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Downs-Thomson paradox and public transit capacity choice in the laboratory.

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ABSTRACT: The aim of this paper is to study empirically the Downs-Thomson (DT) Paradox, a situation where additional road capacity can cause an increase in total travel cost for users that are to choose between Private Car and Public Transit. To this end, we design a laboratory experiment based on a Two-Mode Entry Game where subjects have to enter either in a road mode or in a public transit mode. Road capacity being exogenous, public transit capacity is chosen by the operator. In this theoretical framework, the optimal strategy for operator is to minimize capacity, and the equilibrium for users depends on the endogenous public transit capacity compared to exogenous road capacity. As a consequence, an exogenous increase of road capacity, by shifting users' equilibrium, will cause a decrease in payoffs for all users (DT Paradox). On the contrary, a decrease in Road Capacity should increase total payoff. To test these theoretical predictions, two experimental treatments are implemented, each of them consisting in a certain capacity level for Road. The most important result is that Downs-Thomson Paradox is observed within the laboratory: An increase in road capacity actually shifts participants from Public Transit to Road, causing a decrease in payoffs for the entire group. But the reverse is not empirically true: A decrease in capacity does not raise payoffs, which contradicts our theoretical model. Results also show that the capacity chosen by operator differs from Nash prediction, levels being higher than those predicted by our model.

KEY WORDS: ***Traffic equilibrium; experimental economics; transport capacity; congestion; intermodal competition.***

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1. Introduction

Road congestion is a key problem for many urban areas around the world. Numerous empirical studies report that congestion costs could represent an important waste of time and economic resources. For instance, Koopmans and Kroes (2003) estimate that road congestion cost could represent from 0.5% to 2% of GDP for developed countries. Duranton & Turner (2011) show that annual distance for an American household remains the same between 1995 and 2001, whereas travel time increases from 10% during the same period, suggesting clearly that society allocates billions of dollar more to traffic congestion.

Congestion problem receives therefore considerable attention by policy-makers, and several transportation policies can be implemented in order to rule this issue. Considering decision-making aid, the problem lies in the lack of empirical evidence that supports assessments given for instance by advocacy groups. As an example, the *American Road and Transportation Builders Association* claims that "adding highway capacity is key to reduce traffic congestion" whereas *American Public Transit Association* considers that without new investment in public transit, highways will become so congested that they will no longer work (cited by Duranton and Turner, 2011). Any of these statements nevertheless clearly suggests that solving congestion in urban areas implies a dilemma since increasing road capacity is a substitute of rising public transit capacity.

This paper aims at giving some empirical (experimental) evidence to this debate, by considering an urban transportation system where users can choose between public transit and private transport (private car). More precisely, our work investigates a curious phenomenon, the Downs-Thomson Paradox, where increasing road capacity as a response to congestion problems in urban areas could have detrimental effects for the whole transport system and could possibly lead to higher total travel costs for both users, public and private. The “Downs-Thomson” paradox (Downs, 1962; Thomson, 1977; Mogridge et al, 1987; Mogridge, 1990a,b, Mogrigde, 1997; Arnott & Small, 1994 ; Jones, 2002, Litman, 2005) usually denotes a situation where an increase in road capacities, by causing shifts from public transit to private transport, could lead to a new traffic equilibrium where total transport costs are higher. Indeed, by implementing an additional road capacity (e.g. a new route or more generally a new transport alternative), road speed increase, attracting public transit users towards road transport. Then, as public transit traffic decreases, there is a loss of revenue for public transit operator, who, in the absence of subsidies, might raise fare or cut service.

Such a vicious circle represents an important argument for transport specialists who are promoting urban pricing for private cars and consequently investment in public high capacity transit systems, in order to increase journey speeds (See Webster, 1985; ECMT, 2002).

Although the possibility of the Downs-Thomson (DT) Paradox seems to be well accepted, there is little empirical evidence in the literature to indicate when it might actually occur. Holden (1989) suggests that it may happen "*in a city like London, where a significant fraction of peak traffic is carried on an extensive rail network*". Mogridge et al. (1987) suggest that it may occur by "*allocating even more space to roads when roads are a less efficient carrier of the flow of traffic*". But these statements are mainly qualitative, based on intuition and experience, and it is rather impossible to isolate clearly in the particular case that are used the impact of each relevant variable on travel cost for all users (e.g. capacities, prices, etc.). The possibility to control some variables and to choose relevant changes within an economic system is precisely one strength of the experimental economics approach, as laboratory experiments could be used as a "wind tunnel" (Smith, 1982) for studying the impact of structural changes on individual behaviour, in particular for assessing transport policies and behavioural patterns that could explain traffic outcomes.

Economic experiments about congestion tend to be in a growing number (See for instance Daniel et al., 2009 ; Rapoport et al., 2009 ; Morgan et al., 2009 ; Stein et al., 2007 ; Selten et al., 2007 ; Ziegelmeyer et al., 2008 ; Hartmann, 2006), mainly about road traffic (departure time or route choice) but, to our knowledge, we are the first to study possible interactions between *public transit* and *road traffic* thanks to a laboratory experiment, this strategic interaction being the key issue that could implement a phenomenon like Downs-Thomson Paradox. Actually, the paper closest to ours is Datta and Razzolini (2010), who also implement a laboratory experiment in order to study the Downs-Thomson Paradox. In their experiment, participants could choose between public transit and private car, where cost for private car choice grows linearly as the number of users increases, and cost for public transit could be either high or low depending on the number of public transit users. As for us, they also observe the DT Paradox in the lab[1].

Aiming at providing empirical support about this paradox, we build an economic experiment in which subjects have to choose between two markets, e. g. road and public transit. Our theoretical framework is inspired by the Market Entry Game, a particular class of coordination games (Selten & Güth, 1982 ; Gary-Bobo, 1990), where players have to choose whether or not they enter a market, individual payoff for entry decreasing with the total number of entrants. At a theoretical level, such games are characterized by many equilibriums that implies high level of coordination among players, but each of these equilibriums being not welfare maximizing and implying therefore a social dilemma.

One important problem that is to be considered when dealing with transport choice is that users can choose between alternatives (routes, modes, departure times, etc.). All of these alternatives provide a certain utility level to users, this utility being potentially affected by the total number of users who choose a given alternative. As we are interested in user's choice between Public Transit and Private Car, we build a Two-Mode Entry Game where the user can choose between two modes, payoffs of each option being affected by traffic distribution, implying *crossed-externalities* between users' choices. In particular, the externality produced by road choice is negative, whereas public transit choice generates a positive externality. The other key feature in this model is that the interaction between users depends on a first mover choice, namely the operator choice for public transit capacity, whereas road capacity is exogenously determined and common knowledge. Using Nash equilibrium as a behavioural rule, the comparative statics of this two-stage game implies that entry rate on road increases with road capacity and decreases with endogenous capacity of public transit. Moreover, considering operator, as the marginal revenue of public transit entry is less than the marginal revenue of road entry, the optimal strategy for operator is to choose the lowest possible level for public transit capacity, implying too much entry on road and lack of efficiency for the transport system (Transport cost is not minimized at the traffic equilibrium). In such a game, an exogenous increase in road capacity level will generate a shift of users from public transit to road that leads finally to a new traffic equilibrium where efficiency level (total travel cost) is lower (higher).

The experimental design consists in groups of 15 subjects, one subject A as the operator and 14 subjects B as transport users. At each period, subjects A and B participate to a two-stage game where subject A chooses first a capacity level for public transit. Being informed about A's choice, subjects B have to choose between two options, X (road) and Y (public transit). In order to be able to observe DT Paradox and the reverse phenomenon, two experimental treatments had been implemented that define exogenous levels of road capacity (either HIGH or LOW). The DT Paradox should be observed by confronting participants to the LOW treatment in a first step, the treatment HIGH being implemented in a second step, as this sequence mimics an exogenous increase of road capacity, all things being equal. On the contrary, the reverse

[1] Differently from our approach, Datta and Razzolini (2010), do not consider explicitly capacity levels for public transit and private car in their theoretical model. Moreover, the theoretical model they build implies that two Asymmetric Pure-Strategy Nash equilibriums for traffic distribution are possible, one being payoff dominant (the one where Rail Traffic level is the highest). It is an important difference with our theoretical model, and more generally with laboratory experiments that studied Market Entry Games, where all possible Nash equilibriums are inefficient and could not be Pareto-ranked. In our paper, as cost (payoff) for public transit is a continuous function of the number of users, there is a unique Pure Strategy Nash equilibrium that depicts traffic distribution over the two modes.

phenomenon should be observed by having participants exposed firstly to the HIGH treatment, and secondly faced to the LOW treatment. Half of our 240 participants (i.e. 16 sessions of 15 participants) play in the former first condition (ADD, for adding road capacity), whereas the other half was exposed to the second condition (DEL, for deleting road capacity).

The main results indicate that participants B coordinate remarkably well around the entry rate for each market predicted by Pure Strategy Nash Equilibrium. It is far from being the case for participant A, who chooses average capacity level significantly above the optimal level given by Nash equilibrium. Moreover, we observe Downs-Thomson Paradox in the laboratory, where an increase in road capacity for a given group decrease total payoffs and therefore is associated to lower efficiency levels. But we do not observe the reverse phenomenon, since decreasing road capacity does not improve significantly total payoffs for users.

In a first section, we will make a literature review about the Downs-Thomson Paradox. The second section is devoted to the theoretical model of a Two-Mode Entry Game. The third section describes the experimental design and experiment calibration. The fourth section presents experimental results and the last one is to conclude.

2. Downs-Thomson paradox and Mogridge's conjecture

Arnott & Small (1994) made an extensive review about the three most famous paradoxes related to potential adverse effects of increasing road capacity, namely Pigou-Knight Paradox, Downs-Thomson Paradox and the Braess Paradox. The Pigou-Knight Paradox corresponds to a situation where a given number of commuters have two alternatives (routes or modes) in order to reach a given destination by departing from the same origin, one of these alternatives being better than the other considering travel time, except for high levels of traffic. If travel time for the other alternatives does not depend on traffic level, then for sufficiently small increases of the capacity of the best alternative, the new traffic equilibrium will not give any decrease in travel times for all users. The Braess Paradox (Braess, 1968) is a situation where adding a link into a road network causes total travel time to increase. As it is shown by Morgan et al. (2009) at the theoretical level, the existence of Braess and Pigou-Knight paradoxes depends crucially on size effects: If capacity increase is sufficiently high, or if the number of users is large enough, then adding capacity will decrease total travel costs. They underline the *least congestible route principle*, that is to say the fact that a decrease in travel time could be obtained by the social planner if the improvement lies on the route (mode) that is the least sensitive to network congestion. Arnott \& Small (1994) ask then about the empirical relevancy of these paradoxes, wondering about these paradoxes as very special cases, perhaps no more than intellectual curiosities. Nevertheless, laboratory experiments have been useful to show that these paradoxes could occur quite frequently: Rapoport et al. (2009) and Meinhold and Pickhardt (2009) report experimental results where Braess paradox are observed in a systematic manner. Morgan et al. (2009) made lab experiments in order to study both Braess and Pigou-Knight paradoxes, and observe that traffic flows are close to equilibrium levels (i.e. produce paradoxes), even if they observe systematic deviations at the individual level.

The last paradox, the Downs-Thomson one (Downs, 1962 ; Thomson, 1977; Mogridge, 1986, 1987, 1997), suggests that an increase in road capacities, by causing shifts from public transit to private transport, could lead to a new traffic equilibrium where total transport costs are higher. The consequence is then a decrease in welfare level for the conurbation.

As a study case, Martin J.H. Mogridge in his 1990’s book “*Travel in towns: Jam yesterday, jam today and jam tomorrow?*" observes that, especially in London, increasing road capacity tends to increase traffic congestion: All road investment in a congested urban area, will reduce the average speed of the transport system as a whole – for road and public transport (e. g. urban mass transit). He therefore conjectures that improving collective transport could increase welfare. In fact, Mogridge’s analyze is a renewed version of the Downs-Thomson paradox (Downs, 1962 ; Thomson, 1977), as he clearly explained: "*This states that, in congested* *situation, the equilibrium travel costs will rise if road capacity is increased, if the cost of collective network rises as flow falls. If follows that increasing road capacity in congested situations is counterproductive*"[2].

This paradox regained some interest with the analysis of Martin H. Mogridge in the 80s, since what had been called "Mogridge conjecture" was an important argument for implementing urban pricing in London city[3]. The Mogridge's conjecture was that *"in conditions of suppressed demand, the speed of the road network is determined by the speed of the high-capacity network (rail, bus, etc.)*" (Mogridge, 1997 ; Mogridge, 1986). Such a paradox has often be viewed as the consequence of induced/latent demand effect (Arnott& Small, 1994 ; Abraham & Hunt, 2001 ; Noland, 2001 ; Afimeimounga et al., 2005).

The main empirical evidence about Downs-Thomson Paradox had been given by Mogridge (1990b, 1997). He observed that, for trip origins at any particular distance from the centre of London, peak hour journey times by car and rail to central destinations are equal, a clear consequence of Wardrop's equilibrium first principle[4]. (Wardrop, 1952) according him. Last but not least, average speed actually decreases from 17.2 km/h and 15.6 km/h in 1962 to 15.7km/h and 14.2 km/h in 1981 respectively for car and rail (Mogridge, 1997). Mogridge asserted therefore that the decrease in speeds in London centre was the consequence of Downs-Thomson Paradox, i. e. that successive increases in road network capacity over time cause decline in traffic for mass transit (train), the global consequence being a growth of travel times (a decrease in travel speeds) for both users[5].

Mogridge conjectures then that a decrease in road capacities, or better, an increase in public transit capacity, could shift road users to public transport, decreasing therefore total travel times within big urban areas. His argument was one important element in favour of London urban pricing scheme implemented years after.

But such empirical evidence is not totally convincing since the statistical analysis he conducted is not able to disentangle precisely the various effects of variables that changed in the transport system, and possibly influenced average travel time on such a long period. Then, isolating the pure effect of road capacity on travel times is virtually impossible in this case. That is one major reason for using experimental economics method in order to provide clean empirical evidence about the DT paradox. The main reason is that, in the lab, it is possible to isolate the impact of changing road capacity on users' choices and then on total travel times, all other things remaining constant. The main question concerning possible implementation in the laboratory is to produce a simple theoretical model that is able to obtain DT Paradox in a situation where numerous players are to interact.

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2 Mogridge, 1997 p. 9.

3 « The first (paradox) is that in congested conditions, building more road capacity for cars makes both motorists and users of public transport worse off. By encouraging a shift from public transport to cars it fills up the new road space, makes public transport less frequent and more expensive, and results in a new equilibrium that is slower for all. The second paradox follows from the first: taxing the inefficient road user (the motorist) and subsidising the efficient (on buses and trains) will make all travelers better off » The Times, March, 17th, 2000.

4 The two principles of Wardrop's equilibrium ((Wardrop, 1952) are the following. The first principle states that, at users' traffic equilibrium, all travel times for routes/modes to be used should be equals and less than non-used routes/modes. The second principle states that users' traffic equilibrium does not necessarily minimize total travel cost for users (for more details, see Correa & Stier-Moses, 2011).

5 Another interesting empirical evidence is given by Zeibots & Petocz (2005) who measure mode shifting from public transit to private car after a new motorway opened in the western part of Sydney conurbation, and give therefore support to the idea that equilibrium mechanism described in the DT Paradox works quite well. But it is quite impossible to have a precise idea about the impact of such a motorway on travel cost both for private car users and public transport users, as tariffs tend to change during the period.

3. Theoretical model: A two-mode entry game

Our theoretical model is inspired by a well-known coordination game, the Market Entry Game (MEG, Selten & Guth, 1982 ; Gary-Bobo, 1990). This particular class of games had been studied in many laboratory experiments (among others: Sundali et al., 1995 ; Erev & Rapoport, 1998 ; Ochs, 1998 ; Camerer & Lovallo, 1999 ; Zwick & Rapoport, 2002 ; Duffy & Hopkins, 2005 ; Erev et al., 2010). In this game, players have to choose between entering, the payoff of entry being a linear decreasing function of the difference between the capacity of the market and the number of entrants, or staying out (which gives a constant reward). Compared to this situation, we add a first step of capacity choice by a particular player and, in the second step of entry choice; we substitute to the exit choice a possible entry in a second market.

In our game, two types of agents, A and B have to make choices. The player A is the public transit operator, and has to choose capacity level for public transit. Then, players B (transport users) have to choose between road and public transit. It is assumed that road capacity is given for transport users and that Public Transit one is chosen by Operator. Our game is sequential, that is player A chooses capacity for Public Transit, other parameters being common knowledge. In the second step, users know capacities for each mode, and choose to enter either road or public transit, assuming no exit option. Applying a backward induction argument, and assuming that public transit operator knows how players B choose between road and public transit, optimal capacity levels to be chosen by the operator are to be derived.

3.1 Wardrop-Nash users' traffic equilibrium (stage game)

Players B have to choose simultaneously between the option *X* (Road or Market 1) and *Y* (Public Transit or Market 2)[6].

The individual payoff for a user choosing road transit is:

$$\pi_1^i = k_1 + r_1 (c_1 - m_1) \qquad \text{if } \delta_i = X \tag{1}$$

Whereas the individual payoff of using public transit is:

$$\pi_2^i = k_2 + r_2 (c_2 + m_2) \qquad \text{if } \delta_i = Y \tag{2}$$

Where c_1 and c_2 are respectively the capacities of road and public transit, m_1 and m_2 are respectively the number of users choosing road (market 1) and public transit (market 2), r_1, r_2; k_1, k_2 are positive parameters with $r_1 > r_2$ and $k_1 > k_2$: All these parameters are to be known by players B before choosing which market to enter[7]. Such information is also available for player A (the operator for market 2).

Constraints are:

$$m_1 + m_2 = n \tag{3}$$

Or equivalently

$$m_2 = n - m_1 \tag{4}$$

And that

$$c_1 + c_2 < n \tag{5}$$

6 Differing from the usual MEG, there is no outside option which gives a given payoff for sure.

7 Our game differs from Rapoport et al., (2000) Two Market Entry Game in one major respect: Entering first or second market implies a decrease in individual payoffs for both markets in their game, whereas in our case, more entrants on market 2 increase individual payoff for each entrant.

Where *n* is the finite number of transport users.

In this model, using road transit is supposed to create a negative externality, as in the usual MEG, whereas using public transit is supposed to create a positive externality. This positive externality is linked to the fact that, if capacity is fixed, the increase in public transit demand enables to increase frequencies and then decrease time travel cost (see Arnott and Small, 1994)[8].

Users Subgame Pure Strategy Nash equilibrium is reached when:

$$k_1 + r_1(c_1 - m_1) = k_2 + r_2(c_2 + m_2) \tag{6}$$

Then, combining eqns. (4) and (6), and as $-r_1 + r_2 \neq 0$ we have:

$$m_1 = \frac{k_1 - k_2 - r_2(n + c_2) + c_1 r_1}{r_1 - r_2} \tag{7}$$

And consequently

$$m_2 = \frac{1}{r_1 - r_2}(k_2 - k_1 + n r_1 - c_1 r_1 + c_2 r_2) \tag{8}$$

The entry rate or traffic level on road (respectively public transit) is increasing (decreasing) with c_1; k_1; r_1 and *n*, decreasing (increasing) with c_2; k_2 and r_2. Of course, such a theoretical prediction holds for a continuum of agents and decisions. However, in the experimental game, theoretical predictions that are derived assume a discrete number of agents and a discrete set of strategies (see below).

There is also Symmetric Mixed-Strategy Nash equilibrium, obtained by equating expecting payoffs for Road and Public Transit and by considering that, for a given user, the number of entrants on Road is given by:

$$m_1 = p_1(n-1) + 1 \tag{9}$$

Where p_1 is the probability for entering in market 1 (road). Considering further eqn (4) and using again eqn (6), it is possible to equate expected payoffs either for entering on road or to enter on Public Transit. Finally, the probability of entering road corresponds to:

$$p_1 = \frac{k_1 + c_1 r_1 - c_2 r_2 - r_2 n + r_2 - r_1}{(n-1)(r_1 - r_2)} \tag{10}$$

3.2 *Optimal choice for public transit operator*

We assume that the profit π for public transit operator is simply the difference between the number of public transit users and the capacity she chooses, that is:

$$\pi = m_2 - c_2 \tag{11}$$

Thus, replacing m_2 with eqn (8), and using eqn (11), we obtain

$$\begin{aligned}\pi &= \left(n - \left(\frac{k_1 - k_2 - r_2(n + c_2) + c_1 r_1}{r_1 - r_2}\right)\right) - c_2 = \\ & n - c_2 - \frac{k_1}{r_1 - r_2} + \frac{k_2}{r_1 - r_2} + n\frac{r_2}{r_1 - r_2} - c_1\frac{r_1}{r_1 - r_2} + c_2\frac{r_2}{r_1 - r_2}\end{aligned}$$

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8 "If more people take the train, then trains run more frequently, saving people some waiting time at the station", p.4 . Such a property is a technological property of all types of mass transit, as it was shown by Mohring (1972). For a clear and detailed presentation about this property, see Small & Verhoef, (2007).

If we assume that $\frac{r_2}{r_1 - r_2} < 1$, the optimal solution is a corner solution where c_2 equals zero.

Therefore, in the one-shot two-mode entry game, the standard prediction, under the assumptions of common knowledge of rationality and selfishness and by using backward induction, is that the operator chooses the minimum capacity level and consequently, users coordinate to enter for some of them on "road market" and for the others on "public market" (entry rates for road and public transit being given respectively by eqns (7) and (8)). If players know that this stage game is to be repeated a finite number of times, then the equilibrium for the stage game should be implemented at each period, this equilibrium being the unique perfect Nash equilibrium of the game[9].

3.3 Downs-Thomson (DT) paradox

The Downs-Thomson Paradox is a situation where welfare is to be decreased when road (market 1) capacity increases, all other things being equal. This occurs because too many users shift from road market to public transit market.

The level of welfare in the Double Market Entry Game is defined simply as the sum of all players' payoffs, that is:

$$W = (m_2 - c_2) + m_1 (k_1 + r_1 (c_1 - m_1)) + m_2 (k_2 + r_2 (c_2 + m_2)) \qquad (12)$$

Or, equivalently, given eqn (4)

$$W = (n - m_1 - c_2) + m_1 (k_1 + r_1 (c_1 - m_1)) + (n - m_1) (k_2 + r_2 (c_2 + n - m_1)) \qquad (13)$$

Furthermore, we obtained previously the expression (7) on entry rate in market 1 (road), which could be replaced in the former equation giving welfare. After simplification, it gives:

$$W = \frac{1}{r_1 - r_2} (k_2 - k_1 + nr_1 - c_1 r_1 - c_2 r_1 + 2c_2 r_2 + \\ + n^2 r_1 r_2 - nk_1 r_2 + nk_2 r_1 - nc_1 r_1 r_2 + nc_2 r_1 r_2) \qquad (14)$$

Assume that capacity c_2 is to be constant, since we are for the moment not interested in the behaviour of player A. Let call W_{HIGH} the level of welfare obtained in a situation where road capacity is high, say c_1 and W_{LOW} the level of welfare obtained in a situation where road capacity is low, say C_1^* . We have then $C_1 > C_1^*$

If the DT Paradox is to occur, then an exogenous increase in road capacity should decrease welfare level. If we compute the variation in welfare level from low capacity to high capacity, we have, after manipulation:

$$\Delta W = W_{HIGH} - W_{LOW} = -r_1 \frac{c_1 - c_1^*}{r_1 - r_2} (nr_2 + 1) < 0 \qquad (15)$$

This expression is negative, since all parameters are positive in the DMEG, i.e. increasing road capacity causes a decrease in welfare, which gives a theorem.

Theorem: *In the Two-Mode Entry Game, an increase in Road capacity, Public Transit Capacity remaining constant, will decrease level of Welfare by shifting users from Public*

[9] We follow here Selten's chain-store game argument. Nevertheless, it is fair to remark that in the repeated game, such a prediction does not hold necessarily (see Gaechter & Falk, 2002). One argument is that if players are from different "types", the game is of incomplete information which might rise possibility for playing cooperative behaviour. Kreps, Milgrom, Roberts and Wilson (1982) show that, even if there is a small probability that the adversary is, e.g., a "tit for tat" player, cooperative play can be supported until the final period.

Transit to Road (Downs-Thomson Paradox). And vice versa: A decrease in Road capacity will increase Welfare.

Such a theoretical result is precisely what is to be tested in our experimental treatments.

4. Experimental design

In this section, we present the different experimental treatments that have been implemented in the lab, and therefore, given the specific values we had for parameters, we present the experimental predictions implied by the theoretical model presented above.

4.1 Experimental treatments

For a given experimental session, a group of 15 subjects participate to the double market entry game described above. At the beginning of the experiment, a randomly chosen subject plays role A and the others subjects play role B. Roles remain constant throughout the session (partners design, one subject A and 14 subjects B). Each participant plays 40 periods of a two-stage game. For each period, the two-step game is the following: In the first step, subject A choose a positive integer number concerning capacity level for market 2, from 1 to 11. Then, participants B are informed about A's choice, and have subsequently to choose to enter market 1 (road) or market 2 (Public Transit). At the end of the period, all participants are informed about the current number of entrants on market 1 and market 2, about the payoffs of each participant (payoffs are symmetrical for participants B). Then, a new period begins.

In each session, participants play two subsequent games for 20 periods. Instructions specified that they will play two games of 20 periods subsequently. The only difference between the two games is the capacity of market 1, which could be high or low (see table below about the parameters that have been used). For 20 periods, participants play first low capacity and then high capacity in some sessions (condition ADD) and, in other sessions, participants play first high capacity and then low capacity (condition DEL). There is no contextualization or framing in the instructions that do not talk about transport. Instructions refer to option X (market 1 or road) and option Y (market 2 or public transit) that has to be chosen by participants B. Participants B are aware about the value of c_2 chosen by participant A, which is not described to be an operator who has to choose a given capacity. At the end of the experiment, all participants answer to post-experimental surveys, one to elicit individual risk aversion[10] and the other to have some information about socioeconomic characteristics and to have some debriefing from subjects. The parameters that had been implemented in the experiment are reported in table 1 below.

[10] As many experimenters, we use the Holt-Laury procedure to elicit the level of Constant Risk Relative Aversion (CRRA) index. For more details, see Holt & Laury (2002).

Table 1: Experimental sessions

parameters			sessions	conditions	number of sessions	participants
	LOW treatment	HIGH treatment	ADD	treat 1 + treat2	8	120
k_1	6	6	DEL	treat 2 + treat 1	8	120
k_2	0	0	Total		16	240
r_1	1	1				
r_2	0.25	0.25				
c_1	3	6				
c_2	endogenous	endogenous				

In the experiment, participants' payoffs are given in points, and an exchange rate in Euros is announced for each point to be gained finally at the end of the experiment. In order to avoid income effect, and because losses were possible in a given round for any participants, 4 rounds among the 40 that have been played have been randomly chosen to determine the final payoff, and we add as usual a participation fee.

4.2 Theoretical equilibriums

In this particular kind of game (multiple stage games with observed actions), the equilibriums are obtained by implementing Subgame-Perfect Equilibrium (SPE) method. A strategy profile is a subgame-perfect equilibrium if it represents a Nash equilibrium of every subgame of the original game. As often, we use the common method of backward induction in order to determine subgame perfect equilibriums. Given our particular parameters (see table 2), the SPE corresponds to a capacity choice of $c_2 = 1$ for player A and to an entry rate of 6 players B on market 1 (road), that is 8 players B on market 2 (public transit) when road capacity is equal to 3 (treatment LOW). When road capacity equals 6 (treatment HIGH), the optimal strategy remains to choose $c_2 = 1$ for player A, but the entry rates are changing, giving 10 players B on road (m_1 is the entry rate for road) and consequently 4 players B on public transit (m_2). Of course, there is also different equilibriums for subgame B depending on A's choice about public transit capacity.

For instance, assume we have 7 players B on market 1 and 7 players B on market 2 after player A chose $c_2 = 1$. Each player B gains 2 points. This is not a Nash equilibrium since a player B could gain 0.25 point if she deviate and choose Y (2.25 points for option Y and 3 points for option X). At this point, we have 6 players B on m1 and 8 players B on m_2. If an additional player B deviate to choose Y, he will gain 0.25, obtaining 2.5, but leaving 3 not to choose X. Then, for $c_2 = 1$, Nash Pure Strategy equilibriums for subgame B imply 6 players B choosing X and 8 players B choosing Y.

For c_2 levels higher than 1, the number of entrants on m_1 decreases.

The following table (table 2) summarizes theoretical predictions given the specific calibration of parameters[11].

[11] The probability to enter on Road (Mixed Strategy Nash Equilibrium) p_1 equals $0.49 - 0.025c_2$ for $c_1 = 3$ and $0.79 - 0.025c_2$ for $c_1 = 6$.

Table 2: Theoretical predictions (asymmetric pure strategy nash equilibriums)

treatment	c_2	m_1	m_2	π_A^i	π_B^i if $\delta^i = X$	π_B^i if $\delta^i = Y$	W_{Nash}	W_{Max}
$c_1 = 3$ (LOW)	1	6	8	7	3	2.25	43	90.5
$c_1 = 6$ (HIGH)	1	10	4	3	2	1.25	28	91

An increase in road capacity makes road choice more attractive, implying 4 additional users in HIGH treatment compared to LOW one. The consequence is that payoffs for all individuals decrease, and consequently the efficiency level at the asymmetric Pure Nash Equilibriums is lower in the HIGH treatment. As the maximum level of welfare should be obtained by choosing maximum capacity for public transit, with no or single user entering on road, the change in road capacity is not sufficient to increase efficiency level as it defines a new users equilibrium. Figure 1 below illustrates this point.

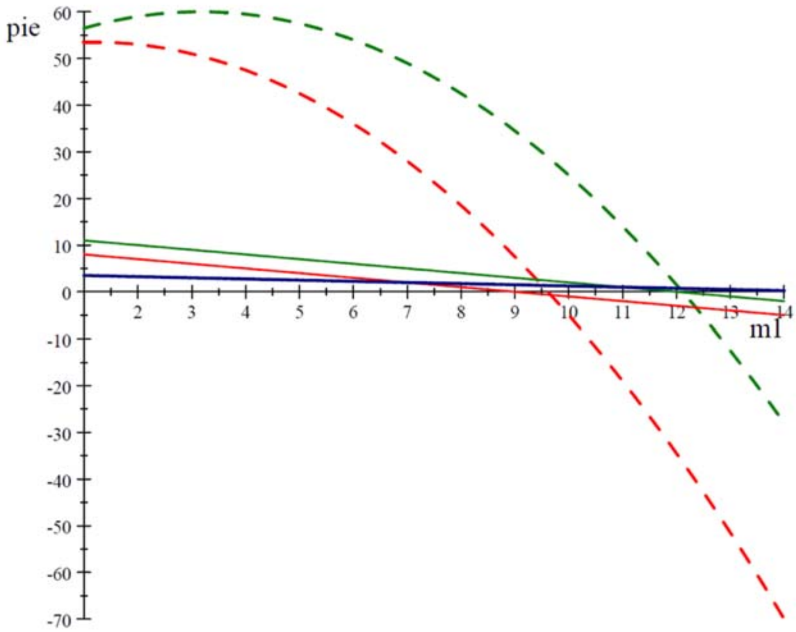

Figure 1: Individual and group payoffs depending on public transit capacity (NB: solid lines correspond to individual payoff and dashed lines to group payoff, assuming c2 = 1. green color is for high capacity and red color for low capacity treatments)

This figure describes user's individual payoffs and total group payoff for road users as a function of road traffic and is built for illustrative purpose12. If road capacity grows (from red solid line to green solid line), all things remaining constant (in particular, individual payoff for public transit choice, indicated by a blue solid line), some individuals shift towards road choice. At the new users' equilibrium, total group payoff for road users in less (red dashed line denotes aggregate payoff in the LOW road capacity, whereas green one is for high road capacity aggregate payoff), which corresponds to the Downs-Thomson Paradox.

[12] This figure is built upon the assumption that operator choose best response equilibrium, that is $c_2 = 1$.

5. Experimental results

Sessions have been held in LABEX-EM, Rennes, from January to April 2008, under the ZTREE platform (Fischbacher, 2007). The average duration of a session was 1h30 for an average payoff of 15 euros for participants B, 20 euros for participants A. 16 sessions of 15 participants were implemented, that is 240 subjects. 8 sessions were made in the ADD condition and also 8 sessions were made in the DEL condition (see table 1).

5.1 Capacity choice for public transit operator

This subsection is to analyze the behaviour of operator who determines the level of public transit capacity. Let remind that theoretical predictions given above indicate that public transit operator capacity choice should not be influenced by exogenous road capacity level, since Nash equilibrium corresponds to a corner solution where capacity is fixed at the minimum level.

The main results concerning capacity choice by subject A are the following. First, there is no significant difference about the level of capacity chosen by A for public transit for treatments HIGH and LOW, as theoretical model suggests. Second, the average capacity chosen by A tend to be significantly higher than levels to be predicted by theoretical model, even if it decreases with repetition. Finally, it has to be noticed that there is considerable heterogeneity within and between the individual data. The following graphs give the distribution of public transit capacity chosen by operators for each experimental treatment.

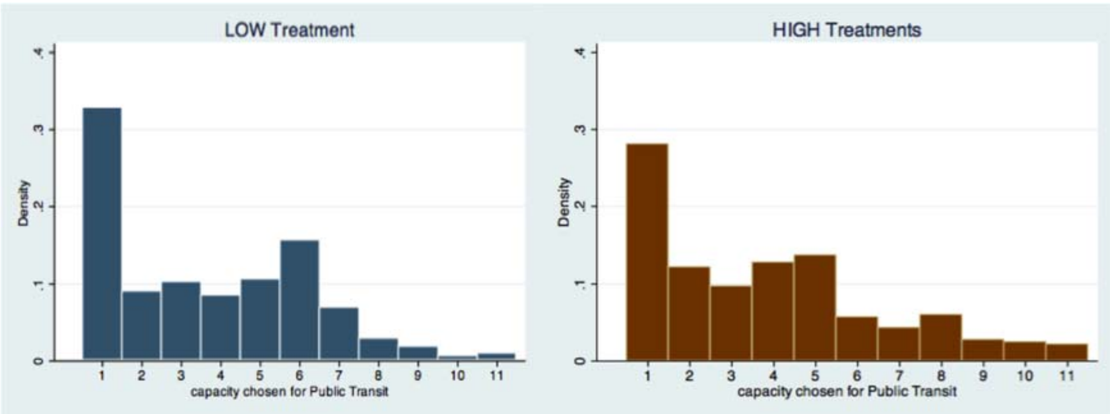

Figure 2: Distribution of chosen public transit capacity: LOW and HIGH treatments

The first comment is that the frequency of theoretical equilibrium among all capacity choices is only near 30%, which represents a poor level for confirming theoretical predictions. But it is also true that the minimum capacity is the highest frequency among possible levels. Moreover, operators' choices tend to concentrate around minimum capacities (the cumulative frequency for $c_2 < 5$ is around 50% for LOW and HIGH treatments). The graphs below also indicate that the distribution of choices is roughly the same between LOW and HIGH treatments. A nonparametric Kolmogorov-Smirnov Test about the equality of distributions between LOW and HIGH treatments confirms this intuition of identical distribution functions (Combined K-S=0.0704, p-value=.380[13]).

The average capacity chosen in LOW treatments is not significantly different from the average capacity chosen in HIGH treatments, as table 3 suggests it.

[13] Komogorov-Smirnov test as estimated by STATA ksmirnov command.

Table 3: Sample statistics, public transit capacity

Statistic	LOW treatment	HIGH Treatment
Average	3.67	3.89
Standard Deviation	2.50	2.74
Median	3.0	3.5

A bilateral Mann-Whitney Wilcoxon rank-sum test about the equality of average capacity chosen in the ADD condition for LOW treatment to the average capacity chosen in the DEL condition for HIGH treatment could not reject the assumption ($z = -0.630$, $p = 0.529$). A similar test assuming the equality of capacity chosen for LOW treatment in the DEL condition to capacity chosen for HIGH treatment in the ADD condition gives comparable results ($z = -0.421$, $p = 0.674$). Similar tests about the median capacity levels give the same results, indicating no difference between experimental treatments. Last but not least, the number of occurrences concerning the choice of minimum capacity had been computed for each group in order to compare fully experimental treatments. There is no significant difference between LOW treatment and HIGH treatment regarding this frequency: A Mann Whitney Wilcoxon Rank Sum test fails to reject the null assumption when data from treatment LOW in ADD condition are compared to data from treatment HIGH in DEL condition ($z = 0.110$, $p = 0.91$). A similar result occurs when data from treatment LOW in DEL condition are compared to data from treatment HIGH in ADD condition ($z = -0.162$, $p = 0.871$). All this web of evidence indicates no treatment effect about capacity to be chosen for Public Transit. Such a result is in line with our theoretical predictions.

The last question is about a possible learning process for operators that might eventually cope with Nash equilibrium, and the last result concerns therefore the temporal trend for public transit capacity choice.

If a within-subjects comparison is conducted, it is possible to observe that average capacity tend to be higher in the first 20 periods (first treatment) compared to the last 20 periods, especially for the DEL condition, as it is suggested by graphs below (see also table 4 for other evidence).

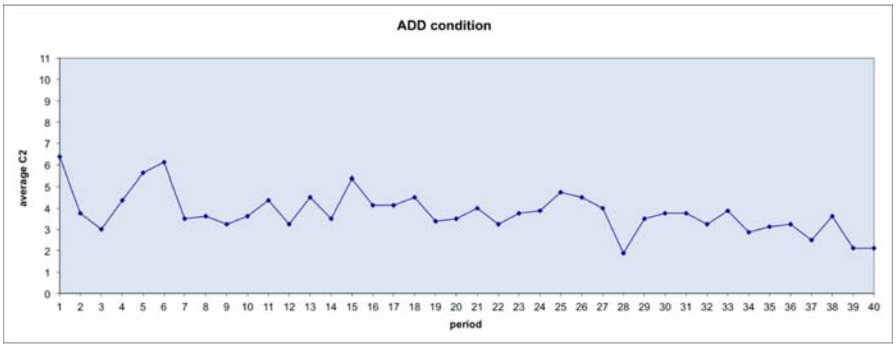

Figure 3: Average capacity chosen by Player B (ADD condition)

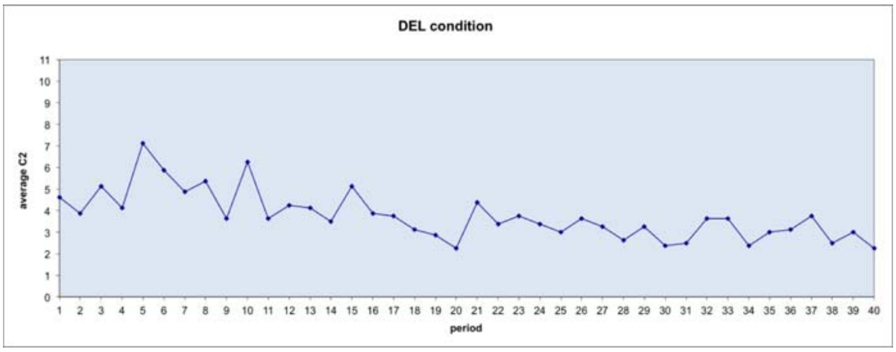

Figure 4: Average capacity chosen by Player B (DEL condition)

Such an intuition is confirmed if data are pooled together (sessions ADD and DEL) and if a Wilcoxon matched-pairs signed rank test is conducted. The assumption is that average capacity chosen by A during the first 20 periods is equal to the average capacity chosen by A during the last 20 periods. Such an assumption is strongly rejected (bilateral Wilcoxon, z = 2.795, p = 0.0052***), suggesting clearly that average capacity chosen in the first 20 periods is significantly higher than the average capacity chosen in the last 20 periods.

This temporal trend is confirmed by a parametrical analysis of operator's choice. We conduct a Panel Regression about individual choices for market 2's capacity (left censored, Tobit Analysis, Random Effects GLS, see table 4). Results are given in the following table.

Table 4: Panel censored Tobit regression on individual choice for capacity choice for public transit

variable	pooled data (1)	ADD (2)	DEL (3)
c_1^t market 1 capacity in period t	0.208**	0.112	-0.111
	(0.0870)	(0.218)	(0.243)
π_i^{t-1} payoff of subject A in period (t-1)	-0.0522	0.00975	-0.0977
	(0.0564)	(0.0753)	(0.0839)
m_2^{t-1} (number of entrants for market 2 in period (t-1)	0.0846	-0.0711	0.222**
	(0.0669)	(0.0955)	(0.0931)
COND (=1 if ADD ; 0 if DEL)	0.194	/	/
	(1.128)	/	/
risk aversion level	-0.622**	-0.133	-0.786**
	(0.254)	(0.355)	(0.358)
t	-0.0754***	-0.0665**	-0.124***
	(0.0112)	(0.0292)	(0.0323)
Constant β_0	6.521***	5.232**	9.071***
	(1.854)	(2.046)	(3.020)
Num. of Obs.	624	312	312
Subjects	16	8	8
Rho	0.369	0.179	0.488

***: significant at 1%, **: sign. at 5%, *: sign. at 10%

NB: The estimated model is

$$c_2^t = \beta_1 c_1^t + \beta_2 \pi_i^{t-1} + \beta_3 m_2^{t-1} + \beta_4 (COND) + \beta_5 (RISK) + \beta_6 t + \beta_0$$

The above regression indicates that market 1 (road) capacity plays an ambiguous role: The coefficient is positive and significant when data are pooled, but becomes non significant when capacity choice is analyzed for each condition. Given the limited number of data, we have to be cautious with econometric results. Nevertheless, some variables play a key role, as risk aversion level and time (period). There is a clear trend to have a decrease in capacity level chosen by A from period to period, as non-parametrical analysis suggested above. Moreover, the more risk averse participant A is, the lower capacity she chooses.

5.2 Entry on markets

5.2.1 Entry on modes and capacity levels

Entry rate on markets is obviously related to capacity level for each market. The theoretical model predicts that when road capacity is LOW, entry rate on road should decrease whereas higher chosen levels of capacity for public transit might decrease it. Actually, the important result is that entry on road is higher when respectively road capacity (public transit capacity) is higher (lower). Figures 4 and 5 give the average entry rate on market 1 (road) respectively for ADD condition and for DEL condition.

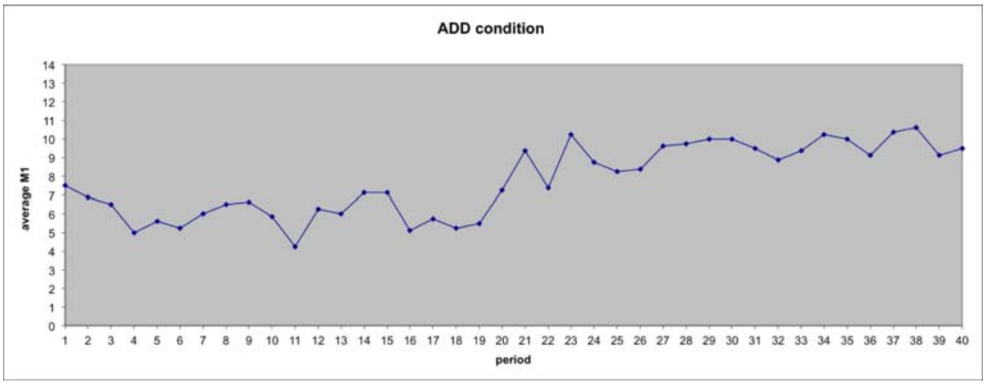

Figure 5: Average number of entrants for road (ADD condition)

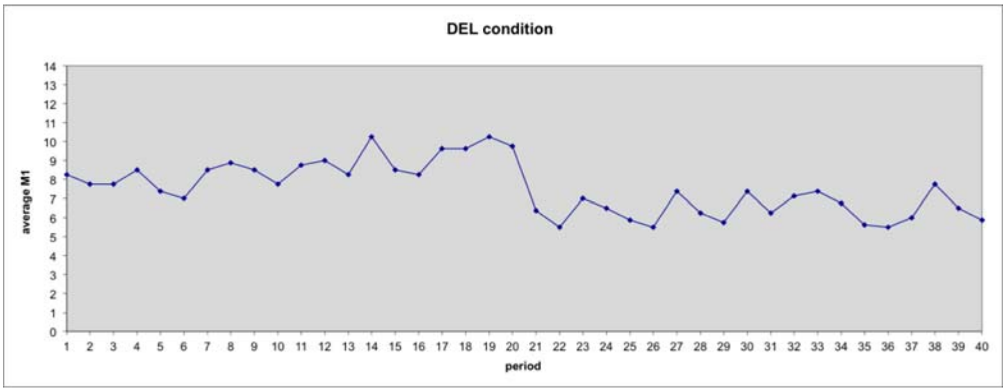

Figure 6: Average number of entrants for road (DEL condition)

The figures displayed above indicate clearly that entry rate increases when road capacity is to be higher. Such empirical result is statistically significant, as non-parametrical tests show. In ADD condition the average entry rate is 6.07 in the LOW treatment compared to an average entry rate of 9.43 in the HIGH treatment (road capacity is doubled). A within subject Wilcoxon test is significant at the 5% level (z = -2.521 ; p = .0117). That is also the case in DEL condition, where average entry rate tends to be higher in HIGH treatment (the average entry rate is around 6.41 in LOW treatment compared to 8.63 in HIGH treatment, the Wilcoxon matched-pairs sign-rank test indicates z = -2.524 ; p = .0116).

Such empirical evidence is also clearly demonstrated when we implement between subjects comparison. If the entry rate of the LOW treatment in the ADD condition is compared to the entry rate in the HIGH treatment for the DEL condition (these two treatments constitute both the first part of the experiment for these participants), the entry rate are respectively 6.07 and 8.63, which is significant at the 1% level (bilateral Mann-Whitney test, z = -3.366, p = .0008). The same result is obtained by comparing average entry rate in each group for the HIGH treatment in the ADD condition and average entry rate per group for the LOW treatment in the DEL condition (such treatments constitute the final part of the experiment). A bilateral Mann-Whitney indicates clearly that entry rate when (road) capacity is high is statistically higher than entry rate when capacity is low (z = +3.363 ; p = .0008, significant at the 1% level).

5.2.2 Temporal trend of entry rates

Another result is that entry rate on road tends to increase over time, indicating at least some learning process for participants B. Throughout the repetition of game, they clearly understood that they tend to under-enter on road market, and they change gradually their choice to match Pure Strategy Nash equilibrium entry rate. But such a result is statistically significant only for the HIGH treatments: Entry rate in ADD condition for the high treatment (part 2 of the experiment) is higher than the entry rate in DEL condition for the same treatment (9.43 compared to 8.63, bilateral Mann-Whitney, z = +2.298, p = .0027, significant at the 1% level). But such a result has to be cautiously interpreted, because it could also be the consequence of participants' heterogeneity. A parametric analysis could be therefore useful to measure this temporal trend more accurately.

5.2.3 Parametric analysis

In order to have more details about participant B behaviour, we conduct a parametrical analysis concerning variables that could influence B's choice. This parametric analysis explains factors that influence the probability p to enter on market 1 (road) for a participant B in period t (Panel Data analysis). Obviously, probability (1 - p) will be the probability not to enter on market 1, and therefore to enter on market 2, since there is no outside option in our game. The results of this Probit regression analysis are given in the following table (see table 5).

Table 5: Panel probit regression about choice to enter on market 1 (road) for participant B

variable	(1) pooled data	(2) ADD	(3) DEL
c_1^t	0.175***	0.190***	0.190***
	(0.0139)	(0.03)	(0.0298)
c_2^t	-0.0561***	-0.0414***	-0.0734***
	(0.00646)	(0.00896)	(0.00951)
m_1^{t-1}	0.0293**	0.00685	0.0528***
	(0.0122)	(0.0182)	(0.0166)
c_2^{t-1}	-0.0190***	-0.0296***	-0.00297
	(0.00697)	(0.00962)	(0.0103)
Risk aversion	-0.0601***	-0.0560**	-0.0645**
	(0.0193)	(0.024)	(0.0314)
π_i^{t-1}	0.0774***	0.0564**	0.0985***
	(0.0175)	(0.0256)	(0.0243)
COND	0.0231	/	/
	(0.0673)		
t	0.00424***	0.00423	0.00841**
	(0.00135)	(0.00364)	(0.00371)
Constant β_0	-0.555***	-0.412**	-0.908***
	(0.161)	(0.205)	(0.306)
Observations	8736	4368	4368
Number of subject	224	112	112
Ln sigma2u	-1.581	-1.752	-1.418
	(0.122)	(0.175)	(0.17)
Sigma u	0.454	0.416	0.492
	(0.028)	(0.037)	(0.042)
rho	0.171	0.148	0.195
	(0.017)	(0.022)	(0.027)

***: significant at 1%, **: sign. at 5%, *: sign. at 10%

NB: The estimated model is

$$\Pr\left(\delta_i = X\right) = \beta_1 c_1^t + \beta_2 c_2^t + \beta_3 m_1^{t-1} + \beta_4 c_2^{t-1} + \beta_5 \left(RISK\right) + \beta_6 \pi_i^{t-1} + \beta_7 \left(COND\right) + \beta_8 t + \beta_0$$

The explained variable is the probability to enter on road in period *t* for a participant B. The explanatory variables are the following. c_1^t is the capacity of market 1 in period *t*, c_2^t is the capacity of market 2 chosen by participant A in period *t*, and c_2^{t-1} is the same lagged variable. m_1^{t-1} is the observed number of entrants on road at the last period, RISK is the level of CRRA index for the participant[14], π_i^{t-1} denotes participant B's payoff in the previous period, COND is a dummy variable concerning experimental condition (= 1 if ADD and = 0 if DEL) and *t* relates to the time variable.

[14] Actually the number of safe lotteries chosen by the participant in our ex post survey, this survey being based on Holt & Laury (2002).

When entry decision is to be analyzed, some intuitive results are to be confirmed, and are in line with our theoretical predictions. Entry rate on a market depends positively on its capacity and negatively of the other market capacity. Moreover, previous choice of capacity for participant A influences entry choice for participant B: The higher level she chose in the previous period, the less he enters on road. Another interesting result concerns users' coordination during the experiment. The number of entrants in previous period increases the probability to enter in the current period (significant at the 5% level for DEL condition and for the pooled data, but not for the ADD condition). Subjects B anticipate that high previous entry rate implies low entry rate for the current period and vice versa (they anticipate some cyclical oscillation around an average entry rate on road). There is also learning processes, since entry on road tends to increase with repetition (subjects understand that road choice is risky but not as much as anticipated (possible negative payoffs)). As before, such a variable is significant at the 5% level for DEL treatment and for pooled data, but not for ADD treatment. Then the above result is confirmed by parametric analysis. Last but not least, for a given participant B, the more risk averse, the less the probability to enter.

5.3 Payoffs and welfare

As road capacity grows, shifts from public transit to road choice may first decrease congestion risk and so increase payoffs for those who choose road. All things being equal, higher capacity should increase group welfare. Of course, such assumption does not hold, since additional users on road may decrease the level for the positive externality of public transit. Moreover, if public transit operator reduces her capacity in order to decrease her operating costs, her profit may decrease also. At the end, these two negative effects could decrease welfare level for the entire group.

5.3.1 Profit for public transit operator

We have observed previously that increasing road capacity does not change significantly capacity choice for subject A. But, it changes drastically the distribution of subjects B by encouraging them to choose road more frequently. The consequence is that, clearly, profit for A (i.e. *M2* - *c2*) decreases. Watching the experimental data, the important result is that profit for B is higher in the LOW treatment compared to the HIGH treatment (see figure 7).

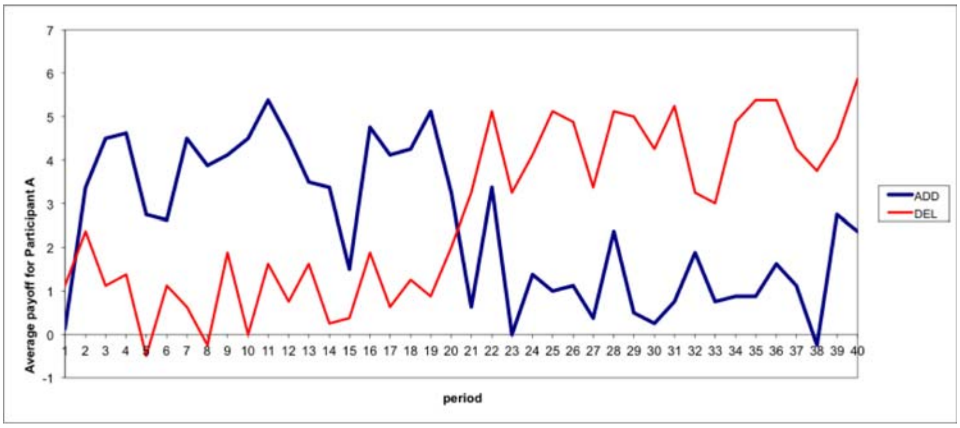

Figure 7: Average payoff for public transit operator (Player B), ADD and DEL conditions

That is precisely one component of the Downs-Thomson paradox. Increasing road capacity will make public transit users shifting to road, which precisely decreases revenue for operator[15]. This empirical result is clearly established with non parametrical tests, both for within and between-subject analysis. A Wilcoxon matched-pairs sign-rank test for each condition establishes a significant difference about A's profit between LOW and HIGH treatments (bilateral, z = +2.521, p = 0.0117, significant at the 5% level). The positive value of z means that A's profit is significantly higher in LOW treatment for both conditions. Such a result is confirmed by between-subject analysis. A Mann-Whitney Rank Sum Test about the equality of A's profit for treatment LOW for ADD condition and for treatment HIGH for DEL condition is strongly rejected (z = +3.046, p = 0.0023, significant at the 1% level). We find a comparable result by assuming the equality of average A's profit for treatment LOW for DEL condition and for treatment HIGH for ADD condition (z = +3.363, p = 0.0008, significant at the 1% level).

5.3.2 *Group welfare*

The following graphs show the evolution of total group payoff throughout the periods of the experiment. The total group payoff for a given group at period t is:

$$W^t = \pi_A^t + m_1^t \left(\pi_{B1}^t\right) + \left(n - m_1^t\right) \pi_{B2}^t \tag{16}$$

The green dashed-line recalls maximum efficiency level, while the red dashed lines recall efficiency level predicted by Asymmetric Pure Strategy Nash equilibriums.

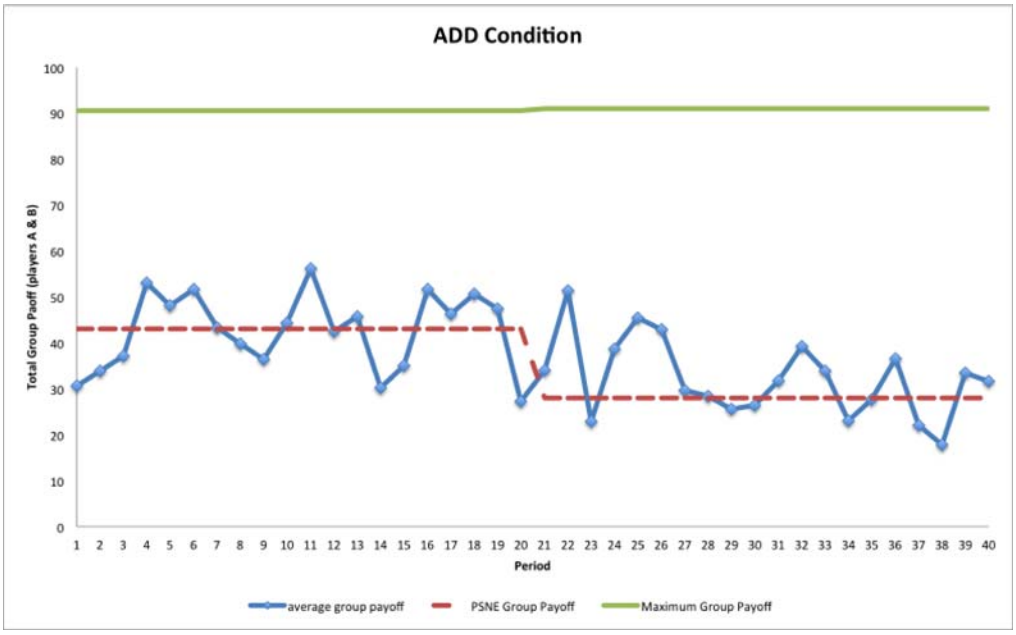

Figure 8: Total group payoff (ADD condition)

The average Group payoff for LOW treatment in ADD condition is 42.6 (indicated by the blue line), which is remarkably near Nash equilibrium efficiency level. In the HIGH treatment, average group payoff is around 32, which is higher than Nash equilibrium level (28), but not significantly. Clearly, Welfare level decreases when road capacity is to be increased. A non-parametrical test confirms this intuition (Wilcoxon, p = 0.0078***) in ADD condition.

[15] Arnott et al. (1993) wrote p.148 "If road capacity is now expanded, users will shift to the road until it is as congested as before. If the railway has to balance its budget, the loss of revenue will force it to increase fares and cut service (...)".

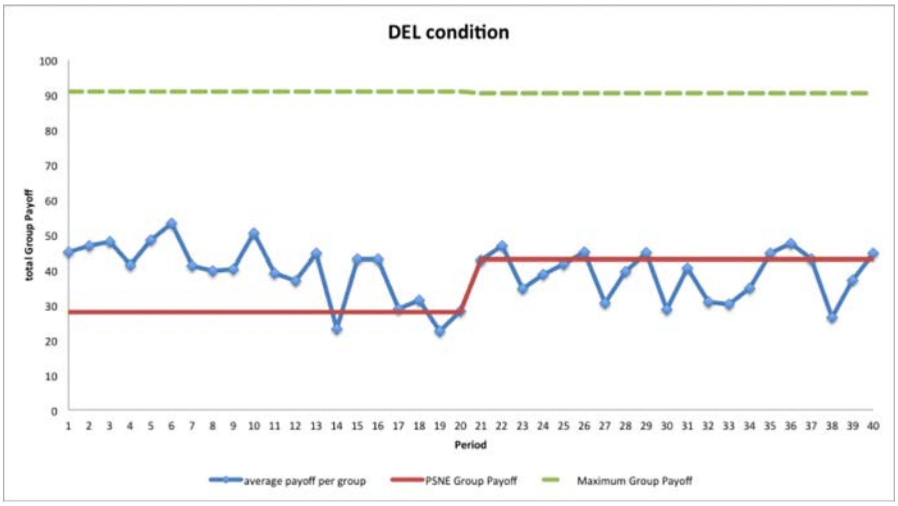

Figure 9: Total group payoff (DEL condition)

In the DEL condition, the average group payoff is around 39.8 for HIGH treatment, to be compared to 38.7 in LOW treatment. Actually, there is no significant difference about welfare between the treatments. The decrease in road capacity does not succeed to increase significantly payoffs both for subjects B and subject A (theoretically, NE should give 28 points in HIGH treatment and then 40 points in the LOW treatment). This is because Group payoff in the first treatment (HIGH) is quite high compared to the Nash prediction (around 40 on average to be compared with 28 theoretically). This relatively high level of welfare results essentially from participant A's behaviour. As she is not extracting all the rent (she should gain 3 points in the HIGH treatment and he actually gains 1 point) by choosing high capacity levels, her payoffs are quite low. But these higher capacity levels do not give higher entry rate for Public Transit (compared to Nash Perfect Subgame equilibrium), which is around 6. That means participants B who choose Public Transit increase their payoff simply because capacity is higher for this mode.

5.3.3 Interaction between operator and users

We present above the results concerning each kind of player, respectively for participant A and for participants B. Indeed, participants A interact with B and the most convenient way to discuss our empirical results is also to explain how B's strategy responds to A's strategy and *vice versa*.

The first result is that participants B coordinate quite well on Subgame Nash Equilibrium after participant A chose market 2 capacity, as it can be viewed in figure 10 below.

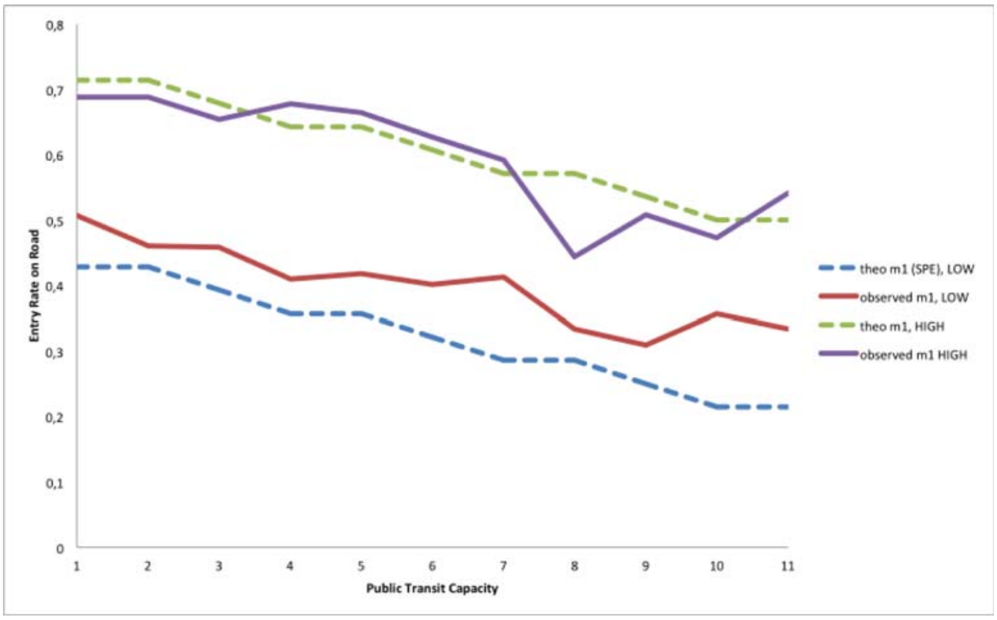

Figure 10: Entry rates on road depending on public transit capacity

This figure gives the empirical average entry rate compared to theoretical entry rate provided by Pure Strategy Nash equilibrium for the subgame of participants B after Public Transit Capacity had been chosen[16].16 The first observation is that empirical entry rate is close to theoretical one, whatever exogenous capacity for market 1 (low or high), e.g. indicating a high level of coordination for participants B. Another observation is that average observed entry rate tends to be higher compared to theoretical one in the LOW treatment, which is not the case in HIGH treatment. Such a result is similar to what was already observed by Camerer & Lovallo (1999) in the usual MEG, who observe that there is over-entry when capacity is low and under-entry when capacity of the market is high.

As the one-shot Double Market-Entry Game is played by *partners* (participant A remains always an A and interacts repeatedly with the same participants B during the whole experiment), our game could be viewed also as some kind of (repeated) Ultimatum Bargaining Game (Güth et al., 1982). Indeed, in the Ultimatum Bargaining one-shot Game (UBG), a proposer A offers to split a cake \$C with a recipient B. The responder B can choose to reject the proposed split, hence each player gets \$0, or to accept the split, and hence the split is implemented. In such a game, the pure strategy Nash equilibrium is that, as the responder should always prefer \$$\varepsilon$ to zero, the proposer should make an offer to the most unequal split, say (\$C - \$$\varepsilon$; \$$\varepsilon$), which is always accepted by the recipient.

Many experimental studies have shown that participants do not choose the unequal split, and prefer approximately an equal split or a slightly unequal split (from 50-50 to 60-40 respectively for proposer and responder). Such empirical results are often explained by reciprocity effects (see Hoffman et al, 2008). If the proposer makes an unfair proposal, the recipient could punish him by rejecting the split, even if punishing is costly for him (he will lose \$$\varepsilon$). Knowing that, the proposer should choose a fairer split, since he could fear being punished. Of course, if the game is repeated with the same partner, such reciprocal dimension should play strongly (there is some kind of tit for tat between proposers and responders who will try to determine his partner's "type").

Such reciprocity could be present in our game, since the operator choice is similar to the proposer's split in the UBG, because the capacity she chooses will determine the possible size

[16] The dashed line has to be interpreted cautiously, since for some capacity levels of market 2, there is more than one theoretical entry rate predicted by Pure Strategy Nash equilibrium. The "average" theoretical entry rate is displayed only for illustrative purpose.

for participants B's payoffs. On the same vein, the choice made by participants B between road and public transit could be also a way to punish participant A: If the capacity level she chooses is too low, participant B could punish her by choosing more often road, even if it is potentially costly for her. Proposer knows that punishment is credible, and therefore chooses capacity levels that are higher compared to Nash equilibrium prediction for capacity level chosen by participants A. This is precisely what had been observed concerning capacity level chosen by A: The average capacity level is significantly higher than the minimum level she should choose accordingly Nash equilibrium (recall figures 2 and 3).

Moreover, as we use a partners design in our experiment, this gives opportunity for participant A to build reputation, a dimension that does not exist in the one-shot game, or in the repeated UBG with strangers design. Then, the fact that the game is repeated with partners will both promote reciprocal effect and reputation effect. The two effects are combining to give a higher level of capacity that is to be chosen by participant A. For reciprocal effect, empirical evidence about UBG one shot game suggests that rejection rates tend to be high, increasing with cake size and with the size of proposed payoff for proposer: The less fair, the more rejection (See Roth, 1995). Moreover, reputation matters: When fixed partners interact repeatedly, conflicts are frequent and rejection rates are higher compared to games with strangers design (See Slembeck, 1999 for empirical evidence[17]). Such empirical phenomenon has been also observed in a different context by Gaechter & Falk, 2002 for the Gift-Exchange game. The Gift-Exchange game is a sequential game where a firm chooses first wage for a worker who then chooses in second position his effort level, effort being costly for him. Of course, the output level increases with effort level, and so does firm's payoff. They observed in the fixed partners' treatment that the average wage proposed by firms is around 3 times the Nash perfect equilibrium subgame wage, and moreover is higher than in the one-shot treatment. The consequence is that average effort is very high in the repeated fixed partners' treatment.

Empirical evidence of some reciprocity and reputation process is given in particular by figure 2 (average capacity chosen by participant A, ADD condition) and figure 3 (average capacity chosen by participant A, DEL condition). The average capacity chosen by A decreases over time in ADD condition, average capacity chosen in LOW treatment being (not significantly) higher than average capacity chosen during the HIGH treatment. Such a trend could simply suggest some learning process for participant A in both conditions. But there is no clear trend for participants A to decrease capacity level over time, even if the former results of Tobit regression given in table 4 indicates that chosen capacity declines slowly over time. Moreover, the fact that participant A uses his bargaining power, in particular in the DEL condition in the HIGH treatment, and also responds reciprocally to participants B former decisions can be observed in the Tobit regression results given in table 5: Participant A tends to increase his capacity level in period t when the number of entrants on market 2 have been higher in (*t - 1*) (the coefficient is significant at the 5% level, whereas it is not significant in the ADD condition and for pooled data), which indicates some positive reciprocity in his behaviour. Indeed, the entry rate on market 2 is the only significant explanatory variable about capacity choice (with risk aversion level), which gives more attention to this reciprocity effect.

An additional aspect concerns the reciprocal behaviour of participants B, i.e. Transport users, regarding capacity chosen by participant A. In a first approach, there is any empirical evidence of such reciprocal behaviour, since entry rates under both experimental conditions are quite similar, those being close to equilibrium predictions. Moreover, as it was noticed above, the parametric analysis is of no help to identify such reciprocity effect of the behaviour of operator on user's decisions, since the sign of the coefficient estimated in the regression analysis about

[17] Slembeck (1999) showed that empirical rejection rates in a repeated finite UBG in the fixed partners treatment is around 38% compared to approximately 27% in the strangers treatment. Moreover, he showed that first mover advantage (the differential payoff obtained by the proposer relatively to cake size) is around 5% in stringers' treatment whereas it is only 2% in fixed partners' treatment. This gives some evidence that, in order to preserve his reputation, proposer is willing to behave more fairly during the repeated game.

the probability to enter on road regarding public transit capacity as an explanatory variable is negative both for treatments LOW and HIGH (see table 5). A strong evidence of reciprocity would have been to find a positive sign for LOW treatment and a negative one for HIGH treatment for instance, suggesting that users "punish" operator in the LOW treatment for any decrease in public transit capacity (as they would enter more frequently on road when public transit capacity is to increase). In order to disentangle the possible effects due to repeated interaction between operators and users (that is, reputation and reciprocity), additional experimental sessions were organized where only players B as users participate. Capacity for the public transit was repeatedly and exogenously fixed to the minimum level (i.e. the Nash equilibrium for the operator) and participants B were confronted to the ADD condition (20 periods of LOW treatment followed by 20 periods of HIGH Treatment). 8 sessions of 14 participants (that is 112 participants) had been implemented in conformity to this design. We therefore compare the average entry rate for each group in this additional experiment to the average entry rate of our initial game regarding only ADD condition, data to be restricted to the cases when capacity chosen by the operator was the minimum level. As the following table shows, the average entry rates are roughly the same, the average entry rate being around 8.5 for our initial experiment and 8.63 for our benchmark experiment, that is, roughly equivalent. Conformingly, a Mann-Whitney signed rank test fails to reject the null assumption of equal mean between the two samples (z = -1.157, p = 0.2472).

Table 6: Entry rates, ADD condition and benchmark

Benchmark			ADD Condition, c2=1		
Group #	Mean entry rate	(sd)	Group #	Mean	(sd)
17	8.475	2.67	1	8.35	2.32
18	8.45	2.48	2	8.67	2.83
19	8.325	2.26	4	8.50	2.29
20	8.65	2.21	5	8.36	1.82
21	8.725	2.31	6	8.20	2.27
22	8.85	2.40	9	7.00	2.00
23	8.55	2.42	10	10.43	1.84
24	9	2.62			

To conclude about these reciprocal effects, it seems that Operator fears possible response of users B concerning their possible over entry in road market due to low capacity choice. But this fear is nonsense, since users do not react differently when confronted to a minimum capacity, whatever it has been exogenously determined or endogenously chosen by a partner.

6. Concluding comments

The aim of this paper was to give empirical, and more precisely, experimental evidence to a well-known phenomenon discussed since years in transport economics, the Downs-Thomson Paradox. To this end we build a theoretical model inspired on the usual Market Entry Game and based, firstly, on an individual choice between two markets, and, secondly, on the fact each market generates either a negative externality or a positive one. The third originality in our model is to implement an endogenous choice of capacity for one of these two markets before individuals (users) have to enter, the other market capacity being exogenous. The theoretical equilibrium is such that, given the particular subgame for users, the operator should choose the minimum capacity for Public Transit, and accordingly, given a certain fixed capacity for the other market, users allocate themselves between Road and Public Transit. An exogenous shock concerning road capacity should give an incentive for users to switch from one market (mode) to the other, the optimal strategy of the operator remaining the same: When exogenous capacity increases, users flew from market 2 to market 1 and *vice versa*. The consequences of the new equilibrium to be reached are that both operator's revenue and users aggregated payoff decline, that is welfare level is to be decreased, which corresponds to the DT Paradox. To test this model, experimental sessions are implemented, where some subjects face initially a low capacity level for road and could experience a higher level later (ADD condition), whereas for other subjects, the reverse situation applied (DEL condition). ADD condition corresponds rigorously to Downs-Thomson Paradox, whereas the DEL condition is closer to Mogridge's conjecture. The results we obtained are the following. Firstly, we observe that Downs-Thomson Paradox is produced in the laboratory, which gives empirical support for such a phenomenon. Secondly, we nevertheless do not observe that decreasing market capacity exogenously does produce some improvement in welfare level. The second result is that, for a given vector of capacity levels, users coordinate remarkably well on average around the entry rate predicted by pure strategy Nash equilibrium for the users' subgame. This result is in line with former results obtained in experimental studies for Market Entry Games, but we have to notice that our game is almost more complex for subjects, which precisely makes coordination problem more difficult to solve for them. The third important result is that operator does not choose the minimum level of capacity, far from it, and that her choice responds very little to exogenous road capacity. But such overcapacity choices by operator could not be clearly explained by any reciprocal dimension coming from users' behaviour regarding entry decision. Considering decision-making aid related to transport policies aiming at solving congestion, our results suggest that, as was saying Roy Kienitz (executive director of the Surface Transportation Policy Project, cited by Litman, 2005): "*Widening roads to ease congestion is like trying to cure obesity by loosening your belt*". It might be useless to solve road congestion by increasing road capacity, at least in the short term. But policy planners might be also cautious about the attractive idea suggesting that a decrease in road capacity (or an increase in public transit capacity, ceteris paribus) might necessarily reduce total transport costs, as our results show that it is not the case.

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Annex: English translation of original French instructions (ADD condition)

You will participate in an experience that you'll be paid. If you read the instructions carefully, you can earn a significant amount of money that will be paid at the end of the experiment, in Euros, by check. This amount consists of a package of 3 Euros and participation gains you have achieved during the experiment.

Indeed, throughout the experience, you will earn or lose points. In this experiment, there will be several rounds. At the end of the experiment, the computer will randomly select some of the rounds you have made and will determine your final earnings on the basis of these parts randomly. Points earned in these rounds will be randomly transformed into Euros on the following basis: *3 points earned 1 euro*.

In this experiment, you are 15 participants. At the beginning of the experiment, one of 15 participants will be randomly selected by computer to have a special role in the experiment, and those participants will be called A. The remaining 14 participants (participants called B) have a similar role. The roles will remain the same throughout the experiment.

At the beginning of each round, participant A at random, must make a choice. The other 14 participants (B) will be informed of this choice made by A and will in turn make a decision. Once the 14 B participants have made their choice, the computer will give information on the choices made by participants A and B, showing its gain to each participant. In this experiment, there will be several rounds.

Principle of the game

The game principle is as follows. Each of the 14 B participants must choose between two options, one option X and option Y. When making this choice, B participants do not know the decision of other participants B, but know the decision of the participant A. The gain of each participant B depends on the number of participants B who chose X and the number of participants B who chose Y, but also the choice initially made by the participant A. The process for each round is always the same: at first, the participant A will choose and then in a second step, participants B will make their choice (X or Y) after becoming aware of the choice made by participant A.

Payoff for each participant will be determined by the following principles:

- The gain points for each participant depends on whether B chose option X or option Y
- The possible payoff for a participant B who chose **X** is equal to:

Gain for decision X = 6 + (m - [number of B having chosen X])

The value of ***m*** is indicated at the beginning of each game on your computer. It does not depend on the decisions of participants A or B.

- The possible payoff for a participant B who chose **Y** is equal to:

Gain for the decision Y = 25% × (n + [number of B having chosen Y])

n is a value chosen at the beginning of each round by the participant A. This value n can be between 1 and 11 and is necessarily an integer, or 1, 2, 3, 4, ... up to 11 inclusive.

- The gain points for the participant A corresponds to the difference between the number of participants B having selected Y and the value ***n***, namely:

Participant A Gain = [number of B having chosen Y] – n

An example may be helpful. Suppose that *m* is initially set to 5 and that the participant A has chosen a value of n equal to 4. If among the 14 participants B, 7 choose option X and therefore 7 choose the option Y, then the gains will be:

- For each participant B who chose X, the gain will be equal to:

Gain of B to X = 6 + (5-7) = 4 points

- For each participant B who chose Y, the gain will be equal to:

Gain of B to Y = 25% × (4 + 7) = 2.75 points

- For participant A, the gain will be equal to:

Gain of A = 7-4 = 3 points

The following instructions detail now the course of the experiment

Detailed instructions of the experiment (continued)

In this experiment, a participant will be randomly selected from the 15 participants to be participant A, the 14 remaining participants are therefore participants B. You will not know the identity of participants B or participant A

In this experiment, there will be two phases. Each phase will consist of 20 periods.

In this first phase, each participant receives an endowment at the beginning of each round of the game. This endowment will be 11 points for participant A and 5 points for each participant B. The points gained or lost during each round will be added or removed from this allocation (different if you play A or B) and give you your net gain in points for each round. In each round, you will not get points accumulated over the previous games or will not suffer the losses of the previous rounds (counters are reset each round). However, your final gain in Euros equal to the draw for some of the rounds you have played.

For example, if a participant B wins one point in round 4, the net gain will be 5 + 1 = 6 points. If round 4 is drawn at the end by the computer to determine the final gain in Euros, then the participant actually win the equivalent of 6 points in Euros plus gains he (or she) has achieved over the other rounds from at random by the computer. But it may also be the gain of another round which will be drawn.

Once the participant A randomly selected, he (or she) shall at the beginning of each game, start by setting the value n, an integer between 1 and 11.

Once this value is determined by A, it will be communicated to all participants B through their computer screens. Once this information given to participants B, they must choose between option X and option Y (only one option can be chosen, and it is impossible not to choose).

If you are a participant B, your gain will depend on your choice, X or Y. This gain is added to your staffing if positive, be subtracted from your endowment if it is negative.

- *If you are a participant B and you have chosen* ***X*****,** then your gain will depend on the number of B has also chosen X. For this first phase of the experiment, **m** is equal to 3. The gain related to the choice X for each participant B is:

Gain decision X = 6 + (3 - [number of B having chosen X])

Gains of each participant B who chose X are calculated in the following table, given the above formula:

Gain related to the choice of option X

Number of B having chosen **X**	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Your gain	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5

- *If you are a participant B and you have chosen* ***Y*****,** then your gain will depend on the number of B who have also chosen Y and on the value of n chosen by A:

Gain the decision Y = 25% × (n + [number of B having chosen Y])

As n is a value chosen by participant A at the beginning of each round, the gain related to the Y option is equal to (see table below):

Gain related to the choice of option Y

Number of B having chosen **Y** ☞ Value of **n** selected by A☟	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75
2	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
3	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25
4	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5
5	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75
6	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5
7	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25
8	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25	5.5
9	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25	5.5	5.75
10	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25	5.5	5.75	6
11	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25	5.5	5.75	6	6.25

For participant A, the gain is equal to:

Gain (participant A) = [number of B having chosen Y] – n

After each game, each participant will have its gain, the gain of B participants who chose X (individual earnings are necessarily the same for all participants B who chose X), the gain of B participants who chose Y (the Individual earnings are necessarily the same for all participants B who chose Y) and the gain of participant A. Moreover, the number of B having chosen X and the number of B having chosen Y will be communicated, just as it will be recalled the value of n chosen by the participant A.

Then, a new game begins.....

Summary

In each round, you will be a participant A or participant B. There is one participant A and 14 B. Once your specific role is taken, it will not change during the experiment.
At the beginning of each round, participant A fixed value of n between 1 and 11. This value is then communicated to all participants B. These must then choose between option X and option Y. The gain for one participant B chooses depends on the number of who have chosen X. The gain for one participant B who has chosen Y depends on the number of B who have chosen Y and on the choice of n made by the participant A.

This phase of the experiment will include 20 games.

Comprehension questions:

1. The value *m* is 7. Assume that participant A chooses a value of n = 4, and the number of participants B who chose X is 8:

   a) the number of participants B who chose Y is:
   b) the gain of participant A is:
   c) the gain of participant B who chose X is:
   d) the gain of participant B who chose Y is:

2. The value m is 2. Assume that participant A chooses a value n equal to 6, and the number of participants B who chose X is 4:

   e) the number of participants B who chose Y is:
   f) the gain of the participant A is:
   g) the gain of participant B who chose X is:
   h) the gain of participant B who chose Y is:

Do you have any questions? ...... Good Luck!

Detailed instructions of the experiment (continued)

In this second phase of the experiment, there is one participant A and 14 B. These are the same participants as in the first phase of the experiment. This second phase will include 20 games.

Each participant receives an endowment at the beginning of each round of the game. This endowment will be 11 points for participant A and 2 points for each participant B. The points gained or lost during each round will be added or removed from this allocation (different if you play A or B) and give you your net gain in points for each round. In each round you will not get points accumulated over the previous games or will not suffer the losses of the previous rounds (counters are reset each round). However, your final gain in Euros equal to the draw for some of the rounds you have played.

For example, if a participant B wins one point in round 4, the net gain will be 2 + 1 = 3 points. If round 4 is drawn at the end by the computer to determine the final gain in Euros, then the participant actually win the equivalent of three points in Euros plus gains he (or she) has achieved over the other rounds from at random by the computer. But it may also be the gain of another round which will be drawn.

Once the participant A randomly selected, he (or she) shall at the beginning of each round of this second phase of the experiment, start by setting the value n, an integer between 1 and 11.

Once this value is chosen by A, it will be communicated to all participants B through their computer screens. Once this information given to participants B, they must choose between option X and option Y (only one option can be chosen, and it is impossible not to choose).

If you are a participant B, your gain will depend on your choice, X or Y. This gain is added to your staffing if positive, be subtracted from your endowment if it is negative.

- *If you are a participant B and you have chosen **X**,* then your gain will depend on the number of B has also chosen X. For this second phase of the experiment, **m** is equal to 6. The gain related to the choice X for each participant B is:

Gain decision X = 6 + (6 - [number of B having chosen X])

Gains of each participant B who chose X are calculated in the following table, given the above formula:

*Gain related to the choice of option **X***

Number of B having chosen **X**	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Your gain	11	10	9	8	7	6	5	4	3	2	1	0	-1	-2

- *If you are a participant B and you have chosen **Y***, then your gain will depend on the number of B have chosen and Y and also the value of n chosen by A:

Gain decision Y = 25% × (n + [number **of B having chosen Y])**

As n is a value chosen by participant A at the beginning of each round, the gain related to the Y option is equal to (see table below):

Gain related to the choice of option Y

Number of B having chosen **Y**☞ Value of **n** selected by A☟	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75
2	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
3	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25
4	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5
5	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75
6	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5
7	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25
8	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25	5.5
9	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25	5.5	5.75
10	2.75	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25	5.5	5.75	6
11	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.25	5.5	5.75	6	6.25

- For participant A, the gain is equal to:

Gain (participant A) = [number of B having chosen Y] – n

After each game, each participant will have its gain, the gain of B participants who chose X (individual earnings are necessarily the same for all participants B who chose X), the gain of B participants who chose Y (the individual earnings are necessarily the same for all participants B who chose Y) and the gain of participant A.

Moreover, the number of B having chosen X and the number of B having chosen Y will be communicated, just as it will be recalled the value of n chosen by the participant A.

Then, a new game begins...

Summary

In each part, you will be a participant A or participant B. There are one participant A and 14 B. The taken roles are the same as in the first phase of the experiment.
At the beginning of each round, participant A fixed value n between 1 and 11. This value is then communicated to all participants B. These must then choose between option X and option Y. The gain for one participant B chooses depends on the number of who have chosen X. The gain for one participant B who has chosen Y depends on the number of B who have chosen Y and also on the choice of n made by the participant A.

This phase of the experiment will include 20 games.

Determination of your final payoff

Your total earnings are determined as follows:

- The computer will draw lots 2 rounds made during the first phase of the experiment (the first 20 games) and 2 rounds made during the second phase of the experiment (the last 20 games)
- Once the draw is made, the computer will tell you which rounds of the experiment were randomly selected and will then give you your gain points,
- \For each participant, gain points are equal to:

Gain Points = (sum of the holdings of four rounds randomly) + (points earned during the 4 rounds randomly) **-** *(lost points over the four rounds selected at random)*

And your gain is in Euros:

Gain in Euros = (gain points / 3) + participation fee of 3 Euros

If you have any questions, please raise your hand

Kindly complete the computer questionnaire and received participation. Please wait an experimenter happening in your box for you to pay.

Thank you for participating!