$; where for $f(.)$ we use the following function:

$$f(n) = \frac{1}{10 \cdot \{1 + \exp[-0,7 \cdot (n-2)]\}}$$

This function satisfies the conditions set in Adserà and Ray, that is f is continuous, strictly increasing and

$$f(0) < R_1 < f(N).$$

As in our experiments N equals 5, we can summarize the rate of return of the sectors in the following table:

	Number of agents in the modern sector					
Sector	**0**	**1**	**2**	**3**	**4**	**5**
traditional	6,0%	6,0%	6,0%	6,0%	6,0%	6,0%
modern	2,0%	3,3%	5,0%	6,7%	8,0%	8,9%

Table 1: Rate of return in the sectors

Initially each of the five agents is endowed with 1 unit of capital, but capital accumulates over time. Capital accumulation is important in our models, as this makes the treatments dynamic even in the absence of a time lag. Each game has 28 periods. We assume that agents invest in each period all the capital they accumulated during the previous periods. Capital is

[8] Our games are based on a parameterization of the model used by Adserà and Ray.

[9] The notation of the treatments is explained below, here we just mention that CNL stands for Cost and No Lag; NCL for No Cost and Lag; while CL for Cost ang Lag.

free to move between sectors, but each relocation has a fixed cost. In treatments CNL and CL the cost of moving from sector 1 (traditional) to sector 2 (modern) is $C_2 = 0.3$; and the cost of changing from sector 2 to sector 1 is $C_1 = 0.03$; while in treatment NCL both costs are zero.

As we already mentioned, an important assumption in the model of Adserà and Ray is the time lag; therefore - to follow the line of their investigation - in treatments NCL and CL we introduce a lag in the speed at which the rate of return in the modern sector catches up with the "appropriate" rate of return corresponding to the division of the capital at the current date. The way we introduce the lag is the following: If an agent invests in the modern sector, she receives half of the corresponding return immediately, while the other half will be paid to her in the next period. That is, for example, if in period t an agent invests her accumulated capital $[I(t)]$ in the modern sector, and the number of agents in this sector (including herself) is n_t, her payoff of this period $[\pi(t)]$is:[10]

$$\pi(t) = \left[1 + \frac{R_2(n_t)}{2}\right] \cdot I(t)$$

and her payoff in period $(t+1)$ in case of investing in sector 2 is:

$$\pi(t+1) = \left[1 + \frac{R_2(n_{t+1})}{2}\right] \cdot \pi(t) + \frac{R_2(n_t)}{2} \cdot I(t)$$

and in case of investing in sector 1:

$$\pi(t+1) = (1 + R_1) \cdot \pi(t) + \frac{R_2(n_t)}{2} \cdot I(t)$$

Before starting with the description of the games[11], we summarizes the characteristics of the three treatments in Table 2:

Treatment	Cost	Lag
CNL	No	No
NCL	No	Yes
CL	Yes	Yes

Table 2: Treatment characteristics

[10] This example for the lag is for the lag is for treatment NCL, where relocation costs are zero.

[11] In our analysis of the three games we concentrate on symmetric pure strategy equilibria.

2.1 Treatment CNL

As mentioned before, in this treatment the corresponding returns in both sectors are paid to agents without delay, but each relocation is costly.

In this setting, if agents maximize their expected payoff taking the decision of the others given, under the assumption of perfect foresight there exist multiple equilibria. Given the complexity of the agents' strategy space, we do not provide the reader with the complete set of symmetric pure strategy Nash equilibria, we only present some examples. In each game, as we are interested in the "best" and "worst" equilibria, we will highlight these outcomes in our analysis.

Any agent who believes that her colleagues will invest during all periods of the game in sector 1, best responds by choosing the same action in each period as the others, that is, choosing (1,1,1,...,1); therefore the outcome where everybody chooses (1,1,1,...,1) is a Nash equilibrium of the game. On the other hand, given the beliefs that all the others choose the actions (2,2,2,...,2), that is, they choose in each period sector 2, the best response is again to "stay" with the others and choose (2,2,2,...,2), hence [(2,2,2,..,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2)] is also a Nash equilibrium of this game.

In general, we can say that all the symmetric outcomes where every agent after changing to sector 2, keeps investing in sector 2 at least during 13 consecutive periods, are Nash equilibria of the game. An outcome where the number of consecutive periods in sector 2 is shorter than 13, may be still a Nash equilibrium, but whether it is or not, depends on the accumulated capital of the agents. For example if all the players play (1,1,...,1,2,2,2), it is an equilibrium, although they stay in sector 2 only 3 periods. On the other hand the sequence of actions (2,2,2,1,1,..,1) can not be part of a Nash equilibrium, because any agent could do better by choosing (1,1,1,..,1).[12]

An important feature of the Nash equilibria is that they can be Pareto-ranked, and the equilibrium [(2,2,2,..,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2)] gives the highest, while the outcome [(1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1)] gives the lowest payoff to the agents. We can also notice, that the latter equilibrium coincides with the equilibrium outcome generated by myopic behavior as long as agents' accumulated capital is less than 15.

[12] In this treatment the unilateral deviation of an agent from sector 1 to 2 is never profitable, as she gets a lower return for that period, and moreover she has to pay the corresponding cost of relocation, therefore her accumulated capital gets lower. The profitable unilateral deviations should be investing instead of sector 2 in sector 1. This already advances the result that the outcome where everybody is in sector 1 in each period, will be the Pareto inferior among the equilibria.

2.2 Treatment NCL

In this game we introduce a lag in the returns on capital invested in the modern sector; hence half of the corresponding return is paid only in the following period. On the other hand, moving between sectors is costless, as in this treatment relocation costs are set zero.

Similarly to the previous game, this one also exhibits multiple equilibria under the assumption of perfect foresight. Some examples for symmetric pure strategy Nash equilibria are again, for example the outcomes [(1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1)] or [(2,2,2,..,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2)].

In this game, any outcome where in each period all the players are in one sector (and if there is a change in the investment destination, they always change sector "together"), is a Nash equilibrium. Hence, for example the outcome [(1,1,1,..,1,2), (1,1,1,..,1,2), (1,1,1,..,1,2), (1,1,1,..,1,2), (1,1,1,..,1,2)] is also a Nash equilibrium of the game.[13]

Again, the Nash equilibria of the game can be Pareto-ranked, the equilibrium [(2,2,2,..,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2)] ensures the highest payoff, while the equilibrium [(1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1)] gives the lowest payoff to the agents. We can state again that the Pareto inferior equilibrium coincides with the outcome resulting from myopic behavior.[14]

2.3 Treatment CL

This treatment is the most complex of the three, as in this one there is a lag in the return of the capital invested in the modern sector, and each relocation is costly.

As the other two games, this one also has multiple equilibria under the assumption of perfect foresight, and to illustrate this, we can again use the two equilibrium outcomes we mentioned above: [(1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1)] and [(2,2,2,..,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2)].

[13] In this treatment the unilateral deviation of an agent from sector 1 to 2 is never profitable, as she gets a lower return for that period, therefore her accumulated capital gets lower. The profitable unilateral deviations should be investing instead of sector 2 in sector 1. This already advances the result that the outcome where everybody is in sector 1 in each period, will be the Pareto inferior among the equilibria.

[14] In this game because of the lag applied in the modern sector, the comparison of the current returns (myopic bahavior) always suggests to keep investing in the traditional sector.

In general, we can say that all the symmetric outcomes where all the agents after changing to sector 2 keep investing in sector 2 at least during 15 consecutive periods, are Nash equilibria of the game. An outcome where the number of consecutive periods in sector 2 is shorter than 15, may be still a Nash equilibrium, but whether it is or not, depends on the accumulated capital of the agents. For example if all the players play the sequence of actions (1,1,...,1,2,2,2), it is an equilibrium, although they stay in sector 2 only 3 periods. On the other hand the action flow (2,2,1,1,..,1) can not be part of a Nash equilibrium, because any agent could do better by choosing (1,1,1,..,1).[15]

We can note that in this game - just as in the other two - the equilibrium [(2,2,2,..,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2), (2,2,2,...,2)] is payoff dominant, and the equilibrium [(1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1), (1,1,1,..,1)] coincides with the outcome lead by myopic behavior of the agents.

3 Experimental design

The participants were undergraduate students from the Universidad de Valencia and from the Universitat Autònoma de Barcelona, recruited using classroom announcements and posters in the campus, where the computerized experimental sessions were conducted (in the computer lab of LINEEX and of the UAB respectively) using the software z-Tree[16]. Each subject was allowed to participate only in one session. Subjects were informed that they would participate in a decision making task. In each session, subjects played 28 rounds in fixed groups of fives. Groups were formed randomly and anonymously. In each session one treatment was implemented. We conducted three sessions with both treatment CNL and NCL, and two with treatment CL. Table 3 summarizes the three treatments and the number of groups in each treatment.

[15] In this game, as in CNL, the unilateral deviation of an agent from sector 1 to 2 is never profitable, as she gets a lower return for that period, and moreover she has to pay the corresponding cost of relocation, therefore her accumulated capital gets lower. The profitable unilateral deviations should be investing instead of sector 2 in sector 1. This already advances the result that the outcome where everybody is in sector 1 in each period, will be the Pareto inferior among all the equilibria.

[16] Fischbacher, 1999

Treatment	Number of periods	Number of subjects	Number of groups
CNL	28	45	9
NCL	28	45	9
CL	28	35	7

Table 3: The different treatments

At the beginning of each session, subjects were randomly seated at the computer terminals and printed instructions were given to them for reading, and after everybody had finished, instructions were read aloud as well. Instructions contained all the rules to calculate the resulting payoff of the participants. In case of treatments CNL and CL bankruptcy rules were set and explained to the subjects in the instructions, but no bankruptcy had occurred during the sessions. Before starting the experiment, subjects were asked to fill in a simple interactive "payoff quiz", which was designed to check whether they had understood the computation of the payoffs and their decision task. The English translation of the instructions and of the payoff quiz for treatment CL can be found in Appendix A.[17] After all subjects answered all the questions correctly, the experiment started.

In each round, participants were asked whether to invest their accumulated capital in sector 1 or in the sector 2. Before making a decision, each subject received on-screen information to facilitate the decision making and computations. When all subjects had entered their decision for the round the computer automatically calculated and displayed the payoffs and other additional information (as specified in the instructions).

At the end of each session, participants were paid individually and privately. Sessions lasted about 90 minutes and the average net payments, including the five euro show-up fee, were around 12 euro (varied between 9 and 17 euro).

4 Experimental Results

In this section we present our experimental results. First we concentrate on the coordination level in the groups for each treatment, in order to see whether it is possible to break free of the initial conditions, and reach the socially efficient equilibrium, that is, perfect coordination in the modern sector. After analyzing the aggregate group behavior, we shed light on the background of the individual decisions of the agents.

[17] The instructions for the other treatments looked similar.

4.1 Coordination within Treatments

Aggregating the data of all groups in each treatment, we plot the evolution of the average number of players in the modern sector for each period in Figure 1 (see Appendix B). We can see that since the forth period the average number of players in the modern sector is the highest in the treatment CNL. The analysis of the fitted values of the regression for treatment CNL shows a logistic tendency, and after the initial increase, the average number of players in the modern sector stays a bit over 4.[18] The fitted values of the observations for treatment CL show a similar logistic shape, but with a slightly different slope. In this treatment the average number of players goes to 3.[19] As the only difference between the two treatments is the presence of lag in the returns of the second sector, the difference observed in the coordination level can be related to this lag. We recall, that even with the time lag, this medium level average coordination of 3 players in the modern sector means leaving behind the bad initial outcome. Our third treatment (treatment NCL) shows a different picture. We can see, that in the absence of the costs the variance of the average number of players in the modern sector is higher, and it is hard to fit a clear tendency to the observations. We can note that the initial average coordination level is quite high (in the first period it is 3.44), but along the time this level can not be improved permanently (the average coordination level for the 29 periods is 3.37). Although we remember, that according to the model of Adserà and Ray the cost structure we use should have no effect on the coordination result, comparing the results of treatments CL and NCL, the most clear difference is the variation of the average coordination level in the latter one. It is clear from the graphs as well, that in case of the treatment NCL there is a quite big oscillation in the average coordination level. Again, as in the experiments the only difference between the two treatments is the presence of the costs in one of them, this effect can be assigned to the positive (and constant) costs of changing sectors.

If we aggregate the data on the level of coordination of the groups of each period, we can have an idea about the frequency of each possible coordination level. We form four groups according to the efficiency of the coordination. GC (Good Coordination) stands for the outcomes of full coordination, that is, here we count the frequency of the outcomes when all five players of a group choose the modern sector. Within the group called NC (No Coordination) we distinguish two cases. To the first one belong the cases where one or two players of a group chooses the modern sector, and to the second the

[18] For the graph of the fitted values for treatment CNL see Figure 1a in Appendix B.

[19] To see the fitted values of the regression for treatment CL, see Figure 1b in Appendix B.

ones where three or four players of a group choose it.[20] In the forth group, called BC (Bad Coordination), we sum up the frequency of those outcomes where all the players of a group chose the traditional sector. The frequency of the outcomes grouped in these four categories can be seen in Figure 2 (see Appendix B). We can observe that in all three treatments the most frequent outcome is the one of the full coordination, its frequency is significant in all the treatments, although while in the treatments CNL and NCL the frequency of this outcome is significantly higher at any reasonable significance level[21] than of any other outcome, in treatment CL there is no significant difference between the frequency of the outcome of full coordination and of the outcomes where three or four players coordinate in the modern sector (34.2% and 33.2% respectively). We can also notice that the frequency of the bad coordination outcome is significantly higher in case of the CL treatment (24.5%) than in the other two treatments (9.5% in case of treatment CNL and 11.9% in case of treatment NCL). Considering the role of the lag in the theoretical model, this result is ambiguous. On one hand, this result is in line with the theoretical solution in the sense that because of the lag in the returns in the modern sector history plays a more important role than in case of the absence of this lag (treatment CNL). On the other hand, theory predicts no significant difference in the results between CL and NCL, as in theory our cost system does not affect the role of the lag, but we can see in this case as well, that there is a significant difference in the frequency of the BC outcomes.

4.1.1 Coordination within Groups

After analyzing the results of the three treatments on aggregate level, we turn our attention to the performance of the groups in the treatments. In treatment CNL we have observations for nine groups. The coordination results for each group are shown in Figure 3a (see Appendix B).

Our experimental data shows that behavior in this game is ambiguous. From the nine groups six arrived to the Pareto dominant equilibrium outcome, but there is a big difference in the speed of coordination. While Group 7 reached this outcome already in the second period, Group 2 in the third,

[20] We consider it important to distingish between these two groups, as while for one or two players it does not pay off to stay in the modern sector (even without considering the costs, the return for one or two players is lower in this sector than in the traditional one); while for three or four it may be worth to stay in the moern sector, if this decision is for long run (specially in case of the presence of costs, as there some time is needed to recover with the higher return the cost paid for changing the sector).

[21] In the rest of the section if we do not write the significance level, it means that the result is significant at any reasonable α.

Group1 and Group 8 in period 5, the other two groups needed significantly more time to get to this point (Group 4 in period 10, Group 5 in period 15). We can note that this outcome is a stable situation, once the groups reached it, they keep in this point. On the other hand there is one group, that does not find the way out of the bad equilibrium state, they get trapped in the initial capital distribution where agents invest in the traditional sector. After period 20 a subject chose sector 2, probably as an initiative to motivate the others to change, but as after some periods none of her colleagues followed her, she decided to return to sector 1. We can see that this outcome is also quite stable. Group 3 and Group 9 managed to reach a "medium level" of coordination, as both managed to reach the coordination of at least three agents in the modern sector. In fact, the individual data of these groups show that in group 3 there were three players that chose sector 2 continuously from the third period on, there was one player who during all 28 periods chose sector 1, and finally there was a player, who took a long time to decide for sector 2 (although clearly it would have been profitable once there were already at least two players there). In Group 4 four agents chose the modern sector from the forth period continuously, but the fifth member did not seem to understand the situation, as - even after changing once to the modern sector - she does not follow them in this decision. Finally both groups reach an intermediate coordination level with four agents in the modern sector.

To summarize the results of this treatment, we find that in this case it is possible to break free from the initial conditions, the majority of the groups managed to reach socially (and individually) more desirable state, but it takes time to reach this outcome. On the other hand we saw that behavior is quite stable in this game, we can not observe big oscillations in the coordination "size". We find it interesting that -as the figure also shows- the results are bipolar.

In treatment NCL we have observations for nine groups. The coordination results for each group are shown in Figure 3b (see Appendix B). The results of this treatment are not as clear as of the ones with cost. From the nine groups one (Group 3) got clearly trapped in the inefficient Nash outcome, although initially we can observe coordination among the agents, in period 5 there are already all the players in the modern sector, but in three periods they quit and turn back to the traditional one, from where they do not move. Three groups (Group 4, 7 and 9) manage to fully coordinate, but in case of the two latter groups, it takes longer to reach it and seems more difficult to maintain it (in both groups there is one player who tries to change back to the traditional sector, although all the other members of her group are in the modern sector). As it turns out less beneficial, both changes back to the modern sector, while the other four agents in both groups stay in the modern sector since period 2 (Group 7) and 11 (Group 9). Two groups (Groups 5 and 6) also manage to get out of the bad outcome, and reach a higher coordination level. In fact both groups manage to maintain at least 3 agents in the modern sector during the session (in fact, there are at least 4 players in the modern sector in both groups during the session, except of three and one periods respectively), but - they do not manage to maintain the full coordination on long run - although they reach it time by time during these 28 periods. The other three groups of this treatment (Groups 1,2, and 8) do not show any reasonable tendency in the coordination level,

In treatment CL we have observations for seven groups. The results of these groups are plotted in Figure 3c (see Appendix B).

Our experimental results for treatment CL look very similar to the ones of treatment CNL. We can see that in this game four out of seven groups managed to leave behind the bad equilibrium outcome, although again there is a significant difference between these groups in the speed of the change. (Group 7 reaches the good outcome in period 6, while Groups 2 and 3 in period 12, and Group 5 only in period 17.) Though behavior in these groups seems quite stable, in case of Group 2 and 5 we can observe a small decrease in the coordination level in the last two periods, one of the subjects in both groups decided to invest in sector 1 in the last two periods. This is not so surprising in the experimental literature, the so called "end effect", this is what we observe in this case, although it means a loss for the deviating agent. In this treatment we can find two groups (Group1 and Group 6) that got completely trapped in the Pareto inferior outcome, without any significant coordination during the whole game, as the maximum size of coordination in these groups was 1 and 2 respectively. The evolution of the last group, Group 4 is more surprising, as they reach a medium size coordination level already in the first period (3 agents in the modern sector), which they maintain during basically the whole the session, but they are not able to reach the outcome that require total coordination. The reason for this is that there is one player in this group who chooses the traditional sector during the whole session, and another who seems to be confused and changes the sectors several times during the session.

Again, as in case of the treatment CNL, we can notice, that the behavior of the groups in this treatment is stable, we can see that there is not much oscillation in the coordination size in any of the groups. This is in line with our expectations about the role of the costs, as the positive relocation costs seem to prevent players from the frequent sector changes.

4.2 Individual Behavior

In this section we analyze the individual behavior of the players, and examine the effects of the different behaviors what lays behind the group performance. According to the frequency of choosing the traditional sector, we classify the players in four categories.[22] In the first one (C1) belong those players who chose the traditional sector maximum 5 times during the experimental session, in the second one (C2) those ones who chose the traditional sector between 6 and 13 times during the experiment (both limits included), in the third one (C3) those who chose the traditional sector between 14 and 23 times (again both limits included), and in the last category (C4) belong those subjects who chose the traditional sector at least 24 times out of the 28 periods. With this grouping we manage to form quite homogeneous categories, and using the same categories for all treatments allows us to compare the main characteristics and differences of the individual behavior not only across categories but also across treatments. The distribution of the players according to this grouping is shown in Figure 4 (see Appendix C).[23]

To analyze the individual considerations that lead to the final decisions, we make to assumptions that are in line with the theoretical solutions. We use a probit regression in order to identify the variables that influence the decisions of the agents in each category. In each treatment we have two categories (C1 and C4) where we can not use this econometric tool to explain the choice of the subjects[24], but for these players we can make a plausible assumption that is in line with the theoretical solutions of the games. We assume that those players who got grouped in the category C1 (that is, they chose less than 6 times the traditional sector) are the ones who were thinking in the long run, and make their decisions in order to maximize their expected payoff over the 28 periods. Examining the individual data we can see that the majority of these players chose the traditional sector if ever, in the very first periods of the game, and once they changed to the modern sector, they stayed there basically till the last period. On the other hand, about those players who got grouped in the category C4 (that is, they chose less than 5 times the modern sector) we assume that they were thinking in the short run, and decided according to the actual differences in the expected monetary payoff of each period. The rest of the categories we will analyze for each treatment.

[22] The way of grouping of the subjects is not obvious, there are several characteristics that could be used for this purpose. We decided for the belowintroduced one, because it seems to be the most relevant to form homogeneous categories.

[23] The mean and standard deviation of the variables for the given categories in each treatment can be seen in Table 4 (Appendix C).

[24] In these groups the dependent variable (CHOICE) has practically no variation (it is a constant), therefore the binary estimation can not be performed.

In treatment CNL we have only one person in the category C2, and checking the series of his decisions, we can notice that she changed to the modern sector in the period 14, and after it she stayed there till the rest of the periods. Considering the number of players from her group in the modern sector, this decision is the payoff maximizing one, but we can wonder why she lasted so long to decide for the change. In the category C3 we have the observations for 3 players, here we already have enough data to run a probit estimation to understand what is behind the decisions. Our estimation results show that these players make their decisions on the basis of their choice of the previous period (CHOI), the accumulated payoff till the actual period (PROF) and the costs paid (COST).[25] The sign of the coefficients show that the higher the accumulated profit or the cost paid, the higher is the probability of choosing the modern sector; while the positive coefficient of the variable "choice of previous period" tells us that if in the previous round a player decided to invest in the traditional sector, the probability of choosing again this sector in the actual round is higher.

In treatment NCL although we have the data of 8 subjects in the category C2, the probit estimation does not give any plausible explanation for the observed behavior. We suspect that these players were not completely understanding the situation that they faced, and tried to "change" time by time to see the consequences. In the category C3 we have 11 players, and the probit regression shows three significant variables in this game. The coefficient of the variable "accumulated payoff till the actual period" (PROF) is positive, so the higher the accumulated payoff, the more probable to choose the traditional sector, the variable "choice of the previous period" (CHOI) has in this case a negative coefficient; and the variable "number of players of your group in the modern sector in the previous period" (SEC2) has a significant negative effect on the probability of choosing the traditional sector. This means that as less players chose the modern sector in the previous period, as higher is the probability of choosing the traditional sector.

In treatment CL, we get very similar estimation results for the two categories, C2 and C3. In both cases we find among the explanatory variables the "choice of the previous period" (CHOI) with positive coefficient, and the "costs paid" (COST) with negative coefficient, both significant at 1%.

From the results of the probit estimation the surprising point is at the treatment NCL. Here, we can see that the negative sign of the coefficient of variable "CHOI" is just the contrary of the corresponding signs in other treatments. This may partly explain the big oscillation observed in the coordination level in this treatment, as this sign suggests, that if in the previous

[25]For the results of the regressions for each treatment see Table 5 in Appendix C).

round a player decided to invest in the traditional sector, the probability of choosing again this sector in the actual round is lower.

5 Conclusion

In this paper we present experiments from a two-sector investment model with positive agglomeration externality, that can be described by a dynamic coordination game with two important features. First, the existence of a (fix) cost of moving between the sectors; second that a part of the returns on modernization arise with one period delay. Combining these features we design three dynamic coordination games and examine them in a controlled environment (experiments).

Under the assumptions of the model there exists multiplicity of Nash equilibria, among which the two most important ones are the one of full coordination in the "good" (modern) sector, and the second is the full coordination of players in the "bad" (traditional) sector. Both of these Nash equilibria are stable.

Our experimental results show that coordinated development may occur but the time that the coordination requires depends strongly on the parameters of the model. In our case we found that both factors, the cost structure and the presence of delay has an important impact on the coordination level. We could see that the positive costs make the individual behavior more stable, therefore in these cases if once the full coordination is reached, this outcome seems stable over time. On the other hand, if in one of the sectors of the economy there is a delay in the adjustment of the returns, this lag makes the full coordination among players more difficult, therefore it also takes longer to implement it. For the same reason, in this situation the frequency of the occurrence of the Pareto inferior Nash equilibrium is higher, a significantly higher proportion of our experimental economies gets trapped in the "bad" outcome, and the average level of coordination is significantly lower than if the returns in the sectors are realized immediately. This means that the presence of the time lag in the realization of the returns strengthens history dependence.

To summarize it, we can observe that in our model both the cost structure and the time lag in the returns has an important impact on the destiny of our experimental economy. In order to be able to leave behind the Pareto inferior outcome, players have to coordinate also on their beliefs and share the same time preferences. If most players plan their investment decisions on the long run, full coordination on modernization can be immediate, while if agents only care with the actual differences between the expected monetary payoffs, the economy can get trapped in the "bad" state for ever.

6 Appendix

A Instructions

A.1 Instructions for treatment CL

Thank you for participating in this experiment. The aim of this session is to study how people make decisions in given situations. From now on till the end of the session any communication with other participants is forbidden. If you have any question, feel free to ask at any point of the experiment. Please do so by raising your hand and one of us will come to your desk to answer your question.

During the session you can earn money. You will receive 5 euro for your participation, in addition to the amount you make as a result of decisions made in the experiment. Your payment is confidential, everybody will be told his own payment and it will be paid in cash at the end of the experiment.

A.1.1 Rounds, Groups, and Roles:

This experiment will have 28 rounds. In each round you will be in a group with 4 other participants. The participants with whom you are grouped will be the same during the whole session.

A.1.2 Description of the Decision Task:

At the beginning of the session – independently of the participation fee - you will get an initial capital of 1 euro, and you have to decide whether to invest in sector 1 or in sector 2. At the beginning of each period, you have to invest the whole payment of the previous year in one of the sectors. Specifically, you will be asked in each round to choose 1 (referring to sector 1) or 2 (sector 2). Initially (before making the first decision) all the participants are in sector 1.

A.1.3 Payoffs:

For each round of the experiment you will receive a payoff depending on the decision you chose. In the first sector the return (R1) is 0.03, while in the second sector the return (R2) depends on the number of players of your group who are in the second sector (including yourself as well if you chose sector 2). Notice that you do not know the decision of the others when you choose between sector 1 and sector 2 (but you know what they chose in the previous period).

		Number of players in the modern sector (including yourself if you also chose this sector)				
		1	2	3	4	5
Your Choice	sector1	0.03 (3%)	0.03 (3%)	0.03 (3%)	0.03 (3%)	0.03 (3%)
	sector2	0.016 (1.6%)	0.025 (2.5%)	0.0335 (3.35%)	0.04 (4%)	0.0445 (4.45%)

Do not worry about memorizing this table, as the program will display it any time you have to make an investment decision.

A.1.4 Costs:

Changing from one sector to the other has a fixed cost: the cost of changing to sector 1 (C1) is 0.03 euro, and the cost of changing to the second sector (C2) is 0.3 euro. This means, that if in one of the rounds you invest in sector 1, and in the next one you decide to invest in sector 2, your payoff for this round will be reduced by 0.3. On the other hand, if in one of the rounds you invest in sector 2, and in the next round you decide to invest in sector 1, your payoff for this round will be reduced by 0.03.

A.1.5 Reception of payments:

The return you receive in a round does not simply depend on the return of the sector that you actually choose, as in addition you get a bonus related to your decision. S1 (defined as 0.03*I) is the bonus corresponding to your actual decision, and you receive it immediately in each period when you chose sector 1. S2 (defined as $R2_{(t-1)} * I_{(t-1)}$) corresponds to your choice of sector 2 in the previous period, what you get with a delay of one period (independently of your actual decision). Notice that S2 depends of R2, what – depending on the number of players in sector 2 – can change between 1.65% and 4.45%.

In particular, the formula to compute your accumulated payoff in round t is the following:

1) If in the **previous round** you chose **sector 1** and **now** you choose:

i. **sector 1**: $Payoff(t) = 1.03 * I + S1$;

where I is the amount of money invested in this round; and S1 is the bonus corresponding to your actual decision (sector 1).

ii. **sector 2**: $Payoff(t) = (1 + R2) * I - 0.3$;

where R2 is the rate of return of this round in sector 2; I is the amount of money invested in this round; and 0.3 is the cost of changing to sector 2.

2) If in the **previous round** you chose **sector 2** and **now** you choose:

i. **sector 1**: $Payoff(t) = 1.03 * I + S2 + S1 - 0.03;$

where I is the amount of money invested in this round; S2 is the bonus corresponding to your previous decision (sector 2); S1 is the bonus corresponding to your actual decision (sector 1); and 0.03 is the cost of changing to sector 1.

ii. **sector 2**: $Payoff(t) = (1 + R2) * I + S2;$

where R2 is the rate of return of this round in sector 2; I is the amount of money invested in this round; and S2 is the bonus corresponding to your previous decision (sector 2).

Do not worry about memorizing these formulas, as the program displays them and also the values of S1, S2 and I, any time you make a decision.

A.1.6 Payoff of the last round:

The bonus of the last round you will get without any delay in both sectors, thus at the end of the session everybody receives the whole return won during the session. In this last round the computer will display the corresponding formulas.

A.1.7 Bankruptcy rules:

In case in any period your accumulative payoff goes negative, you and your whole group finish playing, but will have to remain in your seat till the other groups finish the experiment. In this case the players in your group will get paid the earnings collected till this period plus the participation fee at the end of the session. The person who went bankrupt will get a zero payoff for the decisions-based payment, that is, he will get paid only the participation fee.

A.1.8 Playing a round:

For each round of the experiment, the computer will display all the data you may need to make a decision. You can compute your payoff using the calculator that appears on the left side of the screen before making a decision.

Each player will choose a sector using the buttons on the right hand side of the screen. You may change your choices as often as you like, but once you click on "OK" your choice is final. At no point in time will we identify the other players in your group. In other words, the actions you take in this experiment will remain confidential.

A.1.9 Information that you will receive:

After each round you will be informed about the number of players of your group in the second sector (including yourself if you also chose that sector), your decision of the current and previous rounds, the costs you paid for changing the sector, and the evolution of your payoff from round to round.

A.1.10 Example Payoff Quiz:

Before we begin the experiment, we will ask you to answer some questions, which were designed to check that you understand the game and your decision task. Please raise your hand if you are having trouble answering any of the questions. Once everybody answered the questions correctly, the experiment will start.

B Coordination results

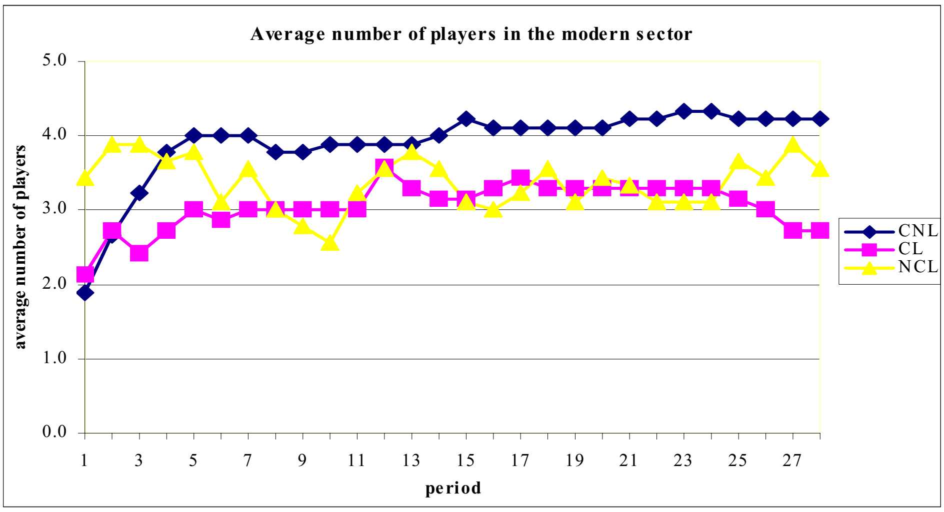

Figure 1: Average number of players in the modern sector

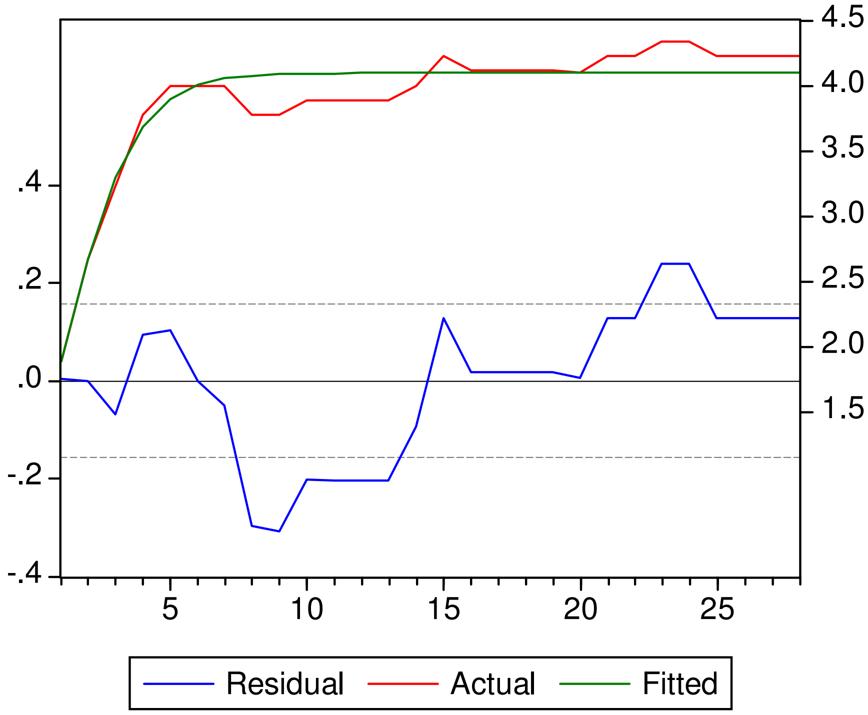

Figure 1a: Fitted values for treatment CNL

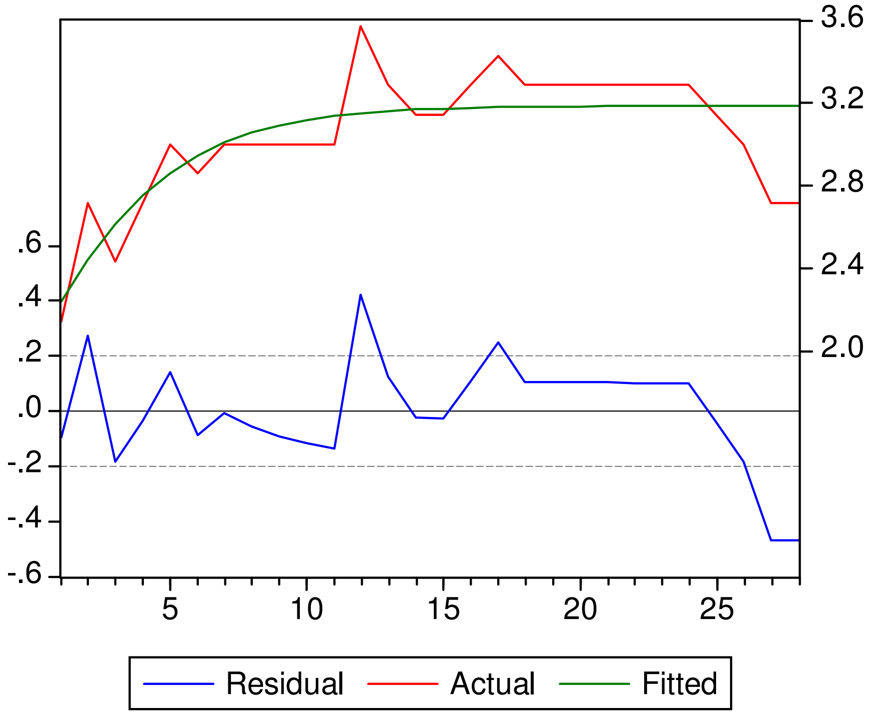

Figure 1b: Fitted values for treatment CL

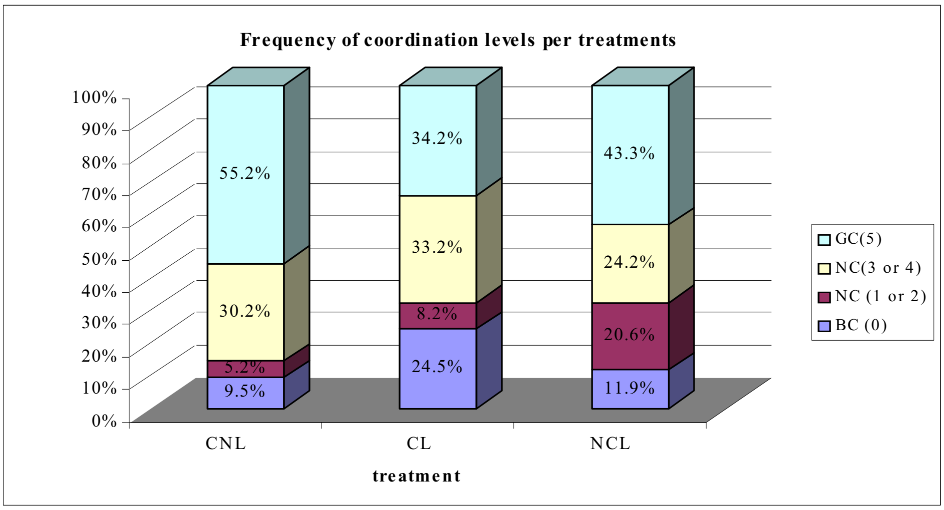

Figure 2: Frequency of coordination levels per treatmens

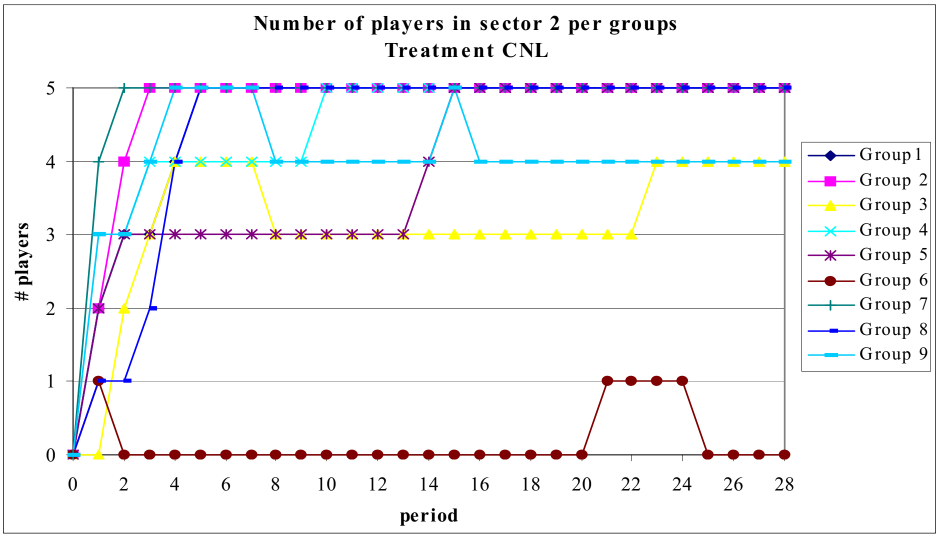

Figure 3a: Coordination in treatment CNL

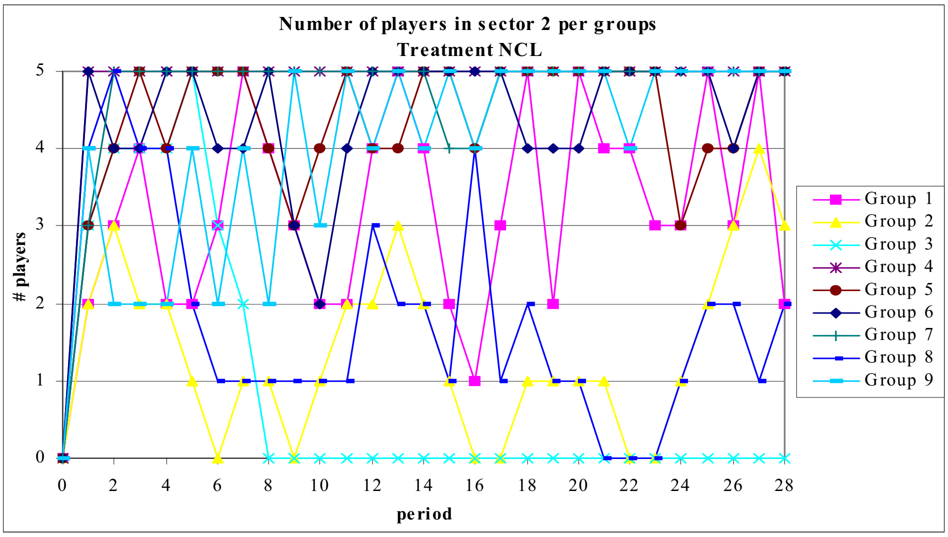

Figure 3b: Coordination in treatment NCL

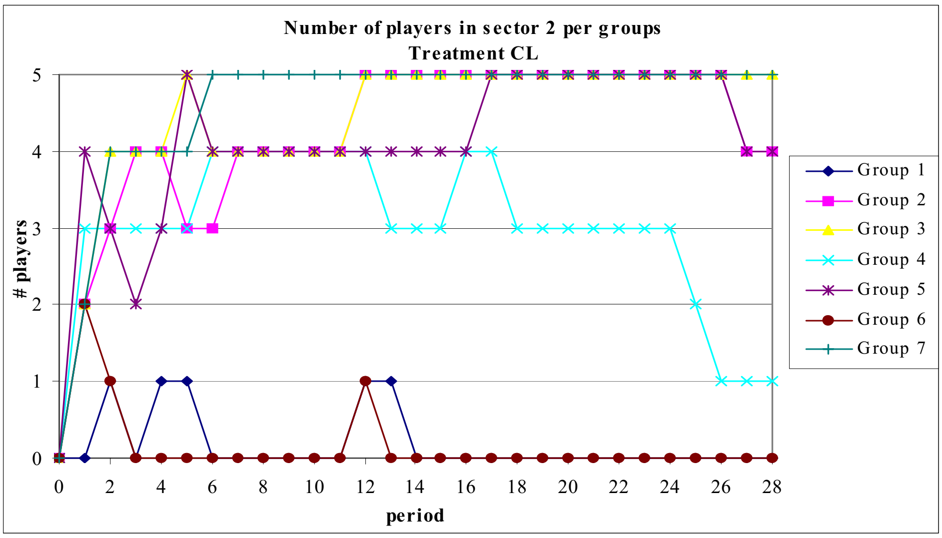

Figure 3c: Coordination in treatment CL

C Individual Results

		Mean				Maximum				Minimum				Std. Dev.			
		CHOICE	SEC2	EARN	PROFIT	CHOICE	SEC2	EARN	PROFIT	CHOICE	SEC2	EARN	PROFIT	CHOICE	SEC2	EARN	PROFIT
CNL	C1	0.05	4.30	0.21	2.78	1	5	0.64	7.841	0.000	0	-0.27	0.004	0.21	1.22	0.171	1.82
	C2	0.46	3.82	0.20	2.799	1	5	0.54	6.610	0.000	0	-0.13	1.060	0.51	1.28	0.159	1.61
	C3	0.64	3.62	0.14	2.275	1	5	0.54	6.550	0.000	0	-0.22	0.899	0.48	1.14	0.126	1.20
	C4	0.97	0.66	0.13	2.415	1	4	0.29	5.112	0.000	0	-0.27	0.733	0.17	1.21	0.076	1.14
NCL	C1	0.06	4.44	0.27	3.591	1	5	0.75	9.583	0.000	0	0.03	0.001	0.24	1.13	0.180	2.24
	C2	0.33	3.25	0.19	2.895	1	5	0.62	7.703	0.000	0	0.03	1.025	0.47	1.48	0.130	1.59
	C3	0.71	1.27	0.15	2.615	1	5	0.39	5.522	0.000	0	0.02	1.025	0.46	1.41	0.078	1.21
	C4	0.92	1.31	2.64	2.644	1	5	0.46	5.266	0.000	0	0.03	1.040	0.28	1.41	0.076	1.22
CL	C1	0.05	4.20	0.17	2.375	1	5	0.53	6.730	0.000	0	-0.28	0.007	0.21	1.17	0.148	1.50
	C2	0.36	3.88	0.15	2.383	1	5	0.45	6.229	0.000	0	-0.25	1.019	0.48	1.24	0.132	1.29
	C3	0.52	3.57	0.07	1.539	1	5	0.20	3.603	0.000	0	-0.27	0.639	0.50	1.17	0.111	0.76
	C4	0.97	0.66	0.13	2.415	1	4	0.29	5.112	0.000	0	-0.27	0.733	0.17	1.21	0.076	1.14

Table 4: Descriptive statistics for the categories in each treatment

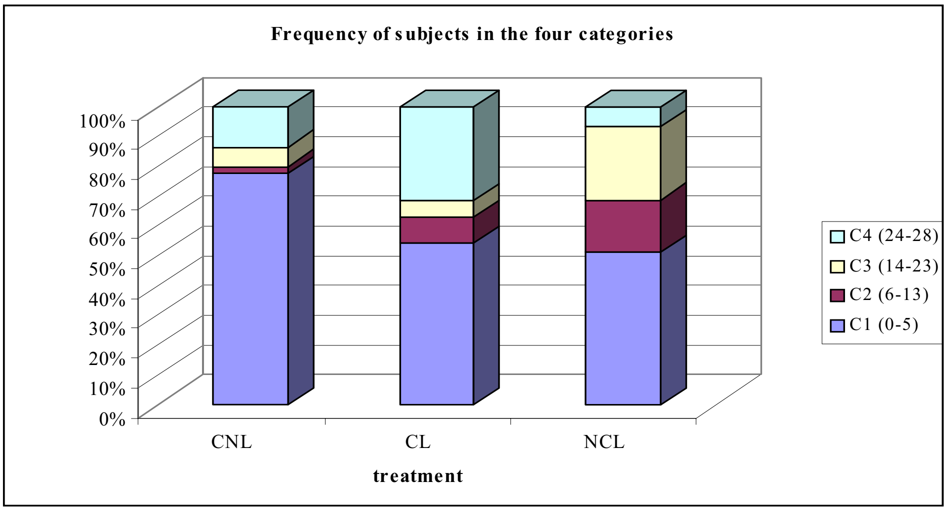

Figure 4: Frequency of subjects in the four categories

		COEFFICIENT				
		Constant term	CHOI	PROF	SEC2	COST
CNL	**C3**	0.145	3.871*	-0.605***	-	-1.558*
NCL	**C3**	1.294*	-0.52586**	0.191**	-0.567*	-
CL	**C2**	-1.698*	4.198*	-	-	-1.357*
	C3	-0.785*	3.007*	-	-	-1.205*

* statistically significant at 1% ** statistically significant at 5% *** statistically significant at 10%

Table 5: Results of the probit estimation

References

[1] Adserà, A. and Ray, D. (1998): "History and Coordination Failure" *Journal of Economic Growth* **3.**, pp.267-276

[2] Bryant, J. (1982): "A Simple Rational Expectations Keynes-Type Model" *Quarterly Journal of Economics* **97.**, pp.525-529

[3] Chamley, C. and Gale, D. (1994): "Information Revelation and Strategic Delay in a Model of Investment" *Econometrica* **62.**, pp.1065-1086

[4] Chatterjee, S. and Cooper, R. (1989): "Multiplicity of Equilibria and Fluctuations in Dynamic Perfectly Competitive Economies" *AEA Papers and Proceedings* **79.**, pp.353-357

[5] Cooper, R.W.; DeJong, D.V. and Forsythe, R. (1989): "Communication in the Battle of Sexes Games: Some Experimental Results" *RAND Journal of Economics* **20.**, pp. 568-587

[6] Camerer, C.F.: *Behavioral Game Theory*, Princeton: Princeton University Press, 2003

[7] Cooper, R.W.; DeJong, D.V. and Forsythe, R. (1990): "Selection Criteria in Coordination Games: Some Experimental Results" *The American Economic Review* **80.**, pp. 218-233

[8] Cooper, R.W.; DeJong, D.V. and Forsythe, R. (1992): "Communication in Coordination Games" *The Quarterly Journal of Economics* ***107.***, pp. 739-771

[9] Duffy, J. and Feltovich, N. (2002): "Do Actions Speak Louder Than Words? An Experimental Comparison of Observation and Cheap Talk" *Games and Economic Behavior* **39.**, pp. 1-27

[10] Ethier, Wilfred J. (1982): "Decreasing Costs in International Trade and Frank Graham's Argument for Protection" *Econometrica* **50.**, pp.1243-68

[11] Fukao, Kyoji and Benabou, Roland (1993): "History Versus Expectations: A Comment" *The Quarterly Journal of Economics* **108.,** pp.535-542.

[12] Gale, D. (1995): "Dynamic Coordination Games" *Economic Theory* **5.**, pp.1-18.

[13] Helpman, Elhanan (1984): *"Increasing Returns, Imperfect Markets and Trade Theory"* in Handbook of International Economics, Vol. I

[14] Henderson, J.V.(1994): "Externalities and Industrial Development" *NBER Working Paper* No.4730

[15] Krugman, Paul (1991): "History Versus Expectations" *The Quarterly Journal of Economics* **106.**, pp.651-667

[16] Matsuyama, Kiminori (1991): "Increasing Returns, Industrialization, and Indeterminacy of Equilibrium" *The Quarterly Journal of Economics* **106.**, pp.617-650.

[17] Mortensen, Dale (1988): "The Persistence and Indeterminacy of Unemployment in Search Equilibrium" *Discussion Paper No.810*, Northwestern University

[18] Murphy, Kevin M.; Shleifer, Andrei and Vishny, Robert W. (1989): “Industrialization and the Big Push” *The Journal of Political Economy* **97**., pp.1003-1026.

[19] Panagariya, Arvind (1986): "Increasing Returns, Dynamic Stability and International Trade" *Journal of International Economics* **20**., pp.43-63

[20] Rosenstein-Rodan, Paul (1943): "Problems of Industrialization of Eastern and Southern Europe" *Economic Journal* **55**., pp.202-211

[21] Straub, Paul, G. (1995): "Risk Dominance and Coordination Failures in Static Games" *The Quarterly Review of Economics and Finance* **35**., pp.339-363

[22] Van Huyck, J.B.; Battlio, R.C. and Beil, R.O. (1990): "Tacit Coordination Games, Strategic Uncertainty, and Coordination Failure" *The American Economic Review* **80**., pp. 234-248