Three Essays on Experimental Economics

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Szüleimnek és Carlos-nak.

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Chapter 1

Introduction

There was a time when the conventional wisdom was that, because economics is a science concerned with complex, naturally occurring systems, laboratory experiments had little to offer economists. But experimental economics has now become a well-established tool that plays an important role in helping game theory bridge the gap between the study of ideally rational behavior modeled in theory and the study of actual "real-world" behavior of agents. Although it has older antecedents, experimental economics is a fairly new line of work, having originated more or less contemporaneously with game theory. As economist focused on microeconomic models which depend on the preferences of the agents, the fact that these are difficult to observe in natural environments made it increasingly attractive to look to the laboratory to see—in a controlled environment—whether the assumptions made about individuals were descriptive of their behavior. But game theory is the part of economic theory that does not focus solely on the strategic behavior of individuals in economic environments, but also on other issues that will be critical in the design of economic institutions, such as how information is distributed, the influence of agents' expectations and beliefs, and the tension between equilibrium and efficiency. Game theory has already achieved important insights into issues such as the design of contracts and allocation mechanisms that take into account the sometimes counterintuitive ways in which individual incentives operate in environments with decision makers that have different information and objectives. However if we do not take steps in the direction of adding a solid empirical base to game theory, but instead continue to rely on game theory primarily for conceptual insights (deep and satisfying as these may be), then it is likely that game theory will have experienced sharply diminishing returns. And again, experimental economics can be called to build this empirical base. Laboratory experiments and the experimental methods can be of support in different ways. Besides the traditional use of verifying theoretical results and predictions, experiments allow the investigator to test the plausibility of assumptions, to measure parameters or variables on which the predictions of theory depend but would be unobservable, or difficult to measure in non-experimental situations, to provide insights into field data, or to suggest new ideas about human reasoning in economic situations.

This thesis is divided into three chapters that present self-contained studies of economic situations where experiments may help game theory to explain field observations. In deriving the results, besides the game theory literature, rigorous statistical and econometric methods are used. The following part of the Introduction is devoted to highlight more details about the main results of each chapter and to locate them in the literature.

1.1 The Way out of the Trap: Experiments on Dynamic Coordination Games

One of the fields where experimental economics has helped theorists, is the class of situations that can be modeled by coordination games. 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.

Coordination games characterize strategic interactions in many fields of economics and real life.[1] 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] 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.

Facing the equilibrium selection problem, numerous investigators examine the role and use of historical factors vs. perfect foresight in predicting the resulting equilibrium. The assumption of perfect foresight may help to answer for a central question posed by Rosenstein-Rodan (1943): how does an economy move from a bad

[1] In economics, they are present for example in models on industrial organization (models of double moral hazard; network externalities, and team production) and macroeconomic models (models of imperfect competition and search).

[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).

to a 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? These questions, as well as the distinction of history versus expectations are of particular importance in the context of development. As Matsuyama points out: [3] "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.

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.[4] We are only aware of a few experimental studies on development under dynamic settings. Lei and Noussair (Lei and Noussair, 2003) study equilibrium selection in a decentralized experimental macroeconomy, which present two Pareto-rankable stable competitive equilibria. They find that there is a tendency for the economy to fall into the Pareto-inferior equilibrium and only if the initial endowments are high, it is more likely to reach the optimal outcome. In a subsequent paper Capra et al. (Capra et al., 2005) study the role of two institutions—communication and voting—in the achievement of the good equilibrium. They find that both communication and voting enables agents to move out

[3] Matsuyama (1991).

[4] For a survey on experimental results on coordination games see for example Camerer (2003).

the economy from the bad outcome.

This first chapter, a joint work with Jordi Brandts, contributes to the experimental literature on development economics. We present an experiment on dynamic coordination games with the purpose of answering the above questions and explaining the observed behavior.

We designed a laboratory experiment to examine agents' behavior in a dynamic two-sector investment situation in a controlled environment. The model we adapted was developed by Adserà and Ray (1998), which is a two-sectors model of sectorial adjustment with positive agglomeration externalities, which manifest themselves with a time lag (that can be vanishingly small).[5] They find that if relocation costs are constant 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). Three treatments are conducted, which defer in cost structure and the presence (or absence) of the time lag: moving between a traditional and a modern sector has a fix cost, and in one of the sectors the positive agglomeration externalities manifest themselves with a time lag, that is, the returns to modernization only arise with some delay. Under these conditions the model exhibits multiple—Pareto rankable—equilibria, and both complete stagnation as well as immediate development are equilibria of the dynamic game independently of the cost and delay, and both equilibria are stable. However, our results show that both the cost structure and the time lag in the returns has an important impact on the destiny of the experimental economies. We find experimental evidence on the fact that the presence of the time lag in the realization of

[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).

the returns strengthens history dependence, but it does not necessarily prevent the full coordination on modernization, the economy can find a way out of the (poverty) trap.

1.2 School Choice and Information: An Experimental Study on Matching Mechanisms

The third and fourth chapter of the thesis explore a different issue of experimental economics. Both studies characterize some theoretically widely explored matching mechanisms under (partial) uncertainty. As many questions regarding the strategic incentives agents face under incomplete information still remain to be answered on theoretical ground, there is an ample room for experiments on this field: they can give some feedback on field observations and add guidance to theory.

In a two-sided matching market, agents belong one of the two disjoint sets that represent the two sides of the market, as for example students and schools. Agents on both sides of the market have ordinary preferences over the agents of the other side of the market, and over the possibility of being unmatched. The problem than reduces to assigning students to schools through some matching mechanism. The working of such mechanisms, along with strategic issues that confront individuals in these contexts, have been explored theoretically. Strategy-proofness, stability and efficiency are highly valued properties of such mechanisms.

Matching is a pervasive phenomenon arising in several economic and social settings: the assignment of civil servants to civil service positions, the admission of students to colleges, or some entry-level labor markets are among the matching situations that have gained attention in the last decades, motivated by some unexpected field observations.

Chapter 3, a joint work with Joana Pais, analyzes three well-known matching mechanisms—the Boston, the Gale-Shapley, and the Top Trading Cycles (TTC) mechanisms—under three different informational settings in the so called school choice model. This matching model has the particularity that only one side of the market (in our case teachers) is formed by strategic agents, the preferences of the other side (in this case of schools) is exogenously given. We are aware of several experimental papers that deal with this problem (Chen and Sönmez (2002a, 2002b, 2003); Harrison and McCabe (1996)), but they ignore the effect of information about the elements of the game on the decisions and on the performance of the matching mechanisms. As we mentioned, theory has explored the properties of these matching mechanisms regarding strategy-proofness and efficiency—in the complete information case.[6] In this study we pose two main questions. First, we compare the individuals' decision making regarding truthtelling and efficiency under the three mechanisms, in each informational setting. The comparison of the mechanisms suggests the superiority of the TTC mechanism. Although regarding the truthful preference revelation—depending on the implemented informational setting—it may give similar results as the Gale-Shapley mechanism, in the achieved efficiency level the TTC mechanism performs clearly better than either the Boston or the Gale-Shapley mechanism. Our second aim is to evaluate the influence of the amount of information held by the individuals on decision making, under the three matching mechanisms. The experimental results show that if participants have no information about the others' preferences —i.e., they only know their own induced preferences, that is, their own payoffs—, they are more likely to play truthfully than in case of having additional information. This truthful preference revelation

[6] For more details see Dubins and Freedman (1981), Roth (1982a, 1982b) and Shapley and Scarf (1974).

results also in a higher efficiency level, except under the TTC mechanism, where the additional amount of information has no significant negative effect on the achieved efficiency. This means that the TTC mechanism results less sensitive to the amount of information that the participants hold. Therefore, we conclude that the use of the TTC mechanism in practice would be more desirable than of the others.

1.3 College Admissions and Information: An Experimental Study on Matching Mechanisms

The fourth chapter also deals with some characteristics of the matching markets, but in this case we take a step further by considering the college admissions problem. The main difference between the school choice and the college admissions problem is that while in the former one only agents on one side of the market (teachers in our case) can behave strategically, in the latter agents of both sides of the market (teachers and schools) have the possibility of manipulating their true preference ordering. This difference has an important effect on strategy-proofness. In this problem, both mechanisms are strategy-proof for the proposing side of the market (in our case for teachers), but agents on the other side (schools) may gain by strategic behavior.

This class of situations—similarly to the school choice problem— are also frequently present in real life situations. We can think about the entry-level labour markets in general, where both candidates and employers can decide freely about the ordering over employers and candidates, respectively.

In this chapter I analyze the effects of the amount of information on individual decisions in both sides of the market, and the performance of the Gale-Shapley and the TTC mechanisms regarding strategy-proofness, stability and efficiency. Again, theory—for the complete information case—has explored the properties of both mechanisms in this problem, and our experimental results confirm these. When comparing the performance of the two mechanisms, I find that the Gale-Shapley mechanism performs as good as the TTC mechanism regarding strategy-proofness, and outperforms TTC in terms of stability and efficiency. I am also interested in the effects of the amount of information participants hold about the elements of the game on the decisions. The experimental results show that information has an important (negative) effect on truthfulness and stability, but regarding efficiency, the Gale-Shapley mechanism is less sensitive to the amount of information participants hold than the TTC mechanism. Therefore, we conclude that the use of the Gale-Shapley mechanism would be desirable in the college admissions situations.

Bibliography

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

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

[3] Capra, C. M. et al. (2005): "The Impact of Simple Institutions in Experimental Economies with Poverty Traps" *Working Paper*

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

[5] Chen, Y. and Sönmez, T. (2002a): "Improving Efficiency of On-Campus Housing: An Experimental Study" *American Economic Review* **92.**, 5, pp.1669-1686

[6] Chen, Y. and Sönmez, T. (2002b): "An Experimental Study of House Allocation Mechanisms" *Economics Letters* **83.**, 1, pp.137-140

[7] Chen, Y. and Sönmez, T. (2004): "School Choice: An Experimental Study" *Journal of Economic Theory*, forthcoming

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

[9] Dubins, L. and Freedman, D. (1981): “Machiavelli and the Gale-Shapley Algorithm“ *American Mathematical Monthly* **88.**, pp.485-494

[10] Harrison, G. and McCabe, K. (1996): “Stability and Preference Distortion in Resource Matching: An Experimental Study of the Marriage Problem“ In V. Smith (ed.) *Research in Experimental Economics* **6.**, pp.53-129, JAI Press

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

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

[13] Lei, V. and Noussair, C. (2003): “Equilibrium Selection in an Experimental Macroeconomy“ *Working Paper,* Emory University

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

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

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

[17] Roth, A. (1982a): “The Economics of Matching: Stability and Incentives“ *Mathematics of Operations Research* **7.**, pp.617-628

[18] Roth, A. (1982b): "Incentive Compatibility in a Market With Indivisibilities" *Economics Letters* **9**., pp.127-132

[19] Shapley, L. and Scarf, H. (1974): "On Cores and Indivisibility" *Journal of Mathematical Economics* **1**., pp.23-28

Chapter 2

The Way out of the Trap: Experiments on Dynamic Coordination Games

2.1 Introduction

One of the first and still open questions in development economics is how to explain that some countries are rich while others are poor. Theorists have studied the question in the last decades, and found several possible—and plausible—explanations. The problem is that there are too many plausible explanations and it is difficult to clearly separate the effect of each factor using field data. Early studies[1] of market economies in the presence of externalities show that there may exist multiple Pareto-ranked equilibria, where the rich countries managed to reach the optimal equilibrium, some others find themselves in a low-income equilibrium, in a poverty

[1] See for example Rosenstein-Rodan (1943), or Murphy, Shleifer and Vishny (1989).

trap. But the key question posed by Paul Rosenstein-Rodan (Rosenstein-Rodan, 1943)—How does an economy move from a bad to a good equilibrium?—is still not satisfactorily answered.

Facing the equilibrium selection problem, investigators offer several possible factors for predicting the resulting equilibrium, such as history[2] or expectations (perfect foresight). The distinction of history versus expectations is of particular importance in the context of development. As Matsuyama (Matsuyama,1991) points out: "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 optimism.

Theoretical studies—under the assumption of perfect foresight— managed to identify the effect of several factors on the equilibrium selection problem. 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

[2] Here we can think about differences in economic, social, and political systems (e.g. Baumol, 1986; Barro and Sala-i-Martin, 1995); in culture (e.g. Knack and Keefer, 1997), in geographic locations or in resources.

an important distinction. They assume that positive agglomeration externalities manifest themselves with a time lag (that can be vanishingly small).[3] They find that if relocation costs are constant or depend negatively on the number of agents in the destination sector, 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).

In field data it is very difficult to identify the effect of each of the factors that may influence the outcome and therefore the path an economy follows, here laboratory experiments result useful, as the different parameters can be controlled. This paper presents an experimental investigation to evaluate the influence of two parameters—cost structure and time lag—on the equilibrium selection, and to shed light on the conditions that allow an economy to break free of the initial conditions—if it is possible at all.

Although in the experimental literature there exists a large number of studies concerned with equilibrium selection problems, most of 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.[4] We are only aware of a few experimental studies on development, under dynamic settings. Lei and Noussair (Lei and Noussair, 2003) study equilibrium selection in a decentralized experimental macroeconomy, which present two Pareto-rankable stable competitive equilibria. They find that there is a tendency for the economy to fall into the Pareto-inferior equilibrium and only if the initial endowments are high, it is more likely to reach the optimal outcome. In a subsequent paper Capra et al. (Capra et al., 2005) study the role

[3] 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).

[4] For a survey on experimental results on coordination games see for example Camerer (2003).

of two institutions—communication and voting—in the achievement of the good equilibrium. They find that both communication and voting enables agents to move out the economy from the bad outcome.

In this paper we study two parameters that although theoretically it was explored by Adserà and Ray (1998), haven't gained much attention in the experimental literature—the cost structure and the speed of realizing returns on investments—in a dynamic two-sector investment model with positive agglomeration externality. In this model moving between a traditional and a modern sector has a fixed cost, and the returns to modernization only arise with some delay. We think these assumptions are not unrealistic, as investors usually have to assume some costs related to their investments and returns on investments are not realized immediately in any economic sector in real life.

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 they will get trapped in the (initial) Pareto inferior equilibrium. The other question we pose is strongly related to the previous one. We want to study which expectations are formed by the agents and see whether the two parameters (cost structure and time lag) affect these expectations and therefore, individual decisions.

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. 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, if investment changes are costly, results are bipolar, the 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" coordination. We use a probit regression to explain the motives that are behind our experimental data on individual decisions, and we see that the different outcomes (resulting from different individual decisions) 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 of the experiment; then in Section 4 we report our experimental results; and the last section concludes.

2.2 The Two-Sector Investment Model

We study a simple two-sector dynamic investment model with positive agglomeration externality, under three different parameterization (treatments), which will be the examined three experimental treatments (CNL, NCL, CL)[5]. 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.[6] 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

[5] 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 and Lag.

[6] As you will see, this initial situation is the Pareto-inferior equilibrium of all three games. We decided to start the economy in this outcome in order to study whether they can move from the worst outcome to a better one, as it was posed by Rosenstein-Rodan.

on the number of agents in this sector. This means, that if there are N agents in the economy, from which n invest 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 f is continuous, strictly increasing and satisfies:

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

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 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.

We chose the values of the switching cost in a way that they are sufficiently high, hence they have importance in the decision making. On the other hand, the cost of switching to the modern sector is sufficiently high in comparison to the cost of changing to the traditional one, therefore this cost structure could "help" the economy to get trapped in the bad initial outcome.

The other parameter we are interested in is the time lag; therefore 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:[7]

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

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:

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

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

Before starting with the description of the games, 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

2.2.1 Mutual Nash equilibria of All Three Games

In our equilibrium analysis of the games—because of the complexity of the strategy space—we concentrate on symmetric pure strategy equilibria. Although the three treatments only differ in the cost structure and the presence or absence of the time lag, they can be described with three different dynamic non-cooperative coordination games. In our settings, 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.

An important feature of the Nash equilibria of the games is that they can be Pareto-ranked. In this section we will describe the "best" and the "worst" outcomes, which are common for the three games.

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. In particular, this outcome is the Pareto inferior one, as it gives the lowest payoff to the agents.[8] We can also notice, that this equilibrium coincides with the equilibrium outcome generated by myopic behavior as long as agents' accumulated capital is less than 15.[9] [10]

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 fact, this equilibrium, which we call the perfect foresight equilibrium, is the Pareto dominant outcome, this generates the highest payoffs to the agents.

2.2.2 Other Nash Equilibria of Each Game

Beside the above described Nash equilibria, each game has other Nash equilibria, depending on the parameters of the game.

In case of the treatment NCL , where moving between the sectors is costless, but in the modern sector there is a one-period lag in the return to the capital invested, 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

[8] In this treatment the unilateral deviation of a single agent from sector 1 to 2 is never profitable, as she gets a significantly lower return for that period, and moreover she has to pay the corresponding cost of relocation, therefore her accumulated capital gets lower. Hence, the profitable unilateral deviations should be investing instead of sector 2 in sector 1, but as long as the others are in sector 2, this change - beside the switching cost - generates lower returns. 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.

[9] In our experiments the accumulated payoff of the subjects was always lower than 15 units.

[10] In the games because of the lag applied in the modern sector and because of the cost structure, the comparison of the current returns (myopic behavior) always suggests to keep investing in the traditional sector.

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.

In treatment CNL, where changing sectors involves a positive cost, but the returns to capital are realized without time lag in both sectors, 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).

In the most complex, and most realistic treatment (CL), where there is a lag in the return of the capital invested in the modern sector, and each relocation is costly, 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).

2.3 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[11]. 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.

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 occurred during the sessions. Before starting

[11] Fischbacher, 1999

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 B.[12] 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).

2.4 Experimental Results

In this section we present our experimental results. First we concentrate on the number of subjects in the modern sector for each group (what we will call coordination level) in 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.

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

2.4.1 Coordination within Groups

In treatment CNL we have observations for nine groups. The coordination results for each group are shown in Graph 1a (see Appendix A).

Our experimental data shows that behavior in this game is bipolar. 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, 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 Graph 1b (see Appendix A). The results of this treatment are not as bipolar 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 Graph 1c (see Appendix A).

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.

2.4.2 Coordination within Treatments

After analyzing the results of the different experimental economies in all three treatments, we turn our attention to the coordination performance of the groups on aggregate level in the 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 Graph 2 (see Appendix A). We can see that since the fourth period the average number of players in the modern sector is the highest in the treatment CNL, and this difference is maintained during the periods. Also, we can notice, that the shape of the graphs of these two treatments look very similar, after an initial "adjustment phase" both curves stay stably around a number. Namely, in treatment CNL the average number of players in the modern sector stays around 4 from the fourth period on, while in the treatment CL the average coordination level stays steadily around 3 after the fifth period. The analysis of the fitted values of the regression for treatment CNL shows a logistic tendency, and after the initial increase, the average coordination level stays slightly over 4 on the long run.[13] 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 on the long run.[14] 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

[13]For the graph of the fitted values for treatment CNL see Graph 2a in Appendix A.
[14]To see the fitted values of the regression for treatment CL, see Graph 2b in Appendix A.

leaving behind the bad initial outcome in the sense, that three players together in the modern sector already make higher profits as if the economy was trapped in the initial outcome (everybody in the traditional sector).

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 28 periods is 3.37). Although we remember, that 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 ones where three or four players of a group choose it.[15] In the fourth group, called BC (Bad Coordination), we sum up the

[15]We consider it important to distinguish between these two groups, as while for one or two

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 Graph 3 (see Appendix A). 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[16] 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.

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 modern 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).

[16] 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.

2.4.3 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.[17] 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 Graph 4 (see Appendix A).[18]

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[19], but for these players we can make a plausible assumption that is in line with the

[17] 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 below introduced one, because it seems to be the most relevant to form homogeneous categories.

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

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

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.

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).[20] 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

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

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

2.5 Conclusions

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).

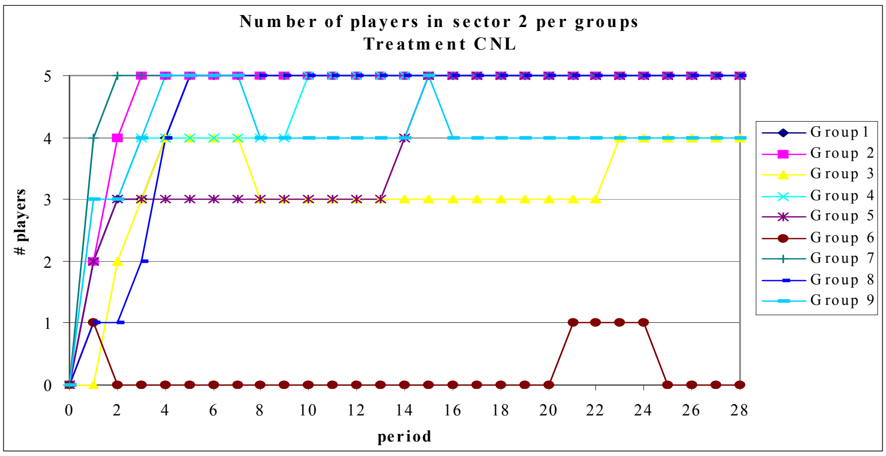
Under the assumptions of the model there exists multiplicity of Nash equilibria, among which the two most important ones are the one of full coordination in the "good" (modern) sector, and the second is the full coordination of players in the "bad" (traditional) sector. Both of these Nash equilibria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

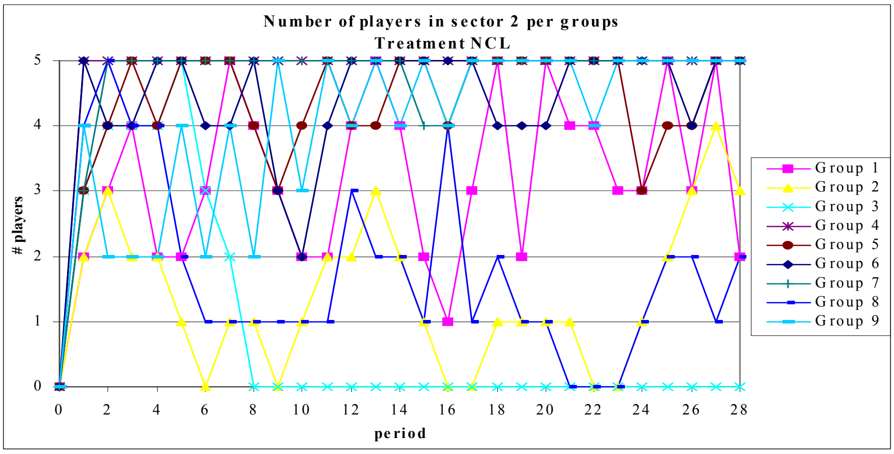
To summarize it, we can observe that in our model both the cost structure and the time lag in the returns has an important impact on the destiny of our experimental economy. In order to be able to leave behind the Pareto inferior outcome, players have to coordinate also on their beliefs and share the 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.

2.6 Appendix A. Results

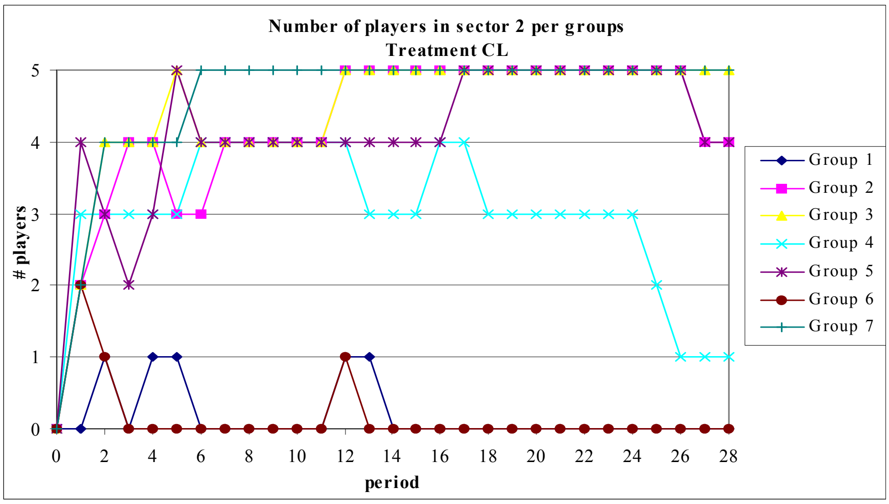
2.6.1 Coordination Results



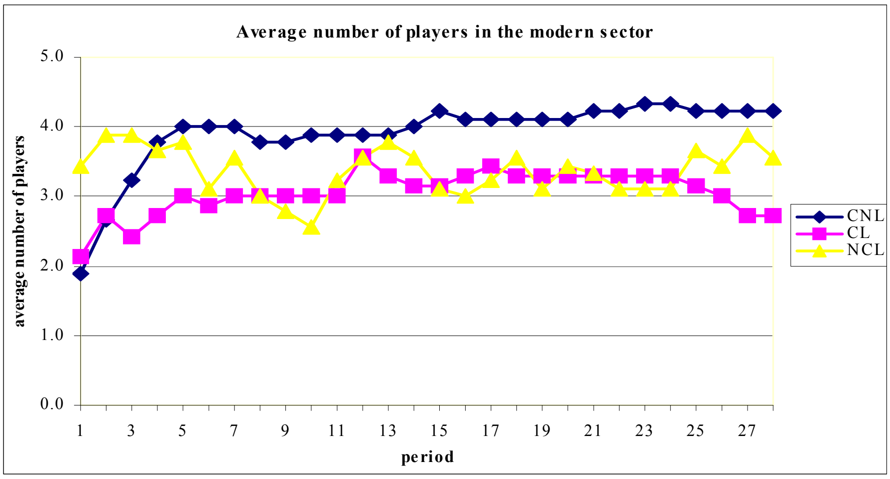
Graph 1a. Coordination in treatment CNL



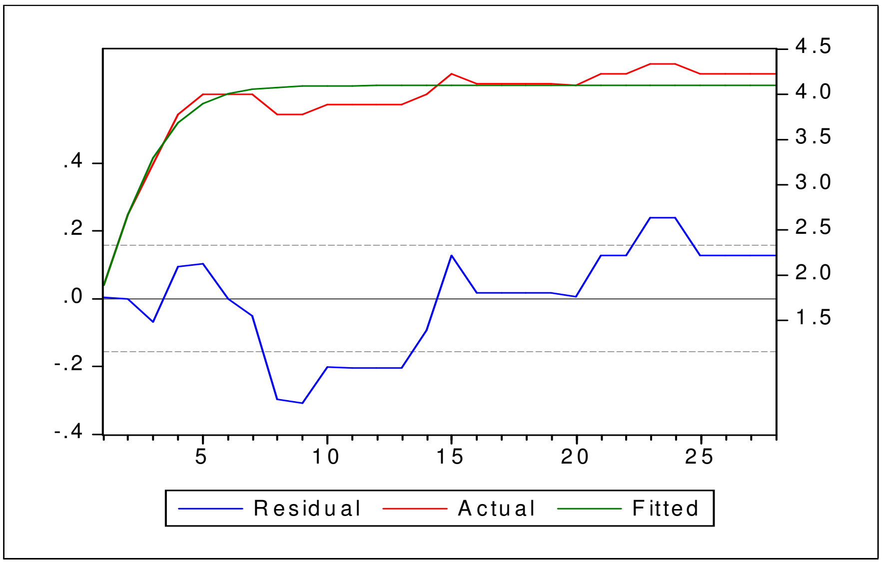
Graph 1b: Coordination in treatment NCL



Graph 1c: Coordination in treatment CL

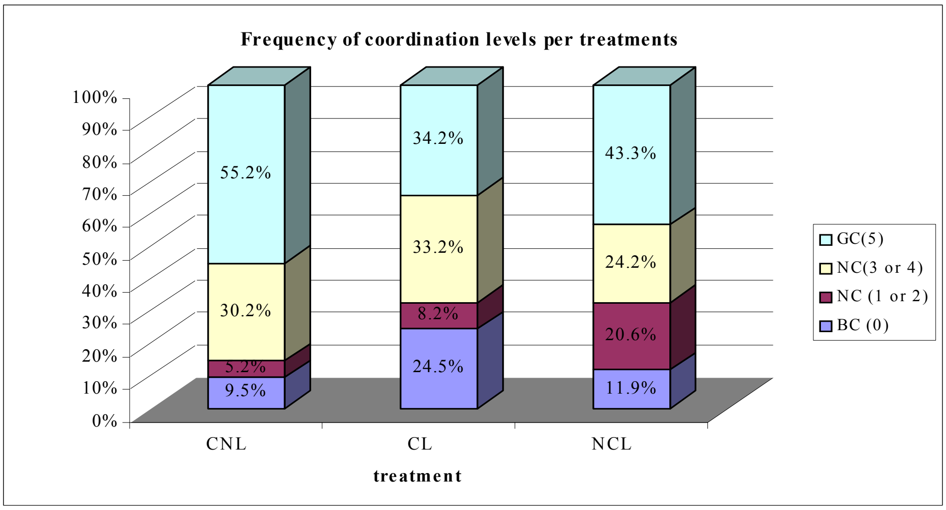


Graph 2: Average number of players in the modern sector



Graph 2a: Fitted values for treatment CNL

Graph 2b: Fitted values for treatment CL

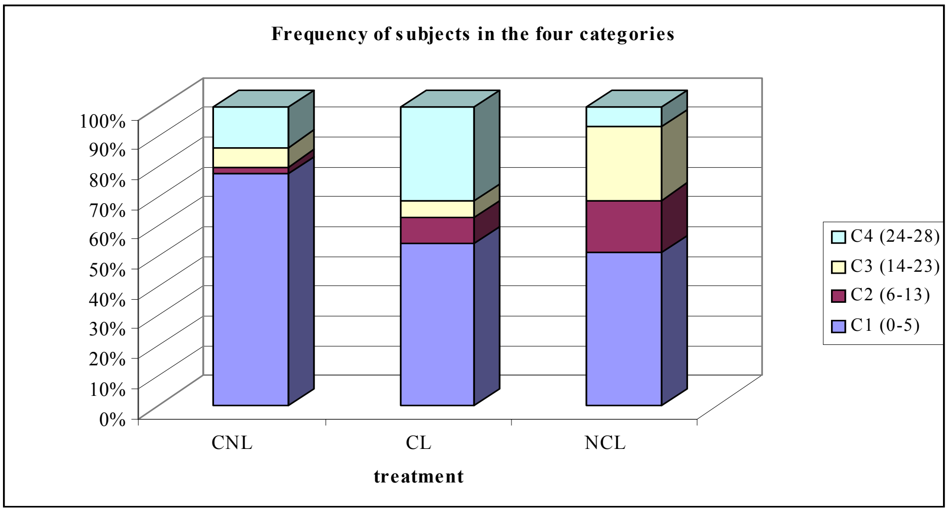


Graph 3: Frequency of coordination levels per treatments

2.6.2 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



Graph 4: Frequency of subjects in the four categories

		COEFFICIENT				
		Constant	**CHOI**	**PROF**	**SEC2**	**COST**
CNL	**C3**	0.145	3.871*	-0.605***	-	-1.558*
NCL	**C3**	1.294*	-0.526**	0.191**	-0.567*	-
	C2	-1.698*	4.198	-	-	-1.357*
CL	**C3**	-0.785*	3.007*	-	-	-1.205*

* statistically significant at α=0.01 ** statistically significant at α=0.05 *** statistically significant at α=0.1

Table 5: Results of the probit estimation

2.7 Appendix B. 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

Bibliography

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

[2] Barro, R. J. and Sala-i-Martin, X. (1995): *Economic Growth* New York:McGraw-Hill

[3] Baumol, W.J. (1986): "Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show" *American Economic Review* **76**., pp. 1072-85

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

[5] Capra, C. M. et al. (2005): "The Impact of Simple Institutions in Experimental Economies with Poverty Traps" *Working Paper,* Emory University

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

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

[8] 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

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

[10] 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

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

[12] 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

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

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

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

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

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

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

[19] Lei, Vivian and Noussair, Charles (2003): "Equilibrium Selection in an Experimental Macroeconomy" *Working Paper,* Emory University

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

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

[22] Murphy, K. M.; Shleifer, A. and Vishny, R. W. (1989): "Industrialization and the Big Push" *The Journal of Political Economy* **97**., pp.1003-1026

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

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

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

[26] 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

Chapter 3

School Choice and Information: An Experimental Study on Matching

3.1 Introduction

There is now a vast literature on matching problems. Matching is a pervasive phenomenon arising in several economic and social settings. The assignment of civil servants to civil service positions, the admission of students to colleges, some entry-level labor markets—as the widely explored market for graduating physicians—, or the school choice problem are among the matching situations that have gained attention in the last decades. The working of some matching mechanisms, along with strategic issues that confront individuals in these contexts, have been explored theoretically.

Very briefly, in a two-sided matching market, agents belong to one of two disjoint sets, say colleges and students, and each agent—college and student—has preferences over the other side of the market—students and colleges, respectively—and the prospect of being unmatched. The matching problem then reduces to assigning students to colleges by means of a matching mechanism. Stability, strategy-proofness, and Pareto efficiency of such mechanisms are highly valued properties. A mechanism is stable if it always selects stable matchings; by definition, under a stable matching every agent in the market prefers his partner to being alone and, moreover, no pair of agents—consisting of a college and a student—who are not matched to each other would rather prefer to be so matched. A mechanism is strategy-proof if it is immune to preference manipulation, i.e., truth is a dominant strategy. A mechanism is Pareto efficient if it always selects Pareto efficient matchings.

The perhaps most famous matching mechanism relies on the Gale-Shapley deferred-acceptance algorithm (Gale and Shapley, 1962). Gale and Shapley were motivated by the problem of the admission of students to colleges and the Gale-Shapley algorithm was written as a means to show that a stable matching always exists in such a two-sided matching market. The Gale-Shapley deferred-acceptance algorithm transforms a matching where all agents are unmatched into a stable matching, thus proving existence. Besides guaranteeing stability, the Gale-Shapley mechanism has other appealing properties. Namely, truth is a dominant strategy for one side of the market (Dubins and Freedman, 1981, Roth, 1982a). Moreover, it is Pareto efficient when the welfare of both sides of the market is considered (Roth, 1982a).

The strategic properties of the Gale-Shapley mechanism—namely the characterization of dominant strategies and equilibria—and, in fact, most theoretical studies on matching mechanisms rely on the assumption of complete information, however implausible: knowing the true preferences of every agent in the market is more than we may reasonably expect in most matching markets. Only a few papers have relaxed this assumption and are thus worth mentioning. Roth (1989) is a first attempt to deal with the incomplete information case. Under incomplete information, even though truth remains a dominant strategy for one side of the market when the Gale-Shapley mechanism is employed, the equilibrium characterization for the complete information case is not robust. Ehlers and Massó (2003) study Bayesian Nash equilibria for mechanisms producing stable matchings—as the Gale-Shapley mechanism—and find a necessary and sufficient condition for truthtelling to be an equilibrium: truthtelling is a Bayesian Nash equilibrium in the revelation game induced by a stable mechanism and a common belief if and only if all profiles in its support have a singleton core. Finally, Roth and Rothblum (1999) and Ehlers (2003, 2004) are less ambitious and do not aim at characterizing equilibria, but give advice to individuals on how to participate in matching markets when there is uncertainty about the others' strategies.

Still, many questions regarding the strategic incentives agents face under incomplete information remain to be answered on theoretical grounds. How the amount of information held by individuals on the elements of the game actually influences individuals' decision making, affecting the performance of matching mechanisms, is thus a question to be explored. For instance, Barberà and Dutta (1995) consider truthtelling as a form of "protective" behavior, claiming that risk averse agents may revert to faithfully revealing their true preferences when they are poorly informed. Moreover, it is clear that in mechanisms for which truth is not a dominant strategy, computing the optimal strategies requires a lot of information on others' preferences. In this paper we present an experimental study to investigate these and other issues, providing a direction into which the role of information on decision making may be ascertained.

We investigate a particular class of matching problems: the assignment of individuals to indivisible items. In these problems, individuals—let us call them teachers—have strict preferences over the indivisible items—henceforth, schools—and, on the other hand, schools have a maximum capacity and a strict priority ordering of all teachers. This problem has been referred to as the school choice problem (Abdulkadiroglu and Sönmez, 2003) and is closely related to the college admissions problem explored by Gale and Shapley (Gale and Shapley, 1962), the main difference being that, in contrast to the college admissions model, here schools are not strategic agents, but mere objects to be assigned to teachers. Hence, while teachers may not straightforwardly reveal their true preferences, schools have no chance of manipulating priorities.

The influence of information is assessed for the Gale-Shapley mechanism and for another well-known matching mechanism, the Top Trading Cycles mechanism (TTC), as well as for the Boston mechanism, which has been widely used in the context of school choice problems.[1] The TTC (Shapley and Scarf, 1974) fulfills two appealing properties: it is both strategy-proof (Roth, 1982b) and Pareto efficient. The Gale-Shapley mechanism is strategy-proof, but not efficient (Roth, 1982a), since we only consider teachers' welfare in this setup. Finally, we have included the Boston mechanism for reference, as it fails to meet both requirements: it is neither strategy-proof nor Pareto efficient. In fact, there is room for profitable manipulation of agents' preferences under this mechanism and misrepresentation leads to major efficiency losses.[2]

[1] School choice programs have become increasingly popular in the US. The best known of these programs rely on the Boston mechanism, used to assign students to schools in Boston, Cambridge, and Seattle, among others.

[2] On the functioning and strategic properties of the Boston mechanism, check Abdulkadiroglu

Besides providing yet another test of theoretical results on matching mechanisms with boundedly rational individuals, we address two main questions. First, we compare the three above mentioned mechanisms under three informational scenarios, ranging from complete ignorance about the other participants' preferences and schools' priorities to complete information on all elements of the game. In particular, we are concerned in comparing the incentives agents face under different mechanisms, as well as in comparing efficiency levels, for different information levels. The results in this paper seem to suggest that the TTC mechanism prevails over the other two in what efficiency is concerned, even though incentives for truthtelling are not significantly different from those given by Gale-Shapley. Second, within each mechanism, we evaluate the influence of the amount of information held by individuals on decision making. Namely, we are concerned in testing whether truthtelling emerges as a very salient form of behavior when information is low. This would imply that, in markets where we expect agents to know little about others, strategy-proofness of the mechanism should not drive the choice of the matching mechanism. Moreover, if we are able to determine that information significantly affects individuals' behavior, we can immediately conclude that the existing theoretical results, which rely on the fundamental assumption of complete information, are insufficient to deal with markets where agents know little about others. Otherwise, if the effect of information is not relevant, theory may be considered apt to deal with the incomplete information case. Our results support the first conjecture: information is actually important. In fact, in a very low information environment, acting straightforwardly is a very salient form of behavior and significantly higher levels of efficiency are achieved under all mechanisms except for TTC, which appears to be less sensitive to the amount of information held by

and Sönmez (2003), Abdulkadiroglu et al. (2005), Chen and Sönmez (2004), and Ergin and Sönmez (2004).

participants.

We are aware of several experimental studies of matching problems, some of which aim at testing the above mentioned mechanisms. These include Harrison and McCabe (1996) that explores the Gale-Shapley mechanism and shows that profitable manipulation of agents' preferences becomes more difficult as markets get larger; Chen and Sönmez (2002a) that compares a random serial dictatorship mechanism used to allocate dormitory rooms in American universities with a variant of the TTC in an incomplete information environment, concluding that the TTC produces significantly more efficient allocations; in a companion paper, Chen and Sönmez (2002b) evaluate the performance of these mechanisms under complete information, reaching the same qualitative results; finally, Chen and Sönmez (2004), consider the school choice problem and analyze the TTC, the Gale-Shapley, and the Boston mechanisms under incomplete information, concluding that, in what efficiency is concerned, Gale-Shapley improves upon the TTC, which outperforms the Boston mechanism. The difference between the above studies and this paper derives from our main objective: to test the role of information in evaluating matching mechanisms. Other experimental studies, dealing with other matching mechanisms, are: Olson and Porter (1994), Nalbantian and Schotter (1995), Kagel and Roth (2000), Ünver (2001), Haruvy, Roth, and Ünver (2001), and McKinney, Niederle, and Roth (2005).

We proceed as follows. In Section 2 we present the theoretical properties of the three matching mechanisms under study. We describe the experimental design in Section 3. Section 4 summarizes the main results of the experiments. Some concluding remarks follow in Section 5.

3.2 The Theoretical Model

We first introduce the model and then describe the three matching mechanisms and their theoretical properties.

In this assignment problem there are a number of teachers to fill a number of vacancies or teaching positions across different schools. Each teacher has strict preferences over all schools, while each school has a strict priority ranking of all teachers, as well as a maximum number of teachers to employ. Priorities are exogenous and not subject to manipulation by schools. The fact that only teachers can act strategically is what distinguishes this problem from the college admissions model. It is not difficult to justify the use of the school choice model. Besides the fact that this model is easier to be implemented in the laboratory, we can find plenty of real-life situations that can be described as one side of the market being inactive. We have already mentioned the use of the school choice problem in the admission of children to public schools in the US, which also applies to other countries as Spain, but we can also think about the admission of students to universities (which is, in most countries, based on students' grades), the MIR system ("Médicos Internos Residentes," a residence training system for physicians in public hospitals based on their performance) in Spain, or in general the assignment of civil servants to civil service positions, which is, in several countries, based on an objective scoring system (for example teachers, judges, or tax inspectors in Spain).

The outcome of the school choice problem is a matching, an assignment of teachers to teaching positions such that each teacher is assigned one vacancy and each vacancy is filled by one teacher only. A matching is Pareto efficient if there is no matching that assigns at least one teacher a strictly better school and every other teacher a weakly better school. A matching mechanism consists of a systematic procedure that selects a matching for each school choice problem. A matching mechanism is efficient if it always chooses Pareto efficient matchings; it is strategy-proof if truth is a dominant strategy, i.e., no teacher can profitably manipulate her preferences, independently of the other agents' strategies.

3.2.1 The Top Trading Cycles Mechanism

In this context, the TTC works as follows:

1. Each school gives priority to a number of teachers up to its capacity; in this setting, for simplicity, each teacher has priority in one school only.
2. Each teacher reports her preferences over the schools.
3. An ordering of teachers is randomly chosen.
4. For any submitted teachers' preferences, schools' priorities, and ordering of teachers, the outcome is obtained after undergoing the following steps:
   (a) Assign each teacher to a school (tentative assignment); in this setting, each teacher is tentatively assigned to her priority school.
   (b) The first teacher in the ordering proposes to her top ranked school. If she has priority at this school, the assignment is finalized and both the teacher and teaching position are removed from the system; the procedure continues with the second teacher in the ordering. Otherwise, the first teacher in the ordering that is tentatively assigned to the proposed school is inserted at the top of the ordering, in front of the requester.
   (c) When the ordering is modified, this procedure is repeated, so that the teacher who just became first in the ordering sends an application to her

highest-ranked school. If she has priority at this school, the assignment is finalized and the procedure continues with the next teacher in line. Otherwise, the first teacher in the ordering tentatively assigned to the proposed school is inserted at the top of the ordering, in front of the requester.

(d) If a cycle forms, it consists of a sequence of proposals of the kind: A proposes to B's tentative assignment, B applies to C's tentative assignment, and C proposes to A's tentative assignment. In such cases, all teachers in the cycle are assigned to the schools they proposed to and teachers, as well as their respective assignments, are removed from the system.

(e) The procedure stops when all teachers are assigned to a position.

The TTC mechanism satisfies two appealing properties: it is strategy-proof, i.e., truth is a dominant strategy for every teacher, and Pareto efficient.[3] We thus expect that individuals reveal their preferences in a straightforward manner, independently of the amount of information they hold on the elements of the game.[4]

3.2.2 The Gale-Shapley Mechanism

The Gale-Shapley is certainly one of the best known mechanisms in the matching literature.

Its theoretical properties and the incentives it gives to agents have been scrutinized and its applications encompass a significant number of markets. In what follows we describe the functioning of the Gale-Shapley mechanism:

[3]Note also that, in this setting, the resulting final assignment is independent of the random ordering of teachers defined in step 3.

[4]Still, Chen and Sönmez (2002a) find, in an experiment about on-campus housing, that about one-third of the subjects manipulate their preferences under a variant of the TTC mechanism.

1. A priority ordering of teachers is determined for each school.

2. Each teacher reports her preferences over the schools.

3. Given the submitted preferences of the teachers and schools' priority orderings, positions are allocated after undergoing the following steps:

   (a) Each teacher proposes to her first ranked school. Each school keeps the applicants with higher priority order on hold until positions are filled, while rejecting the lowest priority teachers in excess of its capacity.

   (b) In general:

   Every teacher who got rejected in the previous step proposes to the next school on her list of preferences. Each school considers the teachers it holds from the previous step together with the new applications. The lowest priority teachers in excess of the school's capacity are rejected, while remaining applications are kept on hold.

   (c) This process is repeated until no applications are rejected. Each participant is then assigned the position at the school that keeps her on hold.

As the TTC mechanism, the Gale-Shapley mechanism is strategy-proof. Again, we expect individuals to faithfully reveal their true preferences over schools in every informational treatment. This mechanism is efficient when the welfare of both sides of the market is taken into account. Nevertheless, in this assignment problem, schools are mere objects to be allocated among teachers and only teachers' welfare is taken into consideration. Since there may exist a matching that Pareto dominates the outcome of the Gale-Shapley mechanism for teachers, the mechanism is not efficient in this setup. It follows that, if theory is to be confirmed, the TTC should outperform the Gale-Shapley in efficiency terms.

3.2.3 The Boston Mechanism

The Boston mechanism has been the most widely used assignment mechanism in real-life applications of school choice problems. It works as follows:

1. A priority ordering of teachers is determined for each school.
2. Each teacher reports her preferences over the schools.
3. Given the submitted preferences of the teachers and schools' priority orderings, positions are allocated after several rounds:
   (a) Each teacher proposes to her top ranked school. Each school accepts the proposals from the teachers with higher priority order until positions are filled (or no teachers remain who have proposed to the school). These applicants and their positions are removed from the system. All other applications are rejected by the schools.
   (b) In general at round k:

       Each teacher remaining in the system proposes to its kth school. Each school with vacant positions accepts the proposals from the teachers with higher priority order until positions are filled (or no teachers remain who have proposed to the school in this round). These applicants and their positions are removed from the system. All other applications are rejected by the schools.

(c) The procedure terminates when each teacher is assigned a position.[5]

A major handicap of the Boston mechanism is that it leads to preference manipulation.[6] In fact, teachers are given incentives to rank high on their submitted preferences the schools where they have good chances of getting in. This has two important consequences. First, evaluating the performance of this mechanism according to the revealed preferences is clearly inadequate. Moreover, even though the outcome of the Boston mechanism is Pareto efficient when teachers submit their true preferences, preference manipulation may lead to a substantial efficiency loss. Hence, we expect a low level of efficiency.

3.3 Experimental Design

We design our experiments to analyze participants' decision taking under different informational settings throughout the above described matching mechanisms: the Boston mechanism, the Gale-Shapley mechanism, and the TTC mechanism. We use a 3x3 design: for each mechanism we construct three treatments differing in the amount of information held by participants about the elements of the game. This allows us to compare decision making in nine treatments. In our analysis we concentrate on the role of information in truthful preference revelation and in efficiency. The environment is designed to capture the key aspects and difficulties of each mechanism, under a controlled environment, with relatively small groups of participants.

[5] Hence, if there are n teachers and l schools, the process ends in a maximum number of l rounds.

[6] Chen and Sönmez (2003) report an experiment where around 80% of the subjects manipulate their true preferences.

Participants are randomly and anonymously sorted into groups of five. Each participant plays the role of a teacher to be assigned to a teaching position. For each group of five teachers, there are five vacancies—or teaching positions—across three schools that differ in capacity (number of opening positions) and desirability. Each position should be assigned to one teacher only. Preferences over schools are induced by the monetary payoff a teacher obtains depending on the school where she fills a vacancy at the end of the experiment. The payoffs obtained are symmetric: every teacher gets 15 euro for her top choice, 9 euro for the second choice, and 3 euro for the last choice, but different teachers need not agree on which school is either her top, second, or last choice. The payoffs of different outcomes are sufficiently dispersed so as to have a monetarily salient difference (12 euro) between getting one's best and one's worst choice.

New groups are formed for each mechanism by shuffling all participants under the "role" of a particular teacher. Participants are informed that new groups are created for each mechanism. Under each mechanism, each group of participants plays the game three times, holding three different, but increasing, amounts of information. As a means to avoid participants from playing from memory when the mechanism is changed, we modify the labeling of schools and alter the schools' characteristics accordingly. It follows that each participant keeps the same preferences over schools throughout the whole experiment, even though her payoff matrix seemingly changes: the performed changes are virtual.

Finally, schools have priorities over teachers. This means that schools may prefer some applicants to others and are able to rank all the participants in a list of priorities. Moreover, as priorities of schools are given, schools are not real strategic agents (i.e., they "play" truthfully) and all the participants know this.

3.3.1 Informational Settings

In each experimental session three different informational treatments are implemented for each mechanism, in the following order:

- **Zero information setting**: In this setting each participant knows her possible payoff amounts depending on the school where she holds a position (i.e., her own induced preferences), but not the other participants' preferences. She is only told that different participants might have different payoff tables. Participants have no information about the schools' priority ordering in this treatment. They are only told the capacity (i.e., the number of vacancies) of each school.
- **Partial information setting**: In this setting, besides her own induced preferences and the capacity of each school, each participant has some partial information about the schools' priority orderings. Namely, each participant is told the favorite candidates of each school, up to its capacity.
- **Full information setting**: In this informational setting each participant has complete information on both the induced preferences of all participants, and the full priority ordering of schools over candidates.

In the case of the TTC mechanism, as the schools' priority orderings are reflected in the tentative assignment, under the "partial information treatment" participants are told—besides their own induced preferences—the tentative assignment of all participants; while in the "full information treatment" they know both the induced preferences of all participants and the tentative assignment.

We conducted sessions with both undergraduate and graduate students from the Universitat Autònoma de Barcelona, recruited using classroom announcements and posters in the campus, where the experimental sessions (on paper/by hand) took place. In total, 30 subjects have participated in the experiment, which makes six groups of five. Each subject was allowed to participate in one session only. Subjects were informed that they would participate in a decision making task. At the beginning of each session, subjects were randomly seated at the tables and printed instructions were given to them. Before starting each mechanism, the corresponding instructions were read aloud. In each session and for each informational setting participants were asked to submit a school ordering, from their top to their last choice. In each session all nine treatments were implemented, so that we have nine decisions from each participant, each under a different mechanism and/or different informational setting. The order of implementation of the mechanisms and informational settings was the following: 1^{st}: Boston mechanism in the zero information setting, 2^{nd}: Boston mechanism in the partial information setting, 3^{rd}: Boston mechanism in the full information setting; 4^{th}: Gale-Shapley mechanism in the zero information setting, 5^{th}: Gale-Shapley mechanism in the partial information setting, 6^{th}: Gale-Shapley mechanism in the full information setting, 7^{th}: TTC mechanism in the zero information setting, 8^{th}: TTC mechanism in the partial information setting, and finally 9^{th}: TTC mechanism in the full information setting. Subjects did not get any feedback about previous decisions or outcomes at any moment of the experiment. At the end of each session, one of the nine treatments was chosen randomly for payment, matching was determined for the chosen treatment and earnings were paid. Sessions lasted about 90 minutes and average net payments—including a 3\euro show-up fee—were around 14\euro.

The instructions and Decision Sheets in English for the Gale-Shapley mechanism can be found in the Appendix.[7]

[7] The instructions for the other mechanisms only differ in the description of the allocation method. The Decision Sheets for players in different roles look similar to the ones shown in the

3.4 Results

In this section we present our experimental results. Our main aim is to examine the importance of the level of information that participants hold in evaluating the three matching mechanisms. The experimental setting we use allows us to analyze the role of information in individuals' decision making and how this affects the theoretic characteristics of the mechanisms. The first keypoint is related to whether individuals report their preferences truthfully. We study whether the amount of information given to the participants influences truthful preference revelation (keeping the mechanism under analysis fixed) and, on the other hand, whether under the same informational setting truthful preference revelation changes with the implemented mechanism. The second main point is related to efficiency. We compare efficiency levels under each mechanism across information settings and across different mechanisms for the same information level.

3.4.1 Truthful Preference Revelation

We first analyze the two questions related to truthful preference revelation. Table 1 shows the proportion of participants who played truthfully (regarding induced preferences) and who used three possible kinds of preference manipulation, in each treatment.

Appendix.

Mechanism	Info	Not.	Truth	PSB	SSB	PSB&SSB	Other
Boston	Zero	B0	86.7%	-	10%	0%	3.3%
	Partial	B1	33.3%	36.7%	6.7%	16.7%	6.7%
	Full	B2	36.7%	43.3%	3.3%	3.3%	13.3%
Gale & Shapley	Zero	GS0	80%	-	6.7%	0%	13.3%
	Partial	GS1	60%	30%	0%	3.3%	6.7%
	Full	GS2	66.7%	10.0%	6.7%	6.7%	10%
TTC	Zero	T0	96.7%	-	3.3%	0%	0%
	Partial	T1	63.3%	23.3%	10%	3.3%	0%
	Full	T2	63.3%	16.7%	10%	0%	10%

Table1: Proportion of truthful play and preference manipulations

We can see that the proportion of players who played truthfully varies between 33,3% and 96,7%, depending on the treatment being implemented. Even though the Gale-Shapley and the TTC mechanisms are strategy-proof, there is some misrepresentation of preferences in these treatments as well, although its extent depends on the implemented information setting. It is important to examine who manipulates the preferences and in which manner. We identify three possible ways of preference manipulations. First, a substantial proportion of the participants has ranked the school where she has priority higher in the submitted ranking than it would be according to the induced preferences; this is what we call the "Priority School Bias" (PSB).[8] The second identified way of manipulating the true preferences is to underrank the most competitive school (i.e., the school with only one vacancy); following Chen and Sönmez (2004) we call this form of behavior "Small School Bias"

[8] In the case of the zero information setting it does not make sense to check for this kind of preference manipulation, as participants in these settings have no information about the priorities of the schools.

(SSB). The third manipulation method (PSB&SSB) is simply the simultaneous use of both previously described ways.[9] We can see that a relatively small proportion of the participants used any of these two latter methods, and the most frequently used method is the PSB. Checking the average payoff of the participants that use this method (8.23 euro), we can infer that PSB is used as a means to ensure their second best payoff (9 euro). This form of behavior can be considered as a kind of risk aversion, since this manipulation allows the participants to avoid their worst payoff (3 euro). Although the SSB and the PSB&SSB methods are used less frequently, they yield a slightly higher payoff to the participants than the previous method.

Now, we would like to analyze whether the quantity of information the participants hold affects behavior. To answer to this question, we compare the proportion of participants playing truthfully in different informational settings under each mechanism.[10]

Result 1: *Under each examined matching mechanism (Boston, Gale-Shapley, and TTC) the amount of information has a significant effect on the decisions of the participants in what truthtelling is concerned. In particular, we find that having no information about the other parties' preferences results in a significantly higher proportion of truthtelling than under any treatment with additional information.*

Statistical evidence: Under each mechanism, the null hypothesis of equal proportions of truthful preference revelation across the three informational settings can be rejected at 5% significance level. In particular, in the Boston and TTC

[9] As we have already mentioned, in the case of the zero information setting it does not make sense to check for the PSB preference manipulation, therefore in these info settings the PSB&SSB manipulation will be included in the SSB manipulation method.

[10] We compare, for each mechanism, three informational settings: B0 vs B1 vs B2; GS0 vs GS1 vs GS2; and T0 vs T1 vs T2.

mechanisms, the null can be rejected at any reasonable significance level and in Gale-Shapley at 3.7%.[11] As the null hypotheses are rejected, multiple comparisons are made. The results of the pairwise comparisons (with the corresponding test statistics of the Quade test[12] in parenthesis) can be found in Table 2:

Mechanism	Boston			Gale&Shapley			TTC		
Null hyp.	B0=B1	B0=B2	B1=B2	GS0=GS1	GS0=GS2	GS1=GS2	T0=T1	T0=T2	T1=T2
Difference	53.3%* (28.8)	50%* (34.3)	3.3% (5.5)	20%* (27)	13.3%** (18)	7% (9)	33.3%* (30.5)	33.3%* (32.5)	0% (2)

* Significant at α=0.01   ** Significant at α=0.1

Table 2: Differences in the proportion of truthtelling across information settings

From the results of the comparisons we can conclude that under the Boston and TTC mechanisms the proportion of truthful preference revelation is significantly higher at 1% significance level in the zero information setting than either in the partial or the full information settings (86.7% vs. 33.3% and 36.7% respectively under the Boston mechanism; 96.7% vs. 63.3% and 63.3% respectively under the TTC mechanism), while there is no significant difference in the proportions between the partial and full information settings. Under the Gale-Shapley mechanism the proportion of truthful preference revelation is significantly higher at 1% significance level in the zero information setting than in the partial information setting (80% vs. 60%), but its difference with the full information setting is only significant at 10% (80% vs. 66.7%). Here again there is no significant difference in the proportion of straightforward behavior between the partial and the full information settings.

[11] The value of the test statistics of the Quade test for k related samples in the Boston mechanism is 8.661, in Gale-Shapley it is 5.385, and in TTC it is 11.479; while the 0.01 quantile of the F distribution with k_1=2 and k_2=10 degrees of freedom is 7.56, and the 0.037 quantile is 5.26.

[12] To learn more about the Quade test used in our analysis, see W.J. Conover (1980).

Result 2: *Across mechanisms we find a significant difference in the proportion of truthtelling. In particular, both in the partial and full information settings, the proportion of truthtelling under the Boston mechanism is lower than under any of the other mechanisms. In the case of the zero information setting, under the TTC mechanism, the proportion of truthful preference revelation is significantly higher than under any other mechanism.*

Statistical evidence: Under the three informational settings, the null hypothesis of equal proportions of truthful preference revelation across the three matching mechanisms can be rejected at 5% significance level. In particular, in both the zero and full information settings the null can be rejected at any reasonable significance level, while in the partial information setting it can be rejected at 3.4%.[13] As the null hypotheses are rejected, multiple comparisons are made. The results of the pairwise comparisons can be found in Table 3:

Info	**Zero**			**Partial**			**Full**		
Null hyp.	**B0=GS0**	**T0=B0**	**T0=GS0**	**GS1=B1**	**T1=B1**	**T1=GS1**	**GS2=B2**	**T2=B2**	**GS2=T2**
Difference	7% (12)	10%** (18)	16.7%* (30)	26.7%** (24)	30%** (30)	3% (6)	30%* (31.3)	26.7%* (27.3)	3% (4)

* Significant at α=0.01 ** Significant at α=0.05

Table 3: Pairwise differences in truthtelling across mechanisms

A significantly smaller number of participants reveal their preferences truthfully in the partial and the full information settings under the Boston mechanism (at 5% significance level) than under either the Gale-Shapley or TTC mechanism (in

[13] The value of the test statistics of the Quade test for k related samples in the zero information setting is 8.636, in the partial information setting it is 5.526, and in the full information setting it is 7.986; while the 0.01 quantile of the F distribution with k_1=2 and k_2=10 degrees of freedom is 7.56, and the 0.034 quantile is 5.484.

the partial information setting 33% vs. 60% and 63% respectively; and in the full information setting 37% vs. 67% and 63% respectively), while there is no significant difference between the Gale-Shapley and TTC mechanisms.[14] As for the case of the zero information setting, our results show that under the TTC mechanism the proportion of truthful preference revelation is significantly higher (at 5% significance level) than under either the Gale-Shapley or the Boston mechanism (97% vs. 80% and 87%),[15] while there is no significant difference in truthtelling under the Boston and the Gale-Shapley mechanisms.

As we have seen above, participants manipulate their preferences in order to increase the chances of getting their top ranked choices, which do not necessarily coincide with their true top choices. Hence, the more participants get their reported but not true top choices, the lower the achieved efficiency. Therefore, it is worth to examine whether under some mechanisms and/or information settings the participants can get their true top choices.

Result 3: *Under each mechanism, in both the partial and full information settings, there is a highly significant difference between the proportion of the participants who receive their reported top choice and those who receive their true top choices. The proportion of subjects who receive their true top choices is significantly higher in the zero information setting than in any other information setting. On the other hand, across mechanisms the TTC mechanism results more successful in terms of the proportion of participants who get their true top choices.*

Statistical evidence: In the zero information setting, under all mechanisms, there is no significant difference between the proportion of subjects who get their

[14] In the case of the full information setting the same result holds already at 1% significance level.

[15] The difference of proportions between the TTC and Gale-Shapley mechanisms is significant already at the 1% significance level.

reported top choices and the ones who get their true top choice. Using a t-test of proportions, the null hypothesis of equal proportions can not be rejected at any reasonable significance level, in favor of the alternative hypothesis of the percentage of reported top choices being higher than the percentage of true top choices.[16] In the case of the partial and full information settings, the same null hypothesis can be rejected at any reasonable significance level; therefore in these cases we can conclude that a significantly higher proportion of participants receive their reported top choices rather than their true top choices.[17]

On the other hand, under each mechanism there is no significant difference in the proportion of subjects that receive their reported top choices in the zero, partial, or full informational settings (under the Boston mechanism: B0: 83.3% vs. B1: 76.7% vs. B2: 80%; under Gale-Shapley: GS0: 66.7% vs. GS1: 50% vs. GS2: 66.7%; and under TTC: TTC0: 80% vs. TTC1: 80% vs. TTC2: 83.3%). If we consider the proportion of participants who receive their true top choices, using again a t-test of proportions we arrive to the conclusion that the null of equal proportions across information settings can be rejected. In particular, we find that under each mechanism a significantly higher proportion of participants receive their true top choices in the zero information setting, than in either the partial or the full information setting, at 10% significance level. Examining the proportion of participants who get their true top choices across mechanisms, we arrive to the

[16] The value of the test statistics in the Boston mechanism is 0.647, in Gale-Shapley it is 1.643, and in TTC it is 0.216; while the 0.01 quantile of the standard normal distribution is 2.327.

[17] The relevant proportions are the following:

Mechanism	Boston		Gale&Shapley		TTC	
Info setting	B1	B2	GS1	GS2	T1	T2
Reported top choice %	76.7%	80.0%	50.0%	66.7%	80.0%	83.3%
True top choice %	23.3%	40.0%	20.0%	36.7%	50.0%	53.3%

Each difference between the reported and true top choices in a treatment is significant, with a p-value <0.001.

conclusion that both in the partial and in the full information settings, under the TTC mechanism, a significantly higher proportion of the participants get their true top choices than either under the Boston or under the Gale-Shapley mechanism (at 10% significance level). In the zero information setting, the Boston and the TTC mechanisms result significantly more successful than the Gale-Shapley mechanism, in the same aspect. The following table contains the differences between information settings and across mechanisms, and indicates whether a difference is statistically significant.[18]

Difference	B0-B1	B0-B2	B2-B1	GS0-GS1	GS0-GS2	GS2-GS1	T0-T1	T0-T2	T2-T1
Diff. true top choice (across info settings)	53.3%* (6.69)	36.7%* (3.91)	16.7%** (1.94)	30%* (3.88)	13.3%*** (1.33)	16.7%** (2.05)	26.7%* (2.74)	23.3%* (2.38)	3.3% (0.18)
Difference	**B0-GS0**	**B0-T0**	**T0-GS0**	**B1-GS1**	**T1-B1**	**T1-GS1**	**B2-GS2**	**T2-B2**	**T2-GS2**
Diff. true top choice (across mechanisms)	26.7%* (2.74)	0% (-0.22)	26.7%* (2.74)	3.3% (0.23)	26.7%* (3.24)	30%* (3.88)	3.4% (0.19)	13.3%*** (1.3)	16.7%** (1.7)

* Difference significant at α=0.01 ** Difference significant at α=0.05 *** Difference significant at α=0.1

Table 4: Difference in the proportion of received true top choices

To summarize our results regarding truthtelling, in lack of any information about the other participants' payoffs and preferences agents are much more likely to revert to truthtelling. This suggests that complete ignorance can be very convenient in this setting. Still, this does not make the TTC less desirable: even under complete ignorance, the TTC mechanism clearly outperforms the other two mechanisms. In the settings where agents have additional information about the elements of the game, both TTC and the Gale-Shapley mechanisms result successful in what incentives for playing truthfully are concerned.

[18] The value of the z-statistic can be found in parenthesis.

3.4.2 Efficiency

We now investigate the efficiency of the three mechanisms in the different informational scenarios. As we know, there is a strong link between the behavior regarding truthtelling and efficiency. In fact, even when the mechanism used is Pareto efficient—in terms of the revealed preferences—strategic behavior may lead to inefficient allocations.

In calculating efficiency levels we use the following definitions. The efficiency of a group of participants is calculated as the ratio of the sum of the actual earnings of the members of the group and the Pareto-optimal earnings of the group. The efficiency of a treatment is simply the average of the efficiency of all the groups. Table 5 shows the average efficiency of each treatment:

Mechanism	**Boston**			**Gale&Shapley**			**TTC**		
Info setting	**Zero**	**Partial**	**Full**	**Zero**	**Partial**	**Full**	**Zero**	**Partial**	**Full**
Notation	**B0**	**B1**	**B2**	**GS0**	**GS1**	**GS2**	**T0**	**T1**	**T2**
Efficiency	92.8%	63.8%	73.9%	82.6%	63.8%	69.6%	98.6%	89.9%	91.3%

Table 5: Average efficiency of the treatments

As we can notice the average efficiency of the treatments varies between 64% and 99%, depending on both the informational setting and the implemented mechanism. Our first question regarding efficiency is whether some informational settings yield higher efficiency levels than others. After this, we will turn our attention to the efficiency differences that may arise as a result of the different characteristics of the implemented mechanisms.

Result 4: *Under the Boston and Gale-Shapley mechanisms the amount of information has a significant effect on the average efficiency achieved by participants,* *while under the TTC mechanism the average efficiency does not depend on the implemented information setting. In particular, under the Boston and Gale-Shapley mechanisms, having no information about the other parties' preferences results in a significantly higher average efficiency than when participants hold partial information. On the other hand, there is no significant difference in the efficiency under any mechanism between the partial and full information treatments.*

Statistical evidence: Under the Boston and Gale-Shapley mechanisms, the null hypothesis of equal average efficiency across the three informational settings can be rejected at 5% significance level. In particular, under the Boston mechanism, the null can be rejected at any reasonable significance level, while under Gale-Shapley at 4.8%.[19] As the null hypotheses in these mechanisms are rejected, multiple comparisons are made. The results of the pairwise comparisons can be found in Table 6:

Mechanism	**Boston**			**Gale&Shapley**		
Null hyp.	**B0=B1**	**B0=B2**	**B2=B1**	**GS0=GS1**	**GS0=GS2**	**GS2=GS21**
Difference	28.99%* (34.5)	18.84%** (19.5)	10.14%*** (15)	18.84%** (28.25)	13% (11.75)	6% (16.5)

* Significant at α=0.01 ** Significant at α=0.05 *** Significant at α=0.1

Table 6: Pairwise differences in efficiency across info treatments

From the results of these multiple comparisons we can conclude that under the Boston and the Gale-Shapley mechanisms the average efficiency is significantly higher (at 5% significance level) in the zero information setting than in the partial information setting (92.8% vs. 73.9% under the Boston mechanism; and 82.6% vs.

[19] The value of the test statistics of the Quade test for k related samples in the Boston mechanism is 12.547, in Gale-Shapley it is 4.228; while the 0.01 quantile of the F distribution with k_1=2 and k_2=10 degrees of freedom is 7.56, and the 0.048 quantile is 4.228.

69.6% under the Gale-Shapley mechanism), while there is no significant difference in the proportions between the partial and full information settings.[20] The high efficiency level achieved in the zero information setting is not very surprising, as in this informational setting the proportion of truthful preference revelation is also significantly higher than in the other ones. In fact, truthtelling pays for the agents and this explains the high efficiency in these cases. In addition, under the Boston mechanism the efficiency in the zero information treatment is significantly higher than in the full information treatment, while this difference is not significant under the Gale-Shapley mechanism (92.8% vs. 73.9% respectively under the Boston mechanism; and 82.6% vs. 69.6% respectively under the Gale-Shapley mechanism). Under the TTC mechanism the null hypothesis of equal average efficiency across the three information setting can not be rejected. So, in this case—although there is a significant difference in the truthful preference revelation of the participants—there is no significant difference in the average efficiency in the three treatments (98.6% vs. 89.9% vs. 91.3%) at any reasonable significance level, although there is a significant difference in the proportion of truthtelling, favoring the zero information setting.[21]

Result 5: *Across mechanisms, we find a significant difference in the achieved average efficiency. In particular, in every informational setting the average efficiency under the TTC mechanism is significantly higher than under any of the other mechanisms. On the other hand, we find no significant difference in average efficiency between the Boston and the Gale-Shapley mechanisms, in any informa-*

[20] Under the Boston mechanism, the difference in the average efficiency in the full and partial information settings is significant at 10% significance level, in favor of the full information treatment.

[21] The value of the test statistics of the Quade test for k related samples in the TTC mechanism is 1.953, while the 0.1 quantile of the F distribution with k_1=2 and k_2=10 degrees of freedom is 2.92.

tional setting.

Statistical evidence: In the three informational settings we can reject the null hypothesis of equal average efficiency across mechanisms at a significance level of 5%. In particular, in the case of the full informational setting we can reject the null at any reasonable significance level, while in the partial and zero informational settings at an 2.5%.[22] As the null hypothesis is rejected in every informational setting, multiple comparisons are made. The results of the pairwise comparisons can be found in Table 7:

Info	Zero			Partial			Full		
Null hyp.	B0=GS0	T0=B0	T0=GS0	B1=GS1	T1=B1	T1=GS1	B2=GS2	T2=B2	T2=GS2
Difference	10.14% (10.5)	5.8%** (19.5)	15.94%* (30)	0% (2)	26.1%* (25)	26.1%** (23)	4.35% (5)	17.39%** (27.5)	21.74%* (32.5)

* Significant at α=0.01 ** Significant at α=0.05

Table 7: Pairwise differences in efficiency across mechanisms

In any informational setting, the TTC mechanism is clearly superior (in terms of efficiency) to any of the other mechanisms. At a significance level of 5%, the difference in average efficiency between the TTC mechanism and either the Boston or the Gale-Shapley mechanism is significant. On the other hand, our data imply that there is no significant difference in the average efficiency between the Boston and the Gale-Shapley mechanisms, in any of the informational settings; although our former results on truthtelling would suggest a slightly higher efficiency level under the Gale-Shapley mechanism (as there truthtelling was significantly higher than under the Boston mechanism).

[22] The value of the test statistics of the Quade test for k related samples in the zero information setting is 6.205, in the partial information setting it is 6.477, and in the full information setting it is 7.656; while the 0.01 quantile of the F distribution with k_1=2 and k_2=10 degrees of freedom is 7.56, and the 0.025 quantile is 6.17.

3.5 Concluding Remarks

In this paper we examine a particular class of matching problems that is closely related to the college admissions problem: the assignment of individuals to indivisible items. We analyze three well-known matching mechanisms—the Boston, the Gale-Shapley, and the TTC mechanisms—under three different informational settings. Our experimental design allows us to explore two main questions.

First, we compare individuals' decision making regarding truthtelling and efficiency under the three mechanisms, in each informational setting. These results may serve as a test of the theoretical characterization of the above mechanisms. Our results show that in the zero information setting, under the TTC mechanism, a significantly higher proportion of participants plays truthfully than under either the Boston or the Gale-Shapley mechanism. In case the participants have partial or full information about the elements of the game, under the Boston mechanism a significantly higher number of participants manipulate their preferences than under either the Gale-Shapley or the TTC mechanism.[23] The first result is specially interesting, as we do not find a significant difference in truthtelling between the Boston and the Gale-Shapley mechanism, although under the latter mechanism straightforward behavior is the dominant strategy. Regarding efficiency, the experimental result is in accordance with the predictions of the theory: in every informational setting, the TTC mechanism yields a significantly higher efficiency level than either the Boston or the Gale-Shapley mechanisms.[24]

Our second aim is to evaluate the influence of the amount of information held

[23] Summarizing, the proportion of truthtelling across mechanisms is the following: B0=GS0<TTC0; B1<GS1=TTC1; B2<GS2=TTC2.

[24] Summarizing, the efficiency levels across mechanisms are the following: B0=GS0<TTC0; B1=GS1<TTC1; B2=GS2<TTC2.

by individuals on decision making under the three matching mechanisms. The experimental results show that if participants have no information about the others' preferences they are more likely to play truthfully than when holding partial or full information. Between the partial and the full information settings we do not find a significant difference in truthtelling under any of the mechanisms.[25] The amount of information plays a role in the achieved efficiency level as well. Under the Boston and the Gale-Shapley mechanism participants reach a higher efficiency level in the zero information setting than in the partial information one. While under the Boston mechanism the efficiency in the zero information setting is significantly higher than in the full information setting, the same difference under the Gale-Shapley mechanism is not significant. Under any of these two mechanisms, there is no significant difference between the partial and the full information case. On the other hand, under the TTC mechanism, the amount of information does not have a significant effect on the achieved efficiency level.[26]

Summarizing, we can conclude that the comparison of the mechanisms suggests the superiority of the TTC mechanism. Although regarding truthful preference revelation—depending on the implemented informational setting—it may give similar results to the Gale-Shapley mechanism, in the achieved efficiency level the TTC mechanism performs clearly better than either the Boston or the Gale-Shapley mechanisms. Moreover, we find that the amount of information plays an important role in participants' decision making. In general we can say that if the participants only know their own induced preferences, i.e., own payoffs, they are more likely to play truthfully than in case of having additional information. This

[25] Summarizing, the proportion of truthtelling across informational settings is the following at α=10%:
B0>B1=B2; GS0>GS1=GS2; TTC0>TTC1=TTC2.

[26] Summarizing, the efficiency levels across informational settings are the following:
B0>B2=B1; GS0>GS1 and GS0=GS2 and GS1=GS2; TTC0=TTC2=TTC1.

truthful preference revelation results also in a higher efficiency level, except for the TTC mechanism, where the amount of information has no significant effect on the achieved efficiency. This suggests that complete ignorance may be very convenient in this context.

3.6 Appendix Instructions

3.6.1 General Instructions (for all three mechanisms)

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.

In this experiment we simulate three different mechanisms to allocate job candidates at workplaces (e.g. teachers at schools). The mechanisms, payment rules, and teacher allocation method are described in the corresponding instructions.

You will play each mechanism three times, but under different informational conditions, which will be described in the corresponding Decision Sheet. Once all the informational treatments are completed for a mechanism, we will read the instructions for the new mechanism aloud.

Groups and Roles:

There are 5 participants in a group. The participants with whom you are grouped will be the same during one mechanism, but might vary with the change of mechanism.

In the simulation, 5 teaching positions are available across 3 schools. Each position should be allocated to a participant. Schools differ in size, location and quality of instructions. As the capacity of each school varies over the mechanisms, about this you will get the relevant information in the specific instructions, and in the Decision Sheet. The desirability of schools in terms of location and quality are summarized in the amounts shown in the payoff table (see Decision Sheets), that contains the payoff amounts corresponding to each school position. The size of this matrix depends on the informational treatment you are, as you will notice during the experiment. Different participants may have different payoff tables!

Submitted School Ranking:

During the experiment you will be asked to complete the Decision Sheet by indicating your preference ordering over schools. Note that the preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

Preference Ordering of Schools:

Schools also have preferences over applicants. This means, that each school may prefer some candidates to others, and on this basis puts all candidates in a preference order. This order may be different for the different schools. About the preferences of the schools in each informational setting you will have different information in the corresponding Decision Sheet.

Payoffs:

During the session you can earn money. You will receive 3€ for your participation, in addition to the amount that you earn in a randomly chosen treatment. This amount is the one of the payoff matrix, corresponding to the position you hold at the end of the chosen treatment.

Note, that the position you hold at the end of the experiment depends on your submitted ordering, and the submitted ordering of the other participants of your group.

Once the experiment has finished, the allocations for all completed mechanisms are determined, each participant will get paid her total payoff.

3.6.2 Instructions for the Gale-Shapley Mechanism

Procedure:

In this mechanism there is one position opening at schools A, and two at schools B and C.

During the experiment, each participant completes the Decision Sheet by indicating her school preferences. You have to rank all three schools. Note that the preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

After all participants have completed their Decision Sheets, the experimenter will collect the Sheets and distribute the ones for the next environment, under the same mechanism. Once a mechanism is completed, so all the informational environments are completed, the experimenter will read the instructions for the new mechanism aloud.

Allocation Method:

With this method, each participant is assigned a position at the best possible school reported in her Decision Sheet that is consistent with the priority order of schools.

Given the submitted preferences of the participants and the priority order of each school, positions are allocated in the following way:

- An application to the first ranked school in the Decision Sheet is sent for each participant.
- Each school accepts the applicants with higher priority order until positions are filled, and keep them on hold, while rejects the lowest priority ones in excess of its capacity.
  Throughout the allocation process, a school can hold no more applications than its number of positions!
- Whenever an applicant is rejected at a school, her application is sent to the next highest school on his Decision Sheet.
- Whenever a school receives a new application (from an applicant that has been rejected in a previous round by a better ranked school), these applications are considered together with the (previously) retained applications for that school. Among the retained and new applicants, the lowest priority ones in excess of the number of the positions are rejected, while remaining applications are retained.
- This process is repeated until no more applications can be rejected, and the allocation is finalized; and each participant is assigned the position at the school that holds her application at the end of the process.

An Example:

We will go through a simple example to illustrate how the allocation method works.

Applicants and schools: In this example there are four applicants (1-4) and three schools (A, B, C).

Positions: There are two positions at school B, and one each at A and C.

Submitted school ranking: Suppose, you know the submitted school ranking of each participant, and these are the following:

	Applicant #1	Applicant #2	Applicant #3	Applicant #4
1st choice	A	B	C	C
2nd choice	C	A	B	A
3rd choice	B	C	A	B

Schools' priority ordering: Suppose, you know the priority ordering of the schools:

	A	B	C
1st choice	2	1	1
2nd choice	4	2	3
3rd choice	1	4	4
4th choice	3	3	2

Allocation: This allocation method consists of the following rounds:

ROUND 1: Each applicant applies to her first choice:

- Applicant #1 applies to School A, #2 to School B, and Applicant #3 and #4 to School C.
- School A retains Applicant #1, School B retains Applicant #2; and School C retains Applicant #3;

- School C rejects Applicant #4, as it only has one position, and School C prefers Applicant #3 to #4.

  ROUND 2: The applicant who is rejected in ROUND 1 (#4) applies to her second choice:

- Applicant #4 applies to School A.
- School A compares Applicant #1 (retained in round 1) and #4, as it only has one position free; and retains #4 and rejects now #1 (as in School A's preference ordering #4 has priority over #1).

  ROUND 3: The applicant who is rejected in ROUND 2 (#1) applies to her second choice:

- Applicant #1 applies to School C.
- School C compares Applicant #3 (retained in round 1) and #1, as it only has one position free. School C retains #1 and rejects now #3 (as in School C's preference ordering #1 has priority over #3).

  ROUND 4: The applicant who is rejected in ROUND 3 (#3) applies to her second choice:

- Applicant #3 applies to School B.
- School B retains Applicant #2 since the first round, but still has a vacancy (as here there are two positions opening), therefore School B accepts Applicant #3. Here the process finishes, as there are no more rejections; and the final allocations are:

Applicant	**#1**	**#2**	**#3**	**#4**
School	C	B	B	A

You will have 15 minutes to go over the instructions at your place, and make your decision. Are there any questions?

3.6.3 Instructions for the TTC Mechanism

Note: For brevity, here we only include those parts of the original instructions that differ from the instructions of the Gale-Shapley mechanism.

(...)

Allocation Method:

- In this process, initially each participant is tentatively assigned to one of the opening positions.
- In order to determine mutually beneficiary exchanges between applicants, all participants are ordered in a queue based on a fair lottery. This means, that each participant has an equal chance of being first in the queue, second, . . . , as well as the last in the queue. To determine this fair lottery, a participant will be asked to draw 5 pieces of papers, one at a time. Each piece of paper has a number on it, corresponding to a participant ID. The sequence of the draw determines the order in the lottery.
- Given the submitted preferences of the participants and the order in the queue determined by the lottery, the allocation process is the following:

- An application to the first ranked school in the Decision Sheet is sent for the participant at the top of the queue.
  * If the application is submitted to the school to which this participant was assigned initially, then her tentative assignment gets her final position; and this participant and his position are removed from the subsequent process. The process continues with the next participant in the queue.
  * If the application is submitted to another school, say school S, then the first participant who tentatively holds a position at school S is moved to the top of the queue, directly in front of the requester.
- Whenever the queue is modified, the process continues in the above described way. Now an application to the first ranked school in the Decision Sheet is sent for the (new) participant at the top of the queue.
  * If the application is submitted to the school to which this participant was assigned initially, etc...
  * If the application is submitted to another school, etc...
- A mutually-beneficial exchange is obtained when a cycle of applications are made in sequence, which benefits all affected participants; e.g. A applies to B's tentative position, B applies to C's tentative position, and C applies for A's tentative position. In this case the exchange is completed and all three participants as well as their assignments are removed from the subsequent process.
- The process continues, till all participants are assigned a position.

An Example

(...)

Priority queue of applicants: Suppose, the lottery gave the following priority ordering: 1 – 2 – 3 – 4.

Tentative assignment: Suppose, the initial (tentative) assignment of positions is the following:

Applicant #1	Applicant #2	Applicant #3	Applicant #4
B	C	B	A

Allocation: The allocation method consists of the following process:

1. The first applicant in the queue (#1) applies to her best choice, to School A, however, the only position here is tentatively held by participant #4. So participant #4 is moved to the top of the queue.

2. The new queue is now 4 – 1 – 2 – 3. Participant #4 ranked School C as her top choice, but the only position in this school is tentatively held by participant #2. Therefore #2 is moved to the top of the queue.

3. The new queue is now 2 - 4 – 1 – 3. Participant #2 ranked School B as her top choice, but the two positions at school B are tentatively held by participant #1 and #3. As #1 has priority over #3 (as she is in front of #3 in the queue), participant #1 is moved to the top of the queue.

4. The new queue is now 1 - 2 - 4 – 3. Remember, that applicant #1 has ranked School A as her best choice. A cycle of participants is now made in sequence in the last three steps: #1 applied to the tentative assignment of #4, #4 applied to the tentative assignment of #2, and #2 applied to the tentative

assignment of #1. These mutually beneficiary changes are made: #1 gets the position in School A, #2 gets one of the two positions in School B, and #4 gets the position in School C. These participants and their assignments are removed from the process.

5. The only participant left to be assigned is #3. As the only school with available position is School B, and this position is tentatively assigned to her, her assignment finishes; and the allocation process ends. The final allocations are:

Applicant	**#1**	**#2**	**#3**	**#4**
School	A	B	B	C

(...)

3.6.4 Instructions for the Boston Mechanism

Note: For brevity, here we only include those parts of the original instructions that differ from the instructions of the Gale-Shapley mechanism.

(...)

Allocation Method:

Given the submitted preferences of the participants and the priority order of each school, positions are allocated in the following way:

1. (a) An application to the first ranked school in the Decision Sheet is sent for each participant.

(b) Each school accepts the participants with higher priority order until positions are filled. These applicants and their positions are removed from the system. All other applications are rejected by the schools.

(a) The applicants remaining in the system send the application to their second ranked position in the Decision Sheet.

(b) If a school still has available positions remaining from Round 1, then it accepts the applicant with higher priority order until all positions are filled. The remaining applications are rejected.

2. Each remaining participant is assigned a position at her last choice.

An Example

(...)

Submitted school ranking: Suppose, you know the school ranking submitted by each participant, and it is the following:

	Applicant #1	Applicant #2	Applicant #3	Applicant #4
1st choice	A	A	A	B
2nd choice	B	C	C	C
3rd choice	C	B	B	A

Schools' priority ordering: Suppose, you also know the priority ordering of the schools:

	A	B	C
1st choice	1	1	2
2nd choice	2	3	3
3rd choice	3	4	4
4th choice	4	2	1

Allocation: This allocation method consists of the following rounds:

ROUND 1: Each applicant applies to her first choice:

- Applicant #1, #2, and #3 apply to School A, Applicant #4 to School B.
- School A accepts Applicant #1 (his first choice)
- School B accepts Applicant #4

Accepted applicants (#1 and #4) and schools without remaining positions (School A) are removed from the subsequent process.

ROUND 2: Each applicant who is rejected in ROUND 1 (#2 and #3) applies to her second choice:

- Applicant #2, and #3 apply to School C.
- School C accepts Applicant #2 (his first choice)

Accepted applicants (#2) and schools without remaining positions (School C) are removed from the subsequent process.

ROUND 3: Each remaining applicant who is rejected in the previous rounds (#3) is assigned her last choice:

- Applicant #3 gets the remaining position in School B.

Based on this method, the final allocations are:

Applicant	#1	#2	#3	#4
School	A	C	B	B

3.6.5 Decision Sheet for the Gale-Shapley Mechanism under Zero-Information

You are participant ID ......, in role #1.

Recall: Your payoff amount depends on the school position you hold at the end of the experiment. Your possible payoff amounts are outlined in the following table:

Position received at school	A	B	C
Your payoff	15	3	9

This means, that if at the end of the experiment you hold a position:

- at school A, you will be paid 15 €;
- at school B, you will be paid 3 €;
- at school C, you will be paid 9 €.

Recall! Different participants might have different payoff tables. That is, payoff by school might be different for different participants.

Recall! The preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

Recall! There are two positions opening at school B and C, and one at school A.

Priority ordering of schools: Schools when offering teaching positions consider the quality of each applicant and the experience they have; and on this basis they make a priority ordering of all candidates. In this first informational environment of the experiment you do not know anything about this ordering.

Please submit your ranking of the schools (A through C) from your first choice to your last choice. Please rank ALL three schools!

1st choice	2nd choice	3rd choice

This is the end of the first informational environment under mechanism GS.

After the experimenter collects your Decision Sheet, you will be given the second Decision Sheet under the same mechanism, but with different information structure.

3.6.6 Decision Sheet for the Gale-Shapley Mechanism under Partial-Information

You are participant ID ......, in role #1.

Recall: Your payoff amount depends on the school position you hold at the end of the experiment. Your possible payoff amounts are outlined in the following table:

Position received at school	**A**	**B**	**C**
Your payoff	15	3	9

This means, that if at the end of the experiment you hold a position:

- at school A, you will be paid 15 €;
- at school B, you will be paid 3 €;
- at school C, you will be paid 9 €.

Recall! Different participants might have different payoff tables. That is, payoff by school might be different for different participants.

Recall! The preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

Recall! There are two positions opening at school B and C, and one at school A.

Priority ordering of schools: Schools when offering teaching positions consider the quality of each applicant and the experience they have; and on this basis they make a priority ordering of all candidates. In this informational environment from the priority ordering of the schools you know only the best candidate(s) of each school. These are the following:

- at School A participant #5 has priority;
- at School B participant #2 and #4 have priority;

- at School C participant #1 (you) and #3 have priority

Please submit your ranking of the schools (A through C) from your first choice to your last choice. Please rank ALL three schools!

1st choice	2nd choice	3rd choice

This is the end of the second informational environment under mechanism GS.

After the experimenter collects your Decision Sheet, you will be given the third Decision Sheet under the same mechanism, but with different information structure.

3.6.7 Decision Sheet for the Gale-Shapley Mechanism under Full-Information

You are participant ID ......, in role #1.

Recall: Your payoff amount depends on the school position you hold at the end of the experiment. Your possible payoff amounts are outlined in the following table:

Position received at school	A	B	C
Payoff of participant #1 (YOU)	15	3	9
Payoff of participant #2	3	9	15
Payoff of participant #3	9	15	3
Payoff of participant #4	9	15	3
Payoff of participant #5	3	15	9

This means, that for example, if at the end of the experiment:

- You hold a position at school A, participant #2 and #3 hold a position at school B, and participant #4 and #5 hold a position at school C, the payoffs would be the following.
- You would be paid 15€; participant #2 would get 9€; participant #3 would get 15€; participant #4 would get 3€; and participant #5 would get 9€.

Recall! The preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

Recall! There are two positions opening at school B and C, and one at school A.

Priority ordering of schools: Schools when offering teaching positions consider the quality of each applicant and the experience they have; and on this basis they make a priority ordering of all candidates. In this informational environment the complete priority ordering of the schools is known by each participant, and is shown in the following table:

	School A	**School B**	**School C**
1st choice	#5	#4	#3
2nd choice	#4	#2	#1
3rd choice	#2	#1	#4
4th choice	#3	#5	#5
5th choice	#1	#3	#2

Please submit your ranking of the schools (A through C) from your first choice to your last choice. Please rank ALL three schools!

1st choice	2nd choice	3rd choice

This is the end of the mechanism GS. After the experimenter collects your Decision Sheet, you will be given the Decision Sheet for a new mechanism.

Bibliography

[1] Abdulkadiroglu, Atila and Sönmez, Tayfun (2003): "School Choice: A Mechanism Design Approach" *American Economic Review* **93.**, 3, pp.729-747

[2] Abdulkadiroglu, Atila, Pathak, P., Roth. A., and Sönmez, Tayfun (2005): "The Boston Public School Match" *American Economic Review, Papers and Proceedings,* forthcoming

[3] Barberà, S. and Dutta, B. (1995): "Protective Behavior in Matching Models" *Games and Economic Behavior* **8.**, pp.281-296

[4] Chen, Yan and Sönmez, Tayfun (2002a): "Improving Efficiency of On-Campus Housing: An Experimental Study" *American Economic Review* **92.**, 5, pp.1669-1686

[5] Chen, Yan and Sönmez, Tayfun (2002b): "An Experimental Study of House Allocation Mechanisms" *Economics Letters* **83.**, 1, pp.137-140

[6] Chen, Yan and Sönmez, Tayfun (2004): "School Choice: An Experimental Study" *Journal of Economic Theory,* forthcoming

[7] Conover, W.J. (1980): *Practical Nonparametric Statistics*, New York: John Wiley & Sons

[8] Dubins, L. and Freedman, D. (1981): "Machiavelli and the Gale-Shapley Algorithm" *American Mathematical Monthly* **88**., pp.485-494

[9] Ehlers, L. (2003): "In Search of Advice for Physicians in Entry-Level Medical Markets" *Mimeo, Université de Montréal*

[10] Ehlers, L. (2004): "In Search of Advice for Participants in Matching Markets Which Use the Deferred-Acceptance Algorithm" *Games and Economic Behavior* **48**., pp.249-270

[11] Ehlers, L. and Massó, J. (2003): "Incomplete Information and Small Cores in Matching Markets" *Mimeo, Universitat Autònoma de Barcelona*

[12] Ergin, Haluk and Sönmez, Tayfun (2004): "Games of School Choice under the Boston Mechanism" *Journal of Public Economics* **90**., pp.215-237

[13] Gale, D. and Shapley, L. (1962): "College Admissions and the Stability of Marriage" *American Mathematical Monthly* **69**., pp.9-15

[14] Harrison, G. and McCabe, K. (1996): "Stability and Preference Distortion in Resource Matching: An Experimental Study of the Marriage Problem" In V. Smith (ed.) *Research in Experimental Economics* **6**., pp.53-129, JAI Press

[15] Haruvy, E., Roth, A., and Ünver, U. (2001): "Dynamics of Law Clerk Matching: An Experimental and Computational Investigation of Proposals for Reform of the Market" *Journal of Economic Dynamics and Control*, forthcoming

[16] Kagel, J and Roth, A. (2000): "The Dynamics of Reorganization in Matching Markets: A Laboratory Experiment Motivated by a Natural Experiment" *Quarterly Journal of Economics* **115(1)**., pp.201-235

[17] McKinney, C., Niederle, M., and Roth, A. (2005): "The Collapse of a Medical Labour Clearinghouse (and Why Such Failures Are Rare)" *American Economic Review* **95**., pp.878-889

[18] Nalbantian, H. and Schotter, A. (1995): "Matching and Efficiency in the Baseball Free-Agent System: An Experimental Examination" *Journal of Labour Economics* **13**., pp.1-31

[19] Olson, M. and Porter, D. (1994): "An Experimental Examination Into Design of Decentralized Methods to Solve the Assignment Problem With and Without Money" *Economic Theory* **4**., pp.11-40

[20] Roth, A. (1982a): "The Economics of Matching: Stability and Incentives" *Mathematics of Operations Research* **7**., pp.617-628

[21] Roth, A. (1982b): "Incentive Compatibility in a Market With Indivisibilities" *Economics Letters* **9**., pp.127-132

[22] Roth, A. (1989): "Two-Sided Matching With Incomplete Information about Others' Preferences" *Games and Economic Behavior* **1**., pp.191-209

[23] Roth, A. and Rothblum, U. (1999): "Truncation Strategies in Matching Markets - In Search of Advice for Participants" *Econometrica* **67**., pp.21-43

[24] Roth, A. and Sotomayor, M. (1990): *Two Sided Matching: a Study in Game Theoretic Modeling and Analysis*, Econometric Society Monograph Series. New York: Cambridge University Press

[25] Shapley, L. and Scarf, H. (1974): "On Cores and Indivisibility" *Journal of Mathematical Economics* **1**., pp.23-28

[26] Ünver, U. (2001): "On the Survival of Some Two-Sided Matching Mechanisms: An Experimental and Computational Investigation of the Stability Hypothesis" *Mimeo, Koç University*

[27] Ünver, U. (2005): "On the Survival of Some Two-Sided Matching Mechanisms" *International Journal of Game Theory* **33**., pp.239-254

Chapter 4

College Admissions and Information: An Experimental Study on Matching

4.1 Introduction

Matching situations have gained increasing attention in economic literature recently. A lot of situations—both economic and social—can be modeled as a matching problem. We can think for example about the assignment of civil servants to civil service positions, the admission of students to colleges, some entry-level labor markets—as the widely explored market for graduating physicians—, or the school choice problem. The working of some matching mechanisms, along with strategic issues that confront individuals in these contexts, have been explored theoretically under the assumption of complete information.

In a two-sided matching market, the problem is to assign agents that belong to one of two disjoint sets, say colleges and students, to each other. Agents—college and student—have ordinal preferences over the agents on the other side of the market—students and colleges, respectively—and the prospect of being unmatched. The matching problem then reduces to match students to colleges by means of a matching mechanism. The most important and valued properties of such matchings are stability, strategy-proofness, and (Pareto) efficiency.

By definition, a matching is stable if every agent prefers her partner to being unmatched, and there is no pair of agents—one of each side of the market—such that they would prefer to be matched together instead of their actual partners. A mechanism that always yields stable matchings, is called stable mechanism. A mechanism is strategy-proof if it is immune to preference manipulation, i.e., truth is a dominant strategy, and Pareto efficient if it always selects Pareto efficient matchings. See that there is a relation between stability and Pareto efficiency: stable matchings are also Pareto efficient, but the inverse is not necessarily true.

In this paper we study the properties of two well-known matching mechanisms: the Gale-Shapley deferred-acceptance algorithm (Gale and Shapley, 1962) and the Top Trading Cycles (TTC) mechanism (Shapley and Scarf, 1974). The Gale-Shapley mechanism is perhaps the most famous one in the matching literature. The algorithm was designed to prove that stable matching always exists in a two-sided matching market. The mechanism transforms an initial matching where all the agents are unmatched into a stable matching, hence proving existence. Besides stability, this mechanism satisfies two other appealing properties: it is strategy-proof for the proposing side of the market (Dubins and Freedman, 1981, Roth, 1982a), and it is efficient when the welfare of both sides of the market is taken into consideration (Roth, 1982a).

The TTC mechanism (Shapley and Scarf, 1974) was designed originally to distribute indivisible items to individuals. This mechanism fulfills two appealing properties: it is both strategy-proof (Roth, 1982b) and Pareto efficient, but it is not stable.

As we mentioned it above, the theoretical studies on the properties of the particular matching mechanisms rely on the assumption of complete information. But expecting to know the preferences of every agent in the market is more than what we can observe (and reasonably expect) in most matching markets. There are only a few theoretical papers that relax this assumption. Roth (1989) is a first attempt to deal with the incomplete information case. Even though truth remains a dominant strategy for one side of the market when the Gale-Shapley mechanism is employed, the equilibrium characterization for the complete information case is not robust to incomplete information. Ehlers and Massó (2003) study Bayesian Nash equilibria for mechanisms producing stable matchings—as the Gale-Shapley mechanism—and find a necessary and sufficient condition for truthtelling to be an equilibrium. Finally, Roth and Rothblum (1999) and Ehlers (2003, 2004) are less ambitious and do not aim at characterizing equilibria, but give advice to individuals on how to participate in matching markets when there is uncertainty about the others' strategies.

Still, in matching theory many questions under incomplete information remain to be answered on theoretical grounds, hence there is an ample room for experiments: they can give some feedback on field observations and add guidance to theory. How the amount of information held by individuals on the elements of the game actually influences individuals' decisions, and affects the performance of matching mechanisms, are thus questions to be explored. For instance, Barberà and Dutta (1995) consider truthtelling as a form of "protective" behavior, claiming that risk averse agents may revert to faithfully revealing their true preferences when they are poorly informed. Moreover, in mechanisms for which truth is not a dominant strategy, computing the optimal strategies requires a lot of information on others' preferences. In this paper we present an experimental study to investigate these and other claims, providing—through laboratory experiments—a direction into which the role of information on individual decisions may be ascertained.

Following a previous work joint with Pais (Pais and Pintér, 2005) where we examined through laboratory experiments the role of information on decision making and the properties of several matching mechanisms in the school choice model, in this second paper we pose similar questions in a more general matching model, the so called college admissions model, explored by Gale and Shapley (Gale and Shapley, 1962). In these problems, individuals—let us call them teachers—have strict preferences over the agents of the other side—henceforth, schools—and vice versa. Schools have a maximum capacity, which is the number of vacancies that should be filled by teachers. In the college admissions model both teachers and schools are strategic agents to be matched to each other. Hence, both teachers and schools may not straightforwardly reveal their true preferences in contrast to the school choice model where schools are mere objects to be assigned to teachers.

In this paper the influence of information is assessed for both the Gale-Shapley mechanism and for the TTC mechanism.[1] Although the TTC mechanism was initially designed for situations where indivisible objects had to be assigned to individuals, it can be fit to the college admissions problems by taking into consideration the schools' preferences as well.

Besides providing some tests of theoretical results on matching mechanisms with

[1] School admission programs have become increasingly popular in the U.S. The best known of these programs rely on the Boston mechanism (not considered in this study because its clear inferiority found in Pais and Pinter, 2005) and the Gale and Shapley mechanism replacing the Boston mechanism in several cities.

boundedly rational individuals, we address a series of practical questions. In particular, we are interested in comparing the incentives agents face under different mechanisms, as well as in comparing efficiency levels and stability of the obtained outcomes, for different amounts of information. Therefore we implement three informational scenarios, ranging from complete ignorance about the other participants' preferences to complete information on all elements of the game.

Second, within each mechanism, we evaluate the influence of the amount of information held by individuals on private decisions. We are concerned in testing whether truthtelling is a salient form of behavior among teachers when information is low. This would imply that, in markets where we expect agents to know little about others, strategy-proofness of the mechanism should not drive the choice of the matching mechanism. If we are able to determine that information is not relevant in individuals' decisions, we can consider existing theoretical results, which rely on the fundamental assumption of complete information, apt to deal the incomplete information case. On the other hand, if we can determine that the amount of information affects significantly individuals' behavior, we must conclude that existing theory is insufficient to describe markets where agents know little about others and here experiments can provide an insight into the direction of changes.

Our results support the first conjecture: information is actually important. In fact, in a very low information environment, acting straightforwardly is a very salient form of behavior not only among teachers, but also among schools. This result for the schools contradicts the theoretical results (for complete information). In stability information has again an important but contrary effect on the two mechanisms: while in the Gale-Shapley mechanism the amount of information has a negative effect on the frequency of stable outcomes, in the TTC mechanism this effect is positive. The same negative relation can be observed between the amount of information and efficiency in the TTC mechanism, while in Gale-Shapley mechanism efficiency is not sensitive to the amount of information participants hold. This happens, because—although in treatments with more and more information we observe more and more unstable outcomes—the payoffs of the unstable outcomes are not very far from a core outcome. Comparing the two mechanisms, the only significant difference in the proportion of truthful play we find in the partial-information treatment, where this proportion is higher in the TTC mechanism. Regarding both stability and efficiency—two connected characteristics, as efficiency is measured here as the average minimum distance from the core—, the Gale-Shapley mechanism results more successful than the TTC.

We are aware of several experimental studies of matching problems, some of which aim at testing the above mentioned mechanisms. These include Harrison and McCabe (1996) that explores the Gale-Shapley mechanism and shows that profitable manipulation of agents' preferences and reaching an efficient outcome become more difficult as markets get larger; Chen and Sönmez (2002a) that compares a random serial dictatorship mechanism used to allocate dormitory rooms in American universities with a variant of the TTC in an incomplete information environment, concluding that the TTC produces significantly more efficient allocations; in a companion paper, Chen and Sönmez (2002b) evaluate the performance of these mechanisms under complete information, reaching the same qualitative results; finally, Chen and Sönmez (2003), consider the school choice problem and analyze the TTC, the Gale-Shapley, and the Boston mechanisms under (partially) incomplete information, concluding that, in what efficiency is concerned, Gale-Shapley improves upon the TTC, which outperforms the Boston mechanism. The difference between the above studies and this paper derives from our main objective: to test the role of information in evaluating matching mechanisms. Other experimental and empirical studies, dealing with matching mechanisms, are: Olson and Porter (1994), Nalbantian and Schotter (1995), Kagel and Roth (2000), Ünver (2001), Haruvy, Roth, and Ünver (2001), and McKinney, Niederle, and Roth (2004).

In Section 2 we present the theoretical properties of the three matching mechanisms under study. We describe the experimental design in Section 3. Section 4 summarizes the main results of the experiments. Concluding remarks follow in Section 5.

4.2 The Matching Mechanisms in Theory

We first introduce the model and then describe the two matching mechanisms and their theoretical properties.

In the assignment problem there are a number of teachers to fill a number of vacancies or teaching positions across different schools. Each teacher has strict preference over all schools, and each school has strict preference over all teachers, as well as a maximum number of teachers to employ (capacity). The fact that both teachers and schools can act strategically is what distinguishes this problem from the school choice model. It is not difficult to justify the use of the college admissions model, we can find plenty of real-life situations that can be described as both sides of the market having the opportunity to act strategically. We have already mentioned the use of the college admissions problem in the admissions of children to (private) schools in the US or Spain, the "marriage market", but we can think about plenty of examples in the entry-level labour markets. One of the most famous one is the labor market for medical interns and residents, which has been deeply explored in the recent years.[2] In general, in the entry-level labour markets

[2] For details see Roth (1984).

both candidates and employers have preference on the agents of the other side of the market, and the final matchings (employments) depend on these preferences and the assignment (employment) procedure applied in the selection process.

The outcome of this problem is a matching, an assignment of teachers to teaching positions (schools) such that each teacher is assigned one position and each position is filled by one teacher only.[3] A matching is Pareto efficient if there is no matching that assigns at least one participant (teacher or school) a strictly better partner and every other participant a weakly better mate. A matching mechanism consists of a strategy space for each participant and a function that selects a matching for each strategy profile. A matching mechanism is efficient if it always chooses Pareto efficient matchings; it is strategy-proof if no participant can profitably manipulate her preferences, independently of the other agents' strategies; and it is stable, if it always selects matchings, where every agent prefers his partner to being alone and, moreover, no pair of agents (each on one side of the market) who are not matched to each other would rather prefer to be so matched.

4.2.1 The Top Trading Cycles Mechanism

In this context, the TTC mechanism is defined as follows:

1. Each school reports her preferences over the teachers, and each teacher reports her preferences over the schools.

2. An ordering (a queue) of teachers is randomly chosen.

3. For any submitted teachers' preferences, schools' preferences, and ordering of teachers, the outcome is obtained after undergoing the following steps:

[3] Of course, there may be schools that offer several positions.

(a) A tentative assignment is made in the following way. Given the submitted preferences of schools, each school gets assigned its top-ranked teachers up to capacity. In case a teacher is preferred by several schools, she gets assigned to the school she prefers (according to her submitted preference ordering), and the other schools keep this position vacant.

(b) The first teacher in the random ordering proposes to her top ranked school. If either the position as vacant or she was tentatively assigned to this school, the assignment is finalized and both the teacher and this teaching position are removed from the system. The procedure continues with the second teacher in the ordering. Otherwise, the first teacher in the ordering who was tentatively assigned to the desired position is inserted in the top of the ordering.

(c) When the ordering is modified, this procedure is repeated, so that the teacher who just became first in the ordering sends an application to her highest-ranked school. If either the position was vacant or she was tentatively assigned to this school, the assignment is finalized and the procedure continues with the next teacher in line; otherwise, the first teacher in the ordering with the initial assignment at the proposed school is inserted in the top of the ordering, in front of the requester.

(d) If a cycle forms, it consists of a sequence of proposals of the kind: A proposes to the school where B was tentatively assigned, B applies to C's tentatively assigned school, and C proposes to A's tentatively assigned school. In such cases, all teachers in the cycle are assigned to the schools they proposed to and teachers and their respective assignments are removed from the system.

(e) The procedure stops when all teachers are assigned to a position.

The TTC mechanism satisfies two appealing properties: it is strategy-proof for agents on the proposing side, i.e., truth is a dominant strategy for every teacher, but schools may gain with untruthful behavior. Therefore in the experiment participants in the teachers' role should reveal preferences truthfully independently of the amount of information they hold about the elements of the game, while from the schools we expect preference manipulations. This mechanism is Pareto efficient for reported preferences[4], but the mechanism is not stable.

4.2.2 The Gale-Shapley Mechanism

The Gale-Shapley mechanism is certainly one of the best known mechanisms in the matching literature.

Its theoretical properties and the incentives it gives to agents have been scrutinized and its applications encompass a significant number of markets. In what follows we describe the functioning of the Gale-Shapley mechanism:

1. Each teacher reports her preferences over the schools and each school reports her preferences over the teachers.
2. Given the submitted preferences of the teachers and of the schools, positions are allocated after undergoing the following steps:
   (a) Each teacher proposes to her first ranked school. Each school keeps the applicants with higher preference rank on hold until positions are filled, while rejecting the lowest ranked teachers in excess of its capacity.

[4] We remind the reader that both mechanisms are Pareto efficient for reported preferences, but—as participants may manipulate their preferences—they may not be efficient regarding true preferences (which is, in fact, what really matters in efficiency terms).

(b) In general at round k:

Every teacher who got rejected in the previous step proposes to the next school on her list of preferences. Each school considers the teachers it holds from the previous step together with the new applications. The lowest ranked teachers in excess of the school's capacity are rejected, while remaining applications are kept on hold.

(c) This process is repeated until no applications are rejected. Each participant is then assigned the position at the school that keeps her on hold.

As the TTC, also the Gale-Shapley mechanism is strategy-proof for the proposing side, i.e. in our case for the teachers; while schools may gain with strategic behavior.[5] Therefore we expect different behavior from teachers and schools: teachers should faithfully reveal their true preferences over schools in every informational treatment, while among the schools we may experience some preference manipulation. This mechanism is Pareto efficient for reported preferences when the welfare of both sides of the market is taken into account, and the mechanism is stable. It follows that, if theory is to be confirmed, the Gale-Shapley mechanism should outperform the TTC in terms of stability, while regarding truthful preference revelation the two mechanisms should perform similarly.

4.3 Experimental Design

We designed an experiment to analyze participants' decisions under different informational settings throughout the above described two matching mechanisms: the

[5] In fact, there is no matching mechanism that would be strategy-proof for all the agents, on both sides of the market.

Gale-Shapley mechanism and the TTC mechanism. We use a 2x3 design: for both mechanisms we construct three treatments differing in the amount of information held by participants about the elements of the game. This allows us to compare the individual decisions in six treatments. In our analysis we concentrate on the role of information in truthful preference revelation, in efficiency and in stability. The environment is designed to capture the key aspects and difficulties of each mechanism, under a controlled environment, with relatively small groups of participants.

At the beginning of each session participants are randomly and anonymously assigned a role: teacher (J-N) or school (A, B, or C). These roles are maintained during the session. Participants are told that they are sorted in groups of eight (five teachers and three schools) but this grouping is anonymous. In each group there are five vacancies across three schools that differ in capacity (number of opening positions) and desirability and each position should be assigned to one teacher only. Preferences over the agents of the other side of the market are induced by the monetary payoff a participant obtains depending on her position in the resulting matching at the end of the experiment. The payoff tables (induced preferences) of different teachers and schools are different and are designed to create a strategic conflict. The payoffs obtained by teachers and schools are symmetric: every teacher gets 15€ for her top choice, 9€ for the second choice, and 3€ for the last choice; while each school gets 15€ for her top choice, 12€ for the second choice, 9€ for the third choice, 6€ for the fourth choice, and 3€ for the last (fifth) choice. As we have mentioned, different teachers or schools need not agree on which school or teacher is either her top, her second, etc., last choice respectively. The payoffs of different outcomes are sufficiently dispersed so as to have a monetarily salient difference between getting one's best and one's worst choice.

Under each mechanism, each group of participants plays the game three times, holding three different, but increasing, amounts of information. As a means to avoid participants from playing from memory when the mechanism is changed, we shuffle the labeling of schools and modify the schools' characteristics accordingly. It follows that each participant keeps the same role throughout the whole experiment, even though her payoff matrix seemingly changes: the performed changes are virtual.

4.3.1 Informational Settings

In each experimental session three different informational treatments are implemented for each mechanism, in the following order:

- **Zero-information setting**: In this setting each participant knows her own induced preference (i.e., the row of the payoff matrix that corresponds to her role), but not the other participants' preferences. She is only told that different participants might have different payoff tables. So, in this treatment teachers and schools have no information about the other side's induced preferences, they are only told the capacity (i.e., the number of vacancies) of each school.

- **Partial-information setting**: In this setting, besides her own induced preference and the capacity of each schools, each teacher and school has some information about schools' and teachers' preference orderings respectively. Namely, each teacher is told the list of favorite teacher(s) of each school, up to its capacity, and each school is told the top choice of each teacher (in both cases according to the induced preferences).

- **Full-information setting**: In this informational setting each participant has complete information on the induced preferences of all participants (teachers and schools), and the capacity of schools.

In the case of the TTC mechanism, as the schools' preference orderings are reflected in the tentative assignment, under the partial-information treatment participants are told—besides their own induced preference—the tentative assignment of all participants given the induced preferences; while in the full-information treatment they know both the induced preferences of all participants, and the tentative assignment. In these two treatments participants are reminded that this initial assignment may change as schools and teachers can manipulate their preferences.

Three sessions were conducted with undergraduate students from the Universitat Autònoma de Barcelona, recruited using classroom announcements and posters throughout the campus, where the experimental sessions (on paper/by hand) took place. Overall 72 subjects participated in the experiment, which makes 9 groups. Each subject was allowed to participate in one session only. Subjects were informed that they would participate in a decision making task. At the beginning of each session, subjects were randomly seated at the tables and printed instructions were given to them. Before starting each mechanism, the corresponding instructions were read aloud. In each session and for each informational setting participants were asked to submit a preference ordering, from their top choice to the last choice. In each session all six treatments were implemented, so we have six decisions from each participant, each under a different mechanism and/or different informational setting. The order of implementation of the mechanisms and informational settings –to avoid learning about others' preferences– was the following:

1^{st}: Gale-Shapley mechanism in the zero-information setting (GS0)

2^{nd}: Gale-Shapley mechanism in the partial-information setting (GS1)

3^{rd}: Gale-Shapley mechanism in the full-information setting (GS2)

4^{th}: TTC mechanism in the zero-information setting (TTC0)

5^{th}: TTC mechanism in the partial-information setting (TTC1), and finally

6^{th}: TTC mechanism in the full-information setting (TTC2).

Subjects did not get any feedback about previous decisions or outcomes at any moment of the experiment. At the end of each session, one of the six treatments was chosen randomly for payment, matching was determined for the chosen treatment and earnings were paid. Sessions lasted for about 90 minutes and average net payment —including a 3€ show-up fee— is around 16€.[6]

4.4 Results

This section presents our experimental results. Our main aim is to examine the importance of the level of information that participants hold in evaluating the two matching mechanisms. The experimental setting we use allows us to analyze simultaneously the role of information in private decisions and whether it affects the theoretical properties of the mechanisms. The first keypoint is related to whether individuals report their preferences truthfully. We study whether the amount of information given to the participants influences truthful preference revelation (keeping the mechanism under analysis fixed) and, on the other hand, whether under the same informational setting, truthful preference revelation changes with the implemented mechanism. The second main point is related to stability and efficiency. Again, we compare stability and efficiency levels under each mechanism across information settings and across different mechanisms for the same information level.

[6] You can find in the Appendix the Decision Sheets for the Gale-Shapley mechanism, for each information treatment. The instructions and the Decision Sheets for the TTC mechanism are available upon request from the author.

4.4.1 Truthful Preference Revelation

We first analyze the two questions related to truthful preference revelation. Table 1 shows the proportion of teachers and schools who played truthfully (regarding induced preferences). Remember that according to the theoretical results, truth is dominant strategy for teachers in both mechanisms, but it is not for schools. Therefore, we expect a significant number of schools playing strategically in both mechanisms.

Mechanism	Info treatment	Truth-telling	
		Teachers	Schools
Gale - Shapley	GS0	76%	48%
	GS1	58%	33%
	GS2	60%	22%
Top Trading Cycles	TTC0	84%	67%
	TTC1	71%	37%
	TTC2	62%	33%

Table 1: Proportion of truthful preference revelation

As we can notice the proportion of truthful preference revelation of teachers varies between 84% and 58%, depending on both the informational setting and the implemented mechanism. We can notice that even though the Gale-Shapley and the TTC mechanisms are strategy-proof for teachers, we have some misrepresentation of preferences, although its extent depends on the implemented information setting. It is important to examine who manipulates the preferences and in which manner. We identify three possible ways of preference manipulations for teachers. We noticed that a substantial proportion of the teachers has ranked the school where she was among the most preferred teachers higher in the submitted ranking than it would be according to the induced preferences, this is what we call the "Priority School Bias" (PSB).[7] The second identified way of manipulating the true preferences is to underrank the most competitive school (i.e., the school with only one vacancy), this behavior we call—following Chen and Sönmez—the "Small School Bias" (SSB). The third manipulation method (PSB&SSB) is simply the simultaneous use of both previously described ways.[8] Comparing the payoff the strategic teachers earn, we can conclude that it is not worth for them to behave strategically, as on average each teacher who manipulates her preferences looses 1.98€ in the Gale-Shapley mechanism, and 2.43€ in the TTC mechanism.[9] Of course, this is not surprising given that—as theoretical results show—both mechanisms are strategy-proof for teachers.

Among the schools preference manipulation is much more frequent but this is not surprising given the predictions of theory (for this side of the market it is not dominant to reveal truthfully their induced preferences). We can observe that the proportion of preference manipulation among schools varies between 78% and 44%, depending on the mechanism and the amount of information these participants hold. In general, we can see that as players get more information about the elements of

[7] In case of the zero-information setting it does not make sense to check for this kind of preference manipulation, as participants in these settings have no information about the preferences of the schools.

[8] As we have already mentioned, in case of the zero-information setting it does not make sense to check for the PSB preference manipulation, therefore in these info settings the PSB&SSB manipulation will be included in the SSB manipulation method.

[9] In this chapter, both for teachers and schools, we compute the realized losses/gains of strategic behavior with respect to their payoff given that everybody plays truthfully.

the game, the proportion of schools that reveal the preferences truthfully decreases, in both mechanisms. In case of the schools we can also observe that schools tend to rank higher those teachers who rank them higher in their (induced) preferences. We can distinguish two versions of this general way of manipulating preferences: there are schools that only manipulate the candidates that are out of its capacity in the induced preference list (i.e. changing the order of the last four or three candidates, depending on the number of vacancies the school has); while there are schools that manipulate over the whole list. Comparing the earnings, we can conclude that in general, this strategic behavior results successful, as schools that decide to manipulate their preferences earn slightly more than if they did not do so. This difference is 0.47€ for the Gale-Shapley mechanism, and 0.13€ for the TTC mechanism. Although these average gains are small, and individually there some schools that loose, others that win by preference manipulations, this result shows that schools manage to benefit from their position.

Now, we analyze whether the amount of information the participants hold affects behavior. To answer this question, we compare the proportion of teachers and schools playing truthfully under the same mechanism, but in different informational settings. That is, for both mechanisms, we check whether the difference in the proportion of truthtelling for different amounts of information is statistically significant.[10]

Result 1a (teachers): *Under both examined matching mechanisms (Gale-Shapley and TTC) the amount of information has a significant negative effect on the decisions of the teachers in what truthtelling is concerned. We find that in both mechanisms, having more information about the other parties' preferences results*

[10] We compare, for both mechanisms, three informational settings: GS0 vs GS1 vs GS2; and T0 vs T1 vs T2.

in a lower proportion of truthtelling.

Statistical evidence: Under both mechanisms, the null hypothesis of equal proportions of truthful preference revelation across the three informational settings can be rejected at 5% significance level.[11] As the null hypotheses are rejected, multiple comparisons are made. The results of the pairwise comparisons (with the corresponding test statistics of the Cochran's test[12] in parenthesis) can be found in Table 2:

Mechanism	Gale-Shapley			TTC		
Null hyp.	GS0=GS1	GS0=GS2	GS1=GS2	TTC0=TTC1	TTC0=TTC2	TTC1=TTC2
Difference	17.78%*	15.56%**	-2%	13.33%**	22.22%*	9%
Test stat.	(5.33)	(3.27)	(0.14)	(3.00)	(5.56)	(1.00)

* Significant at α=0.05   ** Significant at α=0.1

Table 2: Pairwise comparisons of teachers' truthful behavior

We can see that in both mechanisms the zero-information setting results in a significantly higher proportion of truthtelling than in any treatment where teachers got additional information about the (induced) preferences of the other participants. On the other hand, there is no significant difference detected regarding truthful preference revelation between the partial- and full information settings, in any of the mechanisms.

Now, we will turn our attention to the other side of the market, i.e. the behavior of schools. Recall, that for schools the mechanism is not strategy proof,

[11] The value of the Cochran's Q test statistics is 6.71 for the Gale-Shapley mechanism and 6.71 for the TTC.

[12] To learn more about the Cochran's test for related observations used in our analysis see W.J. Conover (1980).

there may be profitable manipulation for these agents. Again, we are interested on whether there is any significant difference in the proportion of truthfulness among the schools.

Result 1b (schools): *Under both examined matching mechanisms (Gale-Shapley and TTC) the amount of information has a significant negative effect on the decisions of the schools in what truthtelling is concerned. In particular, we find that in both mechanisms, having more information about the other parties' preferences results in a lower proportion of truthtelling.*

Statistical evidence: Under both mechanisms, the null hypothesis of equal proportions of truthful preference revelation across the three informational settings can be rejected at 5% significance level.[13] As the null hypotheses are rejected, multiple comparisons are made. The results of the pairwise comparisons (with the corresponding test statistics of the Cochran's test in parenthesis) can be found in Table 3:

Mechanism	**Gale-Shapley**			**TTC**		
Null hyp.	**GS0=GS1**	**GS0=GS2**	**GS1=GS2**	**TTC0=TTC1**	**TTC0=TTC2**	**TTC1=TTC2**
Difference	15%	25.93%*	11%	29.63%*	33.33%*	4%
Test stat.	(2.67)	(6.13)	(2.25)	(5.33)	(7.36)	(0.14)

* Significant at α=0.05

Table 3: Pairwise comparisons of schools' truthful behavior

We can see that in both mechanisms the zero-information setting results in a significantly higher proportion of truthtelling than the full information one and

[13] The value of the Cochran's test statistics is 7.4 for the Gale-Shapley mechanism and 9.73 for the TTC.

in case of the TTC mechanism the difference is significant between the zero- and the partial- information settings as well. This difference comes from the high proportion of truthtelling in this mechanism under zero-information setting. On the other hand, there is no significant difference regarding truthful preference revelation between the partial- and full information settings, in any of the mechanisms.

Regarding the differences in truthfulness across mechanisms, we can see (Table 1) that truthful preference revelation is slightly higher in the TTC mechanism, but the Cochran's test shows that the difference is only significant in the partial-information treatment.

4.4.2 Stability and Efficiency

Other two important properties of a matching mechanism are stability and efficiency. Recall, that the Gale-Shapley mechanism generates outcomes that are stable with respect to the submitted preferences, while the TTC mechanism does not fulfil this property. First we will compare stability—regarding true preferences—across treatments. The average stability of a treatment is calculated simply as the proportion of stable matchings observed among all the matchings realized, given the strategies used by the participants. The set of stable matchings (core) for both mechanisms is described in the following table:[14]

[14] In the column Note we have indicated which of the core outcomes is the teacher-optimal (T.Opt.) and the school-optimal (S.Opt.) matching; the outcome that is obtained by truthful behavior (in both mechanisms) is indicated by TT.

	School - Teacher	School - Teacher	School - Teacher	Note
1.	A - L 6 9	B - M ; N 21 15 ; 15	C - J ; K 15 9 ; 15	T.Opt.; TT
2.	A - L 6 9	B - K ; M 27 9 ; 15	C - J ; N 18 9 ; 9	
3.	A - N 15 3	B - K ; M 27 9 ; 15	C - J ; L 27 9 ; 3	S.Opt.

Table 4: The set of stable matchings

The proportion of stable outcomes differs between 0% and 66.7%, depending on the mechanism and the information setting we examine.

Result 2 (stability): *Depending on the information setting, the difference in stability between the Gale-Shapley and the TTC mechanisms can be insignificant. On the other hand, both mechanisms are sensitive to the amount of information held, but the effect of information on stability is contrary in the two mechanisms.*

Statistical evidence: Table 5 shows the proportion of stable matchings in each treatment:

Treatment	**Gale-Shapley**			**TTC**		
	GS0	**GS1**	**GS2**	**TTC0**	**TTC1**	**TTC2**
Stable matchings	64.20%	45.68%	45.68%	0%	32.10%	66.67%

Table 5: Proportion of stable matchings

Our results show that (on average) stability in the Gale-Shapley mechanism is higher than in the TTC mechanism, but depending on the information setting this difference can be insignificant. When comparing the proportion of stable outcomes obtained across mechanisms (under the same information treatment), we find that the difference is highly significant in the zero- and full-information treatments, while in the partial-information treatment the difference is not significant at a 5% significance level.

To analyze the effect of information on stability, we compare the average stability in each mechanism, under the different information settings. In both mechanisms the null hypothesis of equal proportions of stable outcomes obtained across the three information treatments is rejected at any reasonable significance level[15], therefore pairwise comparisons are made. The results can be found in the following table:

Hypothesis	**GS0=GS1**	**GS0=GS2**	**GS1=GS2**	**TTC1=TTC0**	**TTC2=TTC0**	**TTC2=TTC1**
Difference	18.52%*	18.52%*	0%	32.10%**	66.67%**	34.57%**
Test stat.	(9.78)	(9.78)	(0)	(26)	(54)	(21.78)

* Significant at α=0.01   ** Significant at α=0.001

Table 6: Pairwise comparisons of stability across information treatments

We can see that the amount of information has an important effect on the stability in both mechanisms. In the Gale-Shapley mechanism the proportion of stable outcomes observed is significantly higher in the zero-information treatment than in any other treatment with additional information, but there is no significant difference in stability between the partial- and full-information treatments. In case of the TTC mechanisms the difference in stability is highly significant between any two information treatments. We can notice another important feature: while in

[15] The test statistics of the Cochran's test is 19.57 in the Gale-Shapley mechanism, and 75.45 in the TTC mechanism.

the Gale-Shapley mechanism with the increase of the amount of information –and of the manipulation of preferences– the ratio of the stable matchings decreases, in the TTC mechanisms we observe the opposite: as more information is available and preference manipulation gets more frequent, the likelihood of getting a stable outcome increases.

Following Harrison and McCabe (Harrison and McCabe, 1996) we define efficiency as the minimum payoff distance to the core, which uses the cardinal information contained in the payoff tables. The way of computing this efficiency measure is the following. First, for each core outcome and for each group, we compute the absolute value of the difference between the realized payoff and the core payoff. Now we have for each group the distance to each of the three stable outcomes of our matching market. Then, we choose the minimum over these three distances, and this is the measure we will use to evaluate efficiency.

We are concerned about the possible differences in efficiency across different information settings for each mechanism, and also about the comparison of the two mechanisms in terms of efficiency. If we find that efficiency depends on the amount of information participants hold, this directly implies that under some informational treatment(s) the stability is significantly higher than in some other(s). First we will focus on the effect of information on efficiency.

Result 3: *In the Gale-Shapley mechanism there is no significant difference in efficiency across the information settings, the average minimum distances from the core are close to each other. In case of the TTC mechanism there is a significant difference in efficiency across information settings, in the zero-information setting the efficiency is significantly lower than in the treatments with additional information.*

Statistical evidence: Under the Gale-Shapley mechanism the null hypothesis of equal efficiency (equal distance to the core) across the three informational settings can not be rejected at any reasonable significance level. On the other hand, under the TTC mechanism the same null hypothesis can be rejected at any reasonable significance level.[16] As the null hypothesis is rejected, multiple comparisons are made. The results of the pairwise comparisons (with the corresponding test statistics of the Quade's test[17] in parenthesis) for the TTC mechanism can be found in Table 7:

Treatment	**TTC0**	**TTC1**	**TTC2**
Average distance from core	32*	16.33*	3.67
Hypothesis	**TTC0=TTC1**	**TTC0=TTC2**	**TTC1=TTC2**
Test stat.	(52.5)	(73.5)	(21)

* Significant at α=0.01

Table 7: Pairwise comparisons for efficiency across information settings

We can see that the average distance from the core in the zero-information setting is significantly higher (at any reasonable α) than either in the partial-infomation or the full-information setting. This means that the efficiency is lower in this treatment than in the other two. On the other hand, we do not find any significant difference regarding efficiency between the partial- and full-information settings.

After this, we will turn our attention to the efficiency differences that may arise as a result of the different characteristics of the implemented mechanisms.

[16] The test statistics of the Quade test used in this case, is 11.262.

[17] To learn more about the Quade's test for related observations used in our analysis see W.J. Conover (1980).

Result 4: *Comparing efficiency across the two matching mechanisms, we find that in case the participants have no information about the preferences of other participants, the Gale-Shapley mechanism performs significantly better. In case participants have additional information about the elements of the game, there is no significant difference in efficiency between the Gale-Shapley and the TTC mechanisms.*

Statistical evidence: In the zero-information treatment the Wilcoxon signed ranks test confirms that the average minimum distance from the core is significantly higher under the TTC mechanism than under the Gale-Shapley mechanism, at any significance level no lower than 1.4%.[18] This implies a significantly higher efficiency level under the Gale-Shapley mechanism. The same test in the partial-information setting could not detect significant difference in efficiency (with test statistics: -0.677); while in the full-information setting the difference in efficiency between the two mechanisms is significant only at a significance level higher than 0.088.

4.5 Concluding Remarks

In this paper we examine a particular class of matching problems, that is closely related to the school choice problem: the so called college admissions model. We analyze two well-known matching mechanisms—the Gale-Shapley and the TTC mechanisms—under three different informational settings. Our experimental design allows us –besides providing yet another test of theoretical results on matching mechanisms with boundedly rational individuals– to analyze two main questions.

[18] The test statistics for the Wilcoxon signed ranks test is -2.203, so the null hypothesis of equal efficiency can be rejected in favor of the left-tailed alternative hypothesis. The p-value is 0.014. To learn more about the Wilcoxon signed ranks test, see W. J. Conover (1980).

First, we compare the individuals' decision making regarding truthtelling and efficiency under the two mechanisms, in each informational setting. These results may serve as a test of the theoretical characterization of the above mechanisms. Our second aim is to evaluate the influence of the amount of information held by the individuals on decision making, under these two matching mechanisms.

Our results show that in both mechanisms, having more information about the other parties' preferences results in a lower proportion of truthtelling for teachers. That is, in case the teachers have partial or full information about the elements of the game, a significantly higher number of participants manipulate their preferences than if they only know their own preferences. This result is consistent with the results found in our previous paper on matching and information, even more, this result shows that teachers do not vary significantly their behavior when schools may also behave strategically. The behavior of schools shows a similar pattern regarding truthtelling, but preference manipulation for schools is predicted by theory.

Regarding efficiency, we find that across information settings only in the TTC mechanism can we detect significantly lower efficiency in case of the zero information setting, in the Gale-Shapley mechanism all three treatments yield the same (relatively high) efficiency—and also stability—level. When comparing the two mechanisms in terms of efficiency, we find that the Gale-Shapley mechanism performs better than the TTC mechanism, as in the zero-information setting—when preference manipulation is low—it clearly outperforms the TTC mechanism.

Summarizing, we can conclude that the comparison of the mechanisms suggests the superiority of the Gale-Shapley mechanism. Although regarding truthful preference revelation—depending on the implemented informational setting—it may give similar results to the TTC mechanism, in the achieved efficiency level the Gale-Shapley mechanism performs clearly better than the TTC mechanism.

On the other hand, we find that the amount of information plays an important role in participants' decision making. In general we can say that if the participants (both teachers and schools) only know their own induced preferences, i.e., own payoffs, they are more likely to play truthfully than in case of having additional information.

4.6 Appendix Decision Sheets

4.6.1 Decision Sheet for the Gale-Shapley Mechanism under Zero-Information—Teachers

You are participant ID ......, in the role of **teacher J**.

Capacity: There are two positions opening at school B and C, and one at school A.

Recall: Your payoff amount depends on the school position you hold at the end of the experiment. Your possible payoff amounts are outlined in the following table:

Position received at school	**A**	**B**	**C**
Your payoff	15	3	9

This means, that if at the end of the experiment you hold a position:

- at school A, you will be paid 15 €;
- at school B, you will be paid 3 €;

- at school C, you will be paid 9 €.

Recall! Other participants might have different payoff tables.

Recall! The preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

Recall! There are two positions opening at school B and C, and one at school A.

Priority ordering of schools: Schools when offering teaching positions consider the quality of each applicant and the experience they have; and on this basis they make a priority ordering of all candidates. In this first informational environment of the experiment you do not know anything about this ordering.

Please submit your ranking of schools (A through C) from your first choice to your last choice. Please rank ALL three schools!

1st choice	2nd choice	3rd choice

This is the end of the first game under the first mechanism.

After the experimenter collects your Decision Sheet, you will be given the second Decision Sheet under the same mechanism, but for a new game (with different information structure).

4.6.2 Decision Sheet for the Gale-Shapley Mechanism under Zero-Information—Schools

You are participant ID ......, in the role of school A.

Capacity: There are two positions opening at school B and C, and one at school A.

Recall: Your payoff amount depends on the school position you hold at the end of the experiment. Your possible payoff amounts are outlined in the following table:

Teacher employed	J	K	L	M	N
Your payoff	3	9	6	12	15

This means, that if at the end of the experiment you are matched with teacher:

- J, you will be paid 3 €;
- K, you will be paid 9 €;
- L, you will be paid 6 €;
- M, you will be paid 12 €;
- N, you will be paid 15 €.

Recall! Different participants might have different payoff tables.

Recall! The preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

Recall! There are two positions opening at school B and C, and one at school A.

Priority ordering of teachers: Teachers when applying to schools, make a priority ordering of all schools. In this first informational environment of the experiment you do not know anything about this ordering.

Please submit your ranking of teachers (J through N) from your first choice to your last choice. Please rank ALL five teachers!

1st option	2nd option	3rd option	4th option	5th option

This is the end of the first game under the first mechanism.

After the experimenter collects your Decision Sheet, you will be given the second Decision Sheet under the same mechanism, but for a new game (with different information structure).

4.6.3 Decision Sheet for the Gale-Shapley Mechanism under Partial-Information—teachers

You are participant ID ......, in the role of teacher J.

Capacity: There are two positions opening at school B and C, and one at school A.

Recall: Your payoff amount depends on the school position you hold at the end of the experiment. Your possible payoff amounts are outlined in the following table:

Position received at school	A	B	C
Your payoff	15	3	9

This means, that if at the end of the experiment you hold a position:

- at school A, you will be paid 15 €;
- at school B, you will be paid 3 €;
- at school C, you will be paid 9 €.

Recall! Different participants might have different payoff tables. That is, payoff by school might be different for different participants.

Recall! The preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

Recall! There are two positions opening at school B and C, and one at school A.

Priority ordering of schools: Schools when offering teaching positions consider the quality of each applicant and the experience they have; and on this basis they make a priority ordering of all candidates. In this informational environment from the priority ordering of the schools you know only the best candidate(s) of each school. These are the following:

- at school A teacher N has priority;
- at school B teachers K and M have priority;

- at school C teachers J (you) and L have priority.

Please submit your ranking of the schools (A through C) from your first choice to your last choice. Please rank ALL three schools!

1st choice	2nd choice	3rd choice

This is the end of the second game under the first mechanism.

After the experimenter collects your Decision Sheet, you will be given the second Decision Sheet under the same mechanism, but for a new game (with different information structure).

4.6.4 Decision Sheet for the Gale-Shapley Mechanism under Partial-Information—Schools

You are participant ID ......, in the role of school A.

Capacity: There are two positions opening at school B and C, and one at school A.

Recall: Your payoff amount depends on the school position you hold at the end of the experiment. Your possible payoff amounts are outlined in the following table:

Teacher employed	J	K	L	M	N
Your payoff	3	9	6	12	15

This means, that if at the end of the experiment you are matched with teacher:

- J, you will be paid 3 €;
- K, you will be paid 9 €;
- L, you will be paid 6 €; etc.

Recall! Different participants might have different payoff tables.

Recall! The preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

Recall! There are two positions opening at school B and C, and one at school A.

Priority ordering of teachers: Teachers when applying to schools, make a priority ordering of all schools. In this informational environment of the game you know in which school would each teacher get the highest payoff (according to the payoff table, but not the submitted ordering).

Please submit your ranking of teachers (J through N) from your first choice to your last choice. Please rank ALL five teachers!

1st option	2nd option	3rd option	4th option	5th option

This is the end of the second game under the first mechanism.

After the experimenter collects your Decision Sheet, you will be given the last Decision Sheet under the same mechanism, but for a new game (with different information structure).

4.6.5 Decision Sheet for the Gale-Shapley Mechanism under Full-Information—Teachers

You are participant ID ......, in the role of teacher J.

Capacity: There are two positions opening at school B and C, and one at school A.

Recall: Your payoff amount depends on the school position you hold at the end of the experiment. Your possible payoff amounts are outlined in the following table:

Position received at school	**A**	**B**	**C**
Payoff of participant J (YOU)	15	3	9
Payoff of participant K	3	9	15
Payoff of participant L	9	15	3
Payoff of participant M	9	15	3
Payoff of participant N	3	15	9

This means, that for example, if at the end of the experiment:

- you hold a position at school A, teachers K and L hold a position at school B, and teachers M and N hold a position at school C, the payoffs would be the following:
- you would be paid 15€; teacher K would get 9€; teacher L would get 15€; teacher M would get 3€; and teacher N would get 9€.

¡Recall! The preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

Priority ordering of schools: Schools when offering teaching positions consider the quality of each applicant and the experience they have; and on this basis they make a priority ordering of all candidates. In this informational environment the complete priority ordering of the schools is known by each teacher, and is shown in the following table:

	School A	**School B**	**School C**
1st choice	N	M	L
2nd choice	M	K	J (you)
3rd choice	K	J (you)	M
4th choice	L	N	N
5th choice	J (you)	L	K

Please submit your ranking of the schools (A through C) from your first choice to your last choice. Please rank ALL three schools!

1st choice	2nd choice	3rd choice

This is the end of the games under the first mechanism. After we collect your Decision Sheet, you will be given the Instructions and the first Decision Sheet for a new mechanism.

4.6.6 Decision Sheet for the Gale-Shapley Mechanism under Full-Information—Schools

You are participant ID ......, in the role of school A.

Capacity: There are two positions opening at school B and C, and one at school A.

Recall: Your payoff amount depends on the school position you hold at the end of the experiment. Your possible payoff amounts are outlined in the following table:

Teacher employed	**J**	**K**	**L**	**M**	**N**
School A (tú)	3	9	6	12	15
School B	9	12	3	15	6
School C	12	3	15	9	6

This means, that if at the end of the experiment:

- You are matched with teacher J, school B with teachers K and L, and school C with teachers M and N, the payoffs would be the following:
- You would get 3€; school B: 15€ (12€+3€); and school C 15€ (9€+6€).

¡Recall! The preference ordering submitted on the Decision Sheet does not necessarily need to coincide with the one generated by the payoff matrix.

Priority ordering of teachers: Teachers when applying to schools, make a priority ordering of all schools. In this informational environment of the game all participants know the complete payoff matrix of teachers, which is the following:

Teacher	J	K	L	M	N
1st option	A (you)	C	B	B	B
2nd option	C	B	A (you)	A (you)	C
3rd option	B	A (you)	C	C	A (you)

Please submit your ranking of teachers (J through N) from your first choice to your last choice. Please rank ALL five teachers!

1st option	2nd option	3rd option	4th option	5th option

This is the end of the first mechanism.

After we collect your Decision Sheet, you will be given the Instructions and the first Decision Sheet for a new mechanism.

Bibliography

[1] Abdulkadiroglu, Atila and Sönmez, Tayfun (2003): "School Choice: a Mechanism Design Approach" *American Economic Review* **93.**, 3, pp.729-747

[2] Abdulkadiroglu, Atila, Pathak, P., Roth. A., and Sönmez, Tayfun (2005): "The Boston Public School Match" *American Economic Review, Papers and Proceedings,* forthcoming

[3] Barberà, S. and Dutta, B. (1995): "Protective Behavior in Matching Models" *Games and Economic Behavior* **8.**, pp.281-296

[4] Chen, Yan and Sönmez, Tayfun (2002a): "Improving Efficiency of On-Campus Housing: an Experimental Study" *American Economic Review* **92.**, 5, pp.1669-1686

[5] Chen, Yan and Sönmez, Tayfun (2002b): "An Experimental Study of House Allocation Mechanisms" *Economics Letters* **83.**, 1, pp.137-140

[6] Chen, Yan and Sönmez, Tayfun (2003): "School Choice: an Experimental Study" *Journal of Economic Theory,* forthcoming

[7] Conover, W.J. (1980): *Practical Nonparametric Statistics*, New York: John Wiley & Sons

[8] Dubins, L. and Freedman, D. (1981): "Machiavelli and the Gale-Shapley Algorithm" *American Mathematical Monthly* **88**., pp.485-494

[9] Ehlers, L. (2003): "In Search of Advice for Physicians in Entry-Level Medical Markets" *Mimeo, Université de Montréal*

[10] Ehlers, L. (2004): "In Search of Advice for Participants in Matching Markets Which Use the Deferred-Acceptance Algorithm" *Games and Economic Behavior*, forthcoming

[11] Ehlers, L. and Massó, J. (2003): "Incomplete Information and Small Cores in Matching Markets" *Mimeo, Universitat Autònoma de Barcelona*

[12] Ergin, Haluk and Sönmez, Tayfun (2004): "Games of School Choice under the Boston Mechanism" *Journal of Public Economics* **90**., pp.215-237

[13] Gale, D. and Shapley, L. (1962): "College Admissions and the Stability of Marriage" *American Mathematical Monthly* **69**., pp.9-15

[14] Harrison, G. and McCabe, K. (1996): "Stability and Preference Distortion in Resource Matching: an Experimental Study of the Marriage Problem" In V. Smith (ed.) *Research in Experimental Economics* **6**., pp.53-129, JAI Press

[15] Haruvy, E., Roth, A., and Ünver, U. (2001): "Dynamics of Law Clerk Matching: an Experimental and Computational Investigation of Proposals for Reform of the Market" *Journal of Economic Dynamics and Control*, forthcoming

[16] Kagel, J and Roth, A. (2000): "The Dynamics of Reorganization in Matching Markets: a Laboratory Experiment Motivated by a Natural Experiment" *Quarterly Journal of Economics* **115(1)**., pp.201-235

[17] McKinney, C., Niederle, M., and Roth, A. (2004): "The Collapse of a Medical Labour Clearinghouse (And Why Such Failures Are Rare)" *Working Paper, Harvard University and Stanford University*

[18] Nalbantian, H. and Schotter, A. (1995): "Matching and Efficiency in the Baseball Free-Agent System: an Experimental Examination" *Journal of Labour Economics* **13.**, pp.1-31

[19] Olson, M. and Porter, D. (1994): "An Experimental Examination Into Design of Decentralized Methods to Solve the Assignment Problem With and Without Money" *Economic Theory* **4.**, pp.11-40.

[20] Pais, J. and Pintér, A. (2006): "School Choice and Information: An Experimental Study on Matching Mechanisms" *Working Paper, Universitat Autònoma de Barcelona*

[21] Roth, A. (1982a): "The Economics of Matching: Stability and Incentives" *Mathematics of Operations Research* **7.**, pp.617-628

[22] Roth, A. (1982b): "Incentive Compatibility in a Market With Indivisibilities" *Economics Letters* **9.**, pp.127-132

[23] Roth, A (1984): "The Evolution of the Labor Market for Medical Interns and Residents: A Case Study in Game Theory" *Journal of Political Economy* **92.**, pp. 991-1016

[24] Roth, A (1985a): "The College Admissions Problem Is Not Equivalent to the Marriage Problem" *Journal of Economic Theory* **36.**, pp. 277-288

[25] Roth, A (1985b): "Conflict and Coincidence of Interest in Job Matching: Some New Results and Open Questions" *Mathematics of Operations Research* **10**., pp. 379-389

[26] Roth, A. (1989): "Two-Sided Matching With Incomplete Information about Others' Preferences" *Games and Economic Behavior* **1**., pp.191-209

[27] Roth, A. and Rothblum, U. (1999): "Truncation Strategies in Matching Markets - In Search of Advice for Participants" *Econometrica* **67**., pp.21-43

[28] Roth, A. and Sotomayor, M. (1989): "The College Admissions Problem Revisited" *Econometrica* **57**., pp.559-570

[29] Roth, A. and Sotomayor, M. (1990): *Two Sided Matching: a Study in Game Theoretic Modeling and Analysis*, Econometric Society Monograph Series. New York: Cambridge University Press

[30] Shapley, L. and Scarf, H. (1974): "On Cores and Indivisibility" *Journal of Mathematical Economics* **1**., pp.23-28

[31] Ünver, U. (2001): "On the Survival of Some Two-Sided Matching Mechanisms: an Experimental and Computational Investigation of the Stability Hypothesis" *Mimeo, Koç University*

[32] Ünver, U. (2005): "On the Survival of Some Two-Sided Matching Mechanisms" *International Journal of Game Theory* **33**., pp.239-254