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Damien Besancenot, Radu Vranceanu

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**EXPERIMENTAL EVIDENCE**  
**ON THE ‘INSIDIOUS’ ILLIQUIDITY RISK**

**Damien Besancenot\* and Radu Vranceanu<sup>‡</sup>**

**Abstract**

This paper brings experimental evidence on investors' behavior subject to an "illiquidity" constraint, where the success of a risky project depends on the participation of a minimum number of investors. The experiment is set up as a frameless coordination game that replicates the investment context. Results confirm the insidious nature of the illiquidity risk: as long as a first illiquidity default does not occur, investors do not seem able to fully internalize it. After several defaults, agents manage to coordinate on a default probability above which they refuse to participate to the project. This default probability is lower than the default probability of the first illiquidity default.

*Keywords:* Coordination game, Illiquidity risk, Threshold strategy, Experimental economics.

*JEL Classification:* D81, C92, C72, G20.

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\*University of Paris 13 and CEPN, 99 rue Jean-Baptiste Clément, 93430, Villetaneuse, France. E-mail: besancenot.damien@univ-paris13.fr

<sup>†</sup>ESSEC Business School and THEMA, 105 Av. Bernard Hirsch, 95021 Cergy, France. E-mail: vranceanu@essec.fr.

<sup>‡</sup>A more complex version of this experiment was first implemented with the help of Jean-Pierre Choulet from ESSEC Business School. This version was developed by Delphine Dubart from the ESSEC Experimental Laboratory (See: <http://behavioralresearchlab.essec.edu>). We are extremely grateful to Jean-Pierre and Delphine for their support. We thank Aurélie Dariel, Karine Lamiraud, Bernard Ruffieux and Estephania Santacreu-Vasut for their suggestions and remarks.

# 1 Introduction

Once again, during the Great Recession of 2007-2009, illiquidity proved to be one major factor of economic instability (Pedersen, 2009; Brunermeier, 2009; Miller and Stiglitz, 2010). In a short lapse of time, in the last four months of 2008, traditional buyers of many asset backed securities and bank commercial paper, all vanished. Taking one representative quote from *The Economist* of February 10th, 2010, "Many of those clobbered in the crisis, including Bearn Sterns, Northern Rock and AIG – were struck down by a sudden lack of cash or funding sources, not because they run out of capital."<sup>1</sup> One important lesson from the last recession is that researchers must provide a much better understanding of liquidity crises than they hold today.

Morris and Shin (2009) notice that the credit risk of any institution has three different measures. They define the *insolvency risk* as the conditional probability of default due to deterioration of asset quality if there is no run by short term creditors in the first place. The *total credit risk* is the unconditional probability of default, either because of short-term creditor run or long term asset insolvency. *Illiquidity risk* is the difference between the two, i.e., the probability of a run on an otherwise solvent institution.<sup>2</sup>

In general economists explain illiquidity as an inefficient equilibrium outcome, where, in absence of a coordination mechanism, investors' cannot coordinate their actions on the high equilibrium. The basic rationale was introduced by Summers (2000, p.7):

A crude but simple game, related to Douglas Diamond and Philip Dybvig's (1983) celebrated analysis of bank runs, illustrates some of the issues involved here. Imagine that everyone who has invested \$10 with me can expect to earn \$1, assuming that I stay solvent. Suppose that if I go bankrupt, investors who remain lose their whole \$10 investment, but that an investor who withdraws today neither gains nor loses. What would you do? Each individual judgment would presumably depend on one's assessment of my prospects, but this in turn depends on the collective judgment of all

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<sup>1</sup> Governments also can be victims of sudden and unexpected investors' run. See Summers (2000) and Reinhart and Rogoff (2009).

<sup>2</sup> See also Besancenot and Vranceanu (2007) for a similar decomposition of total risk into insolvency and illiquidity.

of the investors. Suppose, first, that my foreign reserves, ability to mobilize resources, and economic strength are so limited that if any investor withdraws I will go bankrupt. It would be a Nash equilibrium (indeed, a Pareto-dominant one) for everyone to remain, but (I expect) not an attainable one. Someone would reason that someone else would decide to be cautious and withdraw, or at least that someone would reason that someone would reason that someone would withdraw, and so forth. This phenomenon, which Douglas Hofstadter has labeled “reverberant doubt,” would likely lead to large-scale withdrawals, and I would go bankrupt. It would not be a close-run thing. John Maynard Keynes’s beauty contest captures a similar idea.

Hence the theory of global (or coordination) games appears to provide a good background for understanding illiquidity. In these games, the individual payoff to some action is an increasing function in the number of agents that undertake that action (Carlsson and van Damme, 1993; Morris and Shin, 1998; 2007).<sup>3</sup> Bryant (1983) shows that in a complete information set-up these strategic complementarities result in multiple equilibria with self-fulfilling beliefs. The polar situations where either all players undertake the highest action (the Pareto dominant or payoff dominant equilibrium) or the lowest action (the highest security or minimax equilibrium) are intuitively appealing but cannot be justified on pure deductive grounds. To remove this indeterminacy, Van Huyck et al. (1990) have run an experiment of a basic coordination game with complete information and find that, after repeating the game for several times, the security equilibrium takes over the other equilibria.<sup>4</sup>

Rochet and Vives (2004) and Morris and Shin (2009) apply the theory of coordination games to banking crises. The main contribution of these papers is to combine the analysis of illiquidity with that of insolvency. The former can arise if banks cannot roll over their short term debt due to coordination problems, while insolvency is defined as the riskiness of their long-term investment

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<sup>3</sup> The core logic of these n-player games can be inferred from the classical two player ‘stag hunt’ game. See Camerer (2003) for an analysis of its equilibria and empirical tests.

<sup>4</sup> Berninghaus and Ehrhart (2001) consider the same game under different information treatments. See also Devetag (2003). A related problem is the “dying seminar game” introduced by Schelling (1978), and analyzed in an experimental setting by Semeshenko et al. (2009).

projects, conditional of not being illiquid at the first stage.<sup>5</sup> Schotter and Yorulmazer (2004) and Madiès (2006) have provided experimental analyses of classical bank runs; they focus on depositors' decision to pull out their money once that a bank becomes insolvent.

To the best of our knowledge, the relationship between the intrinsic risk of an asset (insolvency) and illiquidity has not been tested in laboratory experiments. In this paper, we report results of a simple experiment aiming to directly assess the contribution of illiquidity to the total risk of an investment project. The project can deliver either a positive gain or nothing, with a known and predetermined probability. Without illiquidity, this "insolvency" or "intrinsic" probability of default is the only risk that investors should take into account. However, for a large and indivisible investment project, investors must pool resources in order to implement it. If the number of investors is too small, the project can only fail, what we refer to as the "illiquidity risk". If the number of investors is large enough, the project is implemented and will succeed or not, depending on the intrinsic probability of success.

*To take an example, suppose that a famous biologist wants to implement a research programme on a new molecule with huge market value for drug companies. He wants to run this project by creating a company, and sells one year bonds for 2000 euros each, with a face value of 3000. In order to be able to carry out its research, he needs a molecular microscope that costs one million euros. So, if there are less than 500 lenders, he cannot buy this heavy equipment, the research cannot be engaged, and his nascent company will fail and lenders will lose their investment. If the microscope is bought, then the gain can be positive (if he succeeds) or zero (if we assume, not very realistically, that a second hand microscope worth nothing).*

To test if whether investors (lenders) are able to internalize this "illiquidity risk", we set up an experiment as a pure coordination game. While the connection with the financial market is

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<sup>5</sup> The finance literature also brings a significant contribution to understanding the illiquidity risk, defined as a situation where suddenly the various arbitrageurs refuse to buy assets. For instance, Acharya and Pedersen (2005) present a simple theoretical model that helps explain how asset prices are affected by liquidity risk and commonality in liquidity. The spiral of panic-driven asset liquidation, specific to the 2008 turmoil, was analyzed by Pedersen (2009). See also Besancenot et al. (2004) and Besancenot and Vranceanu (2007) for another model of interaction between insolvency risk and illiquidity risk (without coordination difficulties).

straightforward, we avoid using words such as "loan, debt, default" that have their own emotional loading. Basically, subjects can pay 20 cents in order to participate to a lottery that brings them 30 cents with a probability  $q$  and nothing with probability  $(1 - q)$ . This intrinsic risk  $(1 - q)$  is common knowledge. If this lottery is interpreted as an investment into a risky project, in case of default of the borrower (with probability  $1 - q$ ), the lender loses his investment, in the opposite case (with probability  $q$ ), the lender makes a net profit of 10 cents.

Students were invited to play two games. In the first game, referred to as the "no-interaction game", the outcome of the investment depends on the individual risk only (with no interaction between individuals' decisions). In the second game, referred to as "the illiquidity game", the positive gain is delivered only if at least  $x\%$  of the subjects have participated to the investment. This *participation constraint* is inspired by the investment story, where the success of a joint project depends on the participation of a large enough number of individual investors. Hence, an investor must not only take into account the individual chances that his investment will bring him the high payoff, but also the would-be decisions of the other investors.

The same group of subjects was asked to play the illiquidity game for several times, for varying levels of the intrinsic risk. We observe for what level of the displayed individual risk they coordinate their actions either on the "invest" or "do not invest" strategy. Actually, the experiment aims to elicit "threshold strategies" on which players do coordinate their decisions, in the line with the experiment implemented by Heinemann et al. (2004).<sup>6</sup>

The experiment provides several interesting insights. Firstly, we observe that the minimax equilibrium – where no investor participates to the market and the investment is not implemented – never occurs. [Appendix 1 provides a theoretical explanation for this outcome]. Secondly, there is a default threshold for the risk probability  $(1 - q)$  on which agents tend to coordinate their actions. Thirdly, this default threshold is smaller in presence of the illiquidity risk than without the illiquidity risk, but agents manage to coordinate on this threshold only after several defaults. We comment on the policy implications of these results in the conclusion section.

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<sup>6</sup> These scholars have designed an experiment of a currency speculative attack model, where chances that devaluation occurs depend on the number of traders that attack the currency.

For sure, as any experimental research, this paper has its own limits. At difference with a standard global game, in our experiment the individual's payoff does not depend on some order statistics of the group (minimum, maximum, average) and the percentage of investors that triggers illiquidity is exogenously given. The advantage of this simple experiment is that it can disentangle the illiquidity risk (stemming from poor coordination) from the total risk of the investment. Further research might test the game for varying participation thresholds, or make this participation threshold endogenous.

The paper is organized as follows. The next section presents the experimental design. Section 3 provides the results of the experiment. Section 4 presents our conclusion.

## 2 Experimental design

All the subjects were recruited by the ESSEC Experimental Laboratory from the student population of the ESSEC Business School, who answered to a call for paid decision experiments. The experimental design was presented via computer interface and all interactions were computerized. The programme was written in Z-tree (Fischbacher, 2007). Instructions were read aloud. Throughout the sessions students were not allowed to communicate and could not see the others' screen. The core study builds on a "within-subjects" design, but we also tested the illiquidity game alone. In the within-subjects set-up, three sessions were conducted in May (9 students), June (15 students) and November 2010 (16 students). [see Appendix 3 for the instructions].

There is a basic lottery  $L$  defined as an elementary two-payoff gamble:

$$\text{Lottery } L : \begin{cases} 30 \text{ cents} & \text{with a probability } q \\ 0 \text{ cent} & \text{with a probability } 1 - q \end{cases}$$

In the first game students were invited to play repeatedly the lottery  $L$ . At each round, they receive 20 cents before making their choice (play or not the lottery); loses and gains were also material. The individual levels of risk, i.e., the probability  $(1 - q)$  of losing the 20 cents bet, was announced and was varied discretely, rising from 0.05 to 0.70 with a step of 0.05 over a total of 14 rounds. After each round the student who chooses to participate is informed about the actual outcome (win/loss). In this paper, we will refer to this game as the "no interaction game".

Students were then asked to play for several times a second game, referred to as "the illiquidity game". As in the former setup, at every round students get 20 cents. They can use them to participate to the lottery  $L$  (with a known probability  $q$  of winning the positive payoff). Yet this time an additional constraint is brought into the picture: if less than 50% of the players participate to the lottery at that round, they will receive nothing whatever the outcome of the individual draw.<sup>7</sup> Hence, the students must take into account not only the individual risk, but also the risk related to the behavior of the others students in the group.

The screen inviting the student to participate to the game recalls the possible payoffs, indicates the "individual risk"  $(1 - q)$  of the lottery at that round and the percent of students who played the lottery at the previous round.

Once that all players have taken their decision (to play the game or not), the computer displays what was the percentage of participants at that round, and, if the student played the game, which was the outcome of the game (0 or 30 cents).

In this game, the level of individual risk (i.e., the loss probability  $1 - q$ ) varies according to a simple rule (Figure 2). The game starts at  $t = 0$  with a small default risk,  $(1 - q) = 0.15$ . As long as no illiquidity default occurs the risk is increased by 0.05 from one round to another. If an illiquidity default occurs, the same level of risk is submitted once again. Then, if illiquidity arises, the level of risk is reduced by 0.05 at the next round; if else, it is increased by 0.05. The experiment stops after 31 rounds.

At the end of the game the software indicates the total gain of every student. A short satisfaction survey is implemented. These experiments last for 45 minutes in average. Students earned in average 13.25 euros from playing the game; the amount includes 5 euros for showing up.

In order to control for the carry over effect specific to the within-subjects design, we run two additional sessions, where we asked students to perform only the illiquidity game, with the same rules as before. These sessions were organized in April 6 and May 18, 2011, with respectively 10 and 12 subjects.

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<sup>7</sup> If 50% or more of the players participate to the lottery, individuals who participated receive the actual outcome of the lottery (such as drew by the computer with the announced probability).



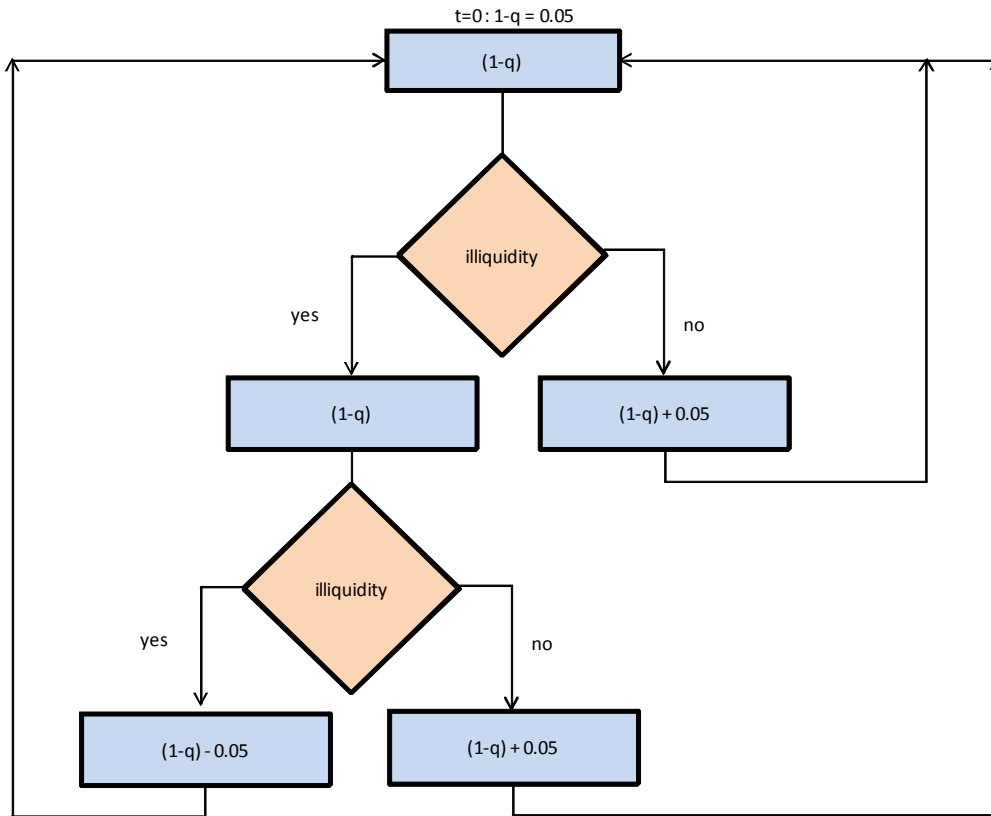


Figure 1: The risk adjustment rule

### 3 Results

#### 3.1 Data from the within-subjects design

We report firstly the result of the within-subjects set of experiments, where the same group of students first played the "no interaction game", and then the "illiquidity game".

Table 1 displays the summary of the results of the "no interaction game": the outcome of an individual decision depends only on the risk  $(1 - q)$ ; there is no interaction between students' decisions. The first line indicates the loss probability  $(1 - q)$ . The next lines indicates for each probability the number of students who accept to play the basic lottery.

$(1 - q) =$	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70
May 26, 2010														
N=9	8	8	9	9	9	8	6	7	5	6	4	2	2	2
June 9, 2010														
N=15	15	15	15	14	14	14	11	9	5	5	2	1	1	2
Nov. 3, 2010														
N=16	14	15	16	15	15	13	10	8	9	8	7	1	2	0

Table 1. Number of students that choose to play the lottery in the no-interaction game

We notice that less than 50% of the students played the lottery when the objective risk  $(1 - q)$  first exceeded 0.55 in the first and third group, and 0.45 in the second group.<sup>8</sup>

Table 2 presents the main results of the "illiquidity game" (students' decisions are now interconnected - the individual gain is paid if at least 50% of the students participate). The data indicate the announced loss probability  $(1 - q)$  that triggered the first illiquidity default (i.e. less than 50% of the students lend), then the loss probability when more than 50% of the students decided to lend again (return-to-market); the same sequence is repeated three more times. The number between brackets gives the number of students who accepted to play the lottery for that "threshold" probability. In Appendix 2 we present graphs that show the evolution of the group decision during the experience (for each group).

	1 <sup>st</sup> default	Lend again	2 <sup>nd</sup> default	Lend again	3 <sup>rd</sup> default	Lend again	4 <sup>th</sup> default	Lend again
May 26, 2010								
N=9	0.40 (4)	0.25 (7)	0.40 (0)	0.25 (6)	0.35 (1)	0.25 (6)	0.35 (1)	x
June 9, 2010								
N=15	0.45 (4)	0.35 (10)	0.40 (6)	0.30 (12)	0.40 (1)	0.30 (13)	0.40 (0)	0.30 (12)
Nov. 3, 2010								
N=16	0.40 (7)	0.25 (8)	0.35 (6)	0.25 (10)	0.30 (7)	0.25 (15)	0.30 (2)	0.25 (14)

<sup>8</sup> Since in this lottery, risk neutral individuals should stop lending for a risk above 0.33, these results indicate that in our setup some individuals might have a preference for risk.

Table 2. Illiquidity and return-to-market thresholds  $(1 - q)$ .

(Between brackets, the number of students who play the lottery)

The first default occurs for  $(1 - p) = 0.40$  in groups 1 and 3, and 0.45 in the second group. Once that illiquidity occurs, students adopt a security attitude, and refuse to lend in a coordinated way until the individual risk is further reduced (below 0.25 for groups 1 and 3, 0.35 for group 2). After a few defaults (not more than three), students manage to coordinate their strategies: a large majority of players refuse to play when a critical threshold is reached (0.35 in the first group, 0.40 in the second and 0.30 in the third). The number of persons that coordinate their decision around this critical value increases throughout the rounds; after three default rounds, almost all the population in the sample coordinate their decision at that level. The fourth default threshold is lower than the first default threshold in the illiquidity game for all the three sessions. The Wilcoxon signed ranks test performed for 40 students shows that the threshold reduction is statistically significant at  $p - value < 0.01$  (there are 27 negative ranks, 1 positive rank and 12 ties).

When comparing data from Table 1 with Table 2, it turns out that the first default threshold in the "illiquidity game" is lower than in the "no interaction game" for the groups 1 and 3; it is the same for the group 2. In order to check whether the reduction is statistically significant over the total sample, we run a Wilcoxon signed ranks test. We must remove from the analysis 7 individuals over 40 whose behavior was inconsistent.<sup>9</sup> The assumption according to which the threshold in the illiquidity game is lower than in the elementary decision can be accepted for a  $p - value < 0.01$  (there are 19 negative ranks, 9 positive ranks and 8 ties).

Figure 3 summarizes these findings. The first set of bars build on data from Table 1 relative to the "no-interaction game"; they indicate for each group the *smallest* risk probability for which less than 50% of the students decided participate to the lottery (similar to the illiquidity scenario in the second game). The next sets of bars build on data from Table 2, pertaining to the "illiquidity game". For each session, we select the critical thresholds  $(1 - q)$  when the first illiquidity default

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<sup>9</sup> These subjects did not participate to the lottery in the "no interaction game for" a small risk, then participated for a higher risk, than did not for a even higher risk. Is is therefore impossible to determine their reservation risk.

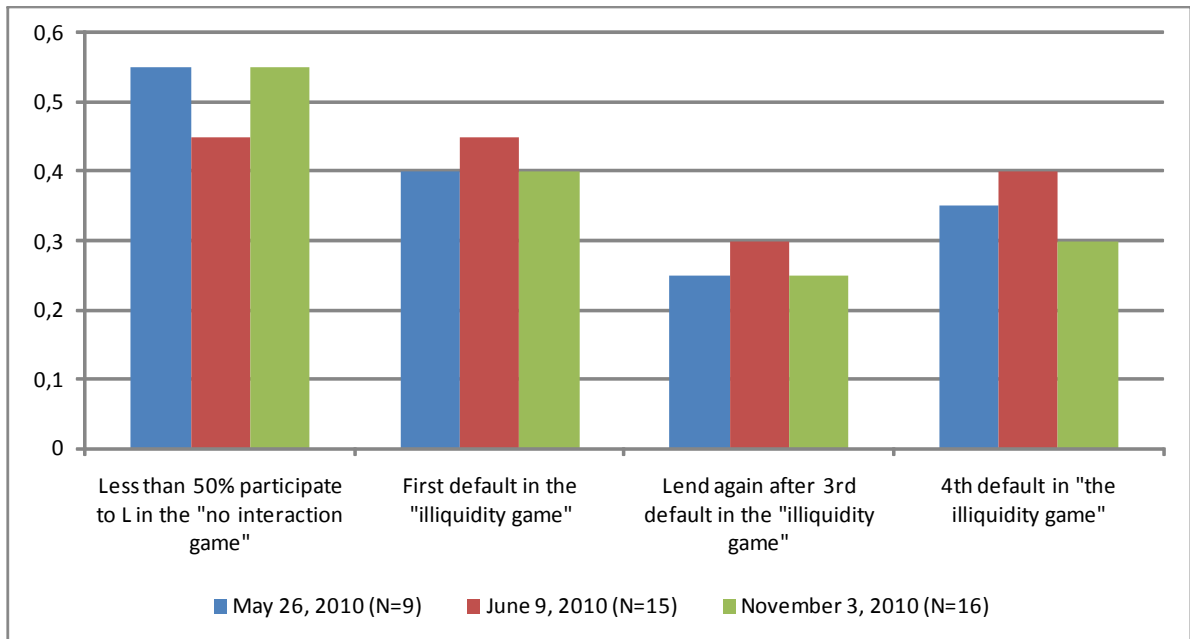


Figure 2: Critical thresholds in the "no interaction game" and the "illiquidity game": a within-subjects design

occurs, the critical thresholds for which students decide to lend again after the 3<sup>rd</sup> default, and the critical thresholds at the fourth default.

We can notice that after several illiquidity defaults, the level of risk above which a majority of students refuse to play the lottery (i.e. the illiquidity threshold  $(1 - q)^*$ ) is much lower than in the individual choice setup, down from  $[0.45 - 0.55]$  to  $[0.30 - 0.40]$ .

### 3.2 Data from the between-subjects design

To check whether this pattern holds in a between-subjects framework, we carried out the experiment twice again in April and May 2011, and asked students to play only the illiquidity game. For sure, in this case there is no perception of change in the rules that could prompt them to be more careful when moving from one game to the other. Results are close to the former within-subjects setup. As shown in Table 4 and the last two graphs displayed in Appendix 2, after a first illiquidity default (that occurs for a high level of risk), investors adjust downwards the acceptable limit.

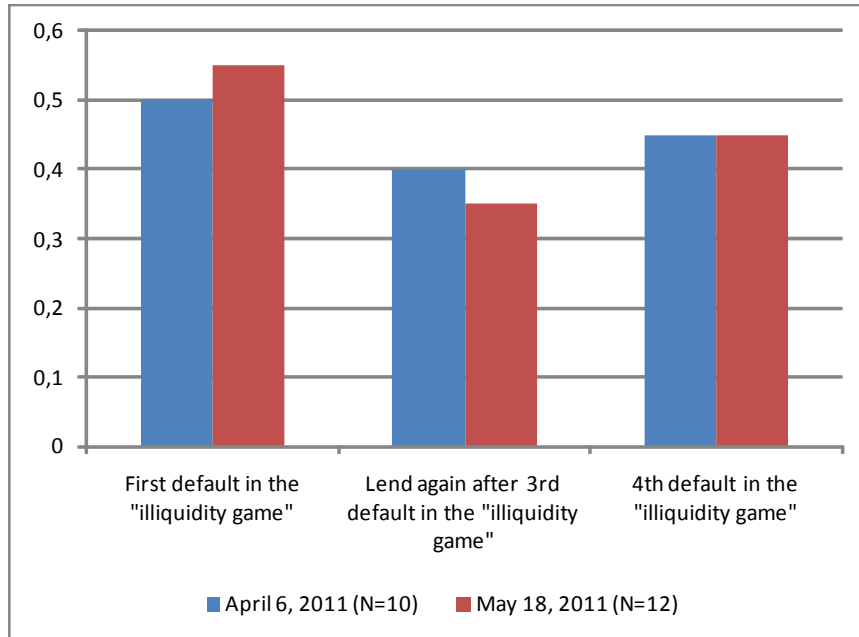


Figure 3: Critical thresholds in the "illiquidity game".

	1 <sup>st</sup> default	Lend again	2 <sup>nd</sup> default	Lend again	3 <sup>rd</sup> default	Lend again	4 <sup>th</sup> default	Lend again
April 6, 2011								
N=10	0.50 (2)	0.35 (6)	0.45 (2)	0.40 (6)	0.45 (2)	0.40 (6)	0.45 (1)	0.40 (6)
May 18, 2011								
N=12	0.55 (1)	0.35 (7)	0.45 (1)	0.35 (8)	0.45 (2)	0.35 (11)	0.45 (2)	–

Table 4. Illiquidity and no-illiquidity thresholds ( $1 - q$ ).

(Between brackets, the number of students who play the lottery)

Coordination around a critical threshold is achieved around a risk probability 0.45, lower than the probability of the first default (see Figure 4).

If we compare now the probability of the first default in the second wave of experiments with the probability where less than 50% participate in the elementary game in the first wave of experiments, the difference is not significant. Without the carry-over effect specific to the within-subjects design, students seem unable to internalize the illiquidity risk: the first default in the illiquidity game is at the same risk level where less than 50% participate to the lottery in the elementary game. Once that default occurs, the learning process is engaged, and they end up

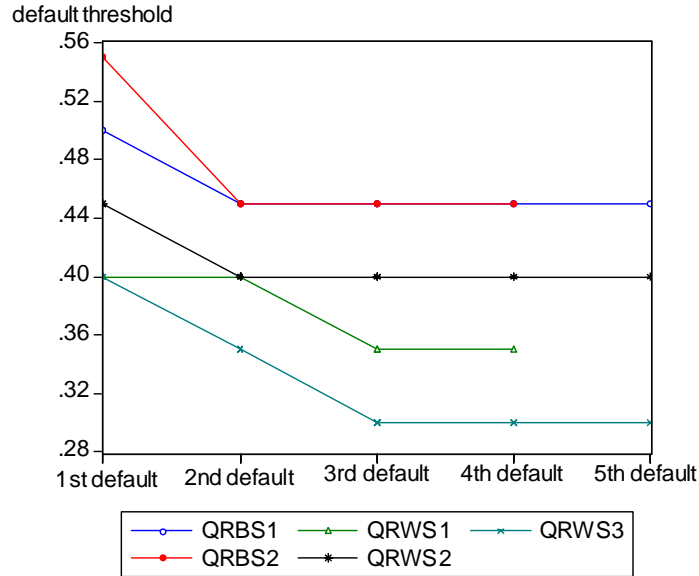


Figure 4: Order- $n$  default thersholds in five experiments

coordinating around a lower default threshold, as they did in the within-subjects design. This default coordination threshold seems to be higher in this last wave of experiments than in the within-subjects experiments (check data in column "4<sup>th</sup> default" in Tables 3 and 4).

### 3.3 A pooled data analysis

A simple pooled data analysis allows us to emphasize as a general pattern the systematic downwards revision in the illiquidity default thresholds. For so doing, we report for each experiment the probabilities that triggered the first, second, third, fourth and fifth default; the order number  $n$  of the default is similar here to the time dimension in standard pooled data analysis.

The series of the threshold default probabilities for each of the within-subjects experiments (May 26, June 9 and November 3, 2010 - data from Table 2) are denoted respectively by  $QRWS1$ ,  $QRWS2$ ,  $QRWS3$ ; the series of the default threshold for the between-subject design (April 6 and May 18, 2011 - data from Table 4) are denoted by  $QRBS1$  and  $QRBS2$ . The five series are displayed in Figure 5, where the horizontal axis corresponds to the order number of the default (first, second, etc.) and the vertical axis indicates the threshold risk  $(1 - q)$  for which the illiquidity default occurred (less than 50% of the students participate to the lottery).

We then run the regression:

$$QR_{jn} = C + F_j + an + bn^2 + \epsilon_{jn} \quad (1)$$

where  $j$  stands for the experiment [WS1, WS2, WS3, BS1, BS2],  $C$  is the overall constant,  $F_j$  is the fixed effect for each experience (a dummy variable),  $n$  is the order number or the default,  $a$  and  $b$  are coefficients and  $\epsilon_{jn}$  is an error term. The quadratic form is interesting since it allows for a dampening effect, representative of the convergence put forward in the descriptive statistics.

The OLS estimation of Equation (1) are displayed in Table 5. The dependent variable is the illiquidity default threshold  $QR_{jn}$ . Model 1 is a special case of model 2, where we omit the quadratic term.

Variable	MODEL 1	MODEL 2
C	0.4581***	0.517***
n	-0.0175***	-0.0700***
n <sup>2</sup>	–	0.0091***
Fixed effects (cross section)		
WS1-F	-0.0394	-0.0356
WS2-F	0.0043	0.0023
WS3-F	-0.0756	-0.0776
BS1-F	0.0543	0.0523
BS2-F	0.0606	0.064319
Nb obs. (unbalanced)	23	23
R <sup>2</sup> –Adjusted	0.857	0.922
Proba(F-stat)	0.00	0.00

(\*\*\*) indicates significance at 1%.

Table 5. Output of the regression model

As expected, the coefficient  $a$  is negative in both models: players revise downwards their default thresholds. In model 2, the small and positive coefficient of the quadratic term is also consistent

with our expectations: after several successive defaults, the strength of the adjustment is declining. From model 1, we notice that from the first to the fourth default, in average the default threshold would vary by  $-0.0525$ , i.e. 11% below the average first default threshold. Model 2 would suggest that after three more defaults, the default threshold would vary by  $-0.0735$ , i.e., 14% below the average first default threshold.

The analysis of the fixed effects also brings some interesting insights. Indeed, as we have already seen, the default thresholds in between-subjects experiments (BS1 and BS2) are systematically higher than in within-subjects experiments (WS1, WS2, WS3).

## 4 Conclusion and some policy implications

In a world where financial markets would further deepen and broaden, the lack of coordination of lenders or investors might well generalize as a factor of risk. The Asian crisis of 1997, the Argentinean default of 2001, the 2007-2009 Great Recession are representative of the dramatic consequences of sudden illiquidity upspring.

The main contribution of this paper is to provide an experimental framework able to replicate the essential features of institutional credit risk, where default of the borrower can stem from both an intrinsic risk specific to the project, and illiquidity or poor coordination of the investors.

Our simple laboratory experiment has confirmed the insidious nature of the illiquidity risk: as long as a first illiquidity default does not happen, subjects do not seem able to fully internalize it: the first default threshold in the illiquidity game is systematically higher than the fourth default threshold. If in real life investors can neither fully internalize the illiquidity risk, it is not surprising that there are not many signals that can call policymakers' attention on the accumulation of such imbalances. Indeed, illiquidity crises often come as a surprise. This phenomenon was extremely prominent during the Great Recession, when in 2008 buyers of many financial assets vanished in a short lapse of time and many financial markets, such as the market for CDOs, literally collapsed.

Our Lab experiment has shown that subjects become aware of the illiquidity risk after several defaults; they tend to adopt a threshold strategy that allows them to coordinate on a level of risk above which they refuse to participate to the market. In the experiment, it took a small



number of defaults to reach this lower default threshold. In policy terms, for all financial markets where liquidity matters, the measure of what a "sustainable risk level" is should be adjusted downwards.<sup>10</sup> Many asset-pricing models build their evaluation on the asset's past performance; in the light of our analysis, if one asset has never been shunned by investors, then the price predicted by these models will have an upward bias due to an underestimated illiquidity risk.

Finally, immediately after a first illiquidity default, subjects in our experiment adopted a security stance, and refused to lend until the objective risk declined in a substantial way (without falling to zero). This second effect can be responsible of some crisis hysteresis. Before the Great Recession, banks were financing many high risk projects. Actually, many observers claim that this "race for risk" is a deep underlying factor of the crisis (Besancenot and Vranceanu, 2011). Yet after the crisis, the same banks were criticized on ground that they were too cautious, and did not lend enough. Our analysis points out that this extremely prudent attitude is the normal behavioral response after an illiquidity-driven crisis. Banks need to test the coordination mechanism before they start lending again.

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<sup>10</sup> In turn, a higher risk premium, would push out of the market other lenders. This feed-back mechanism is central to many of the theoretical papers mentioned in the Introduction.

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## 5 Appendix 1. Theory: equilibrium of the illiquidity game

In this Appendix, we analyze the equilibrium of the game from a theoretical perspective. We consider an imperfect information game where a group of  $n$  identical risk-neutral players (where  $n$  is an odd number) are invited to play a lottery  $L$  that can pay:

$$\begin{cases} 30 \text{ cents} & \text{with a probability } q \\ 0 \text{ cent} & \text{with a probability } 1 - q \end{cases}$$

The probability  $q$  is public information. The cost of entering this lottery is 20 cents.

For sure, if no other motive of default is present, identical risk-neutral individuals would participate to the lottery if the *winning probability* exceeds a threshold  $\hat{q}$ , implicitly defined by equation:

$$20 = 30q. \quad (2)$$

If  $q < \hat{q} = 2/3$ , a risk-neutral, rational player will not participate to the lottery.

In order to bring into the picture the risk of illiquidity, we impose the exogenous rule according to which if less than  $x\%$  of the subjects participate to the lottery, they all get nothing whatever the outcome of the individual draw.

While in this game all individuals know the intrinsic risk  $(1 - q)$ , they might not have the same *perception* of the illiquidity risk, which depends on the decision of all other players. Thus, given  $q$ , each player must decide whether to play the lottery (strategy  $y$ ) or to refrain from playing (strategy  $n$ ) depending on his own assessment the actions of the others. In such a game, the optimal strategy  $s$  of an individual  $i$  consists in choosing a reservation probability  $q_i^*$  and play the game if the actual probability is larger than this critical threshold (and vice-versa), i.e.:

$$s_i = \begin{cases} y, & \text{if } q \geq q_i^* \\ n, & \text{if } q < q_i^* \end{cases} \quad (3)$$

According to his subjective expectation of the others' behavior, each individual  $i$  will choose his specific reservation probability  $q_i^*$ .

Let us order now the  $n$  players according to their  $q_i^*$ , from the lowest to the highest value. We define as the "pivot player" the player  $m$  such that the number of players with  $q^* > q_m^*$  represent

$x\%$  of the total number of subjects. For an objective risk  $q$ , if the  $m$  individual plays  $y$  ( $q > q_m^*$ ), then illiquidity does not arise; to the opposite, if he plays  $n$ , then more than  $x\%$  of the players do the same, and illiquidity occurs. It must be noticed that, when taking their individual decision, players should consider only the decision of the pivot player, and not the individual decision of all players. As a consequence, the outcome of this game should not depend on the number of players.<sup>11</sup>

We denote by  $F^i()$  the player's  $i$  subjective c.d.f of  $q_m^*$ .

For a given probability of getting the positive gain in the lottery,  $q$ , the gain from participating to the illiquidity game  $U^i(y)$  is obtained by multiplying the positive payoff in the lottery (30) by the individual probability of winning ( $q$ ) and by the probability that the pivot player does play the game, i.e. that  $q_m^*$  is lower than  $q$ ; this probability is defined for the individual  $i$  as  $\Pr^i[q_m^* < q] = F^i(q)$ .

$$U^i(y) = 30qF^i(q) \tag{4}$$

We notice that  $U^i(y)$  is a monotonous increasing function in  $q$  with  $U^i(y) = 0$  for  $q = 0$  and  $U^i(y) = 30$  for  $q = 1$ .

The reservation probability  $q_i^*$  turns out to be the value of  $q$  such that an individual  $i$  is indifferent between the two strategies, i.e.  $U^i(n) = U^i(y)$ , where in this game  $U^i(n) = 20$ . Formally,  $q_i^*$  is the implicit solution to:

$$20 = 30qF^i(q). \tag{5}$$

Figure 1 represents the left-hand terms in Eq. (2) and Eq. (5) as two functions of  $q$ . At point  $A$  we get the critical default probability in the elementary setting (no interaction), at point  $A'$  the critical default probability in the illiquidity game. Even in the simplified context of this theoretical analysis (homogenous, risk neutral players), *in presence of the liquidity constraint players require a higher winning probability (or a lower default probability) in order to accept the lottery*. Should investors have different preferences towards risk, it would be more difficult to foresee the behavior

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<sup>11</sup> If players can implement some form of coordination, probably the number players should matter.

of the pivot player (the p.d.f. of  $F$  would become wider and flatter), and the minimum winning probability required to participate would rise.

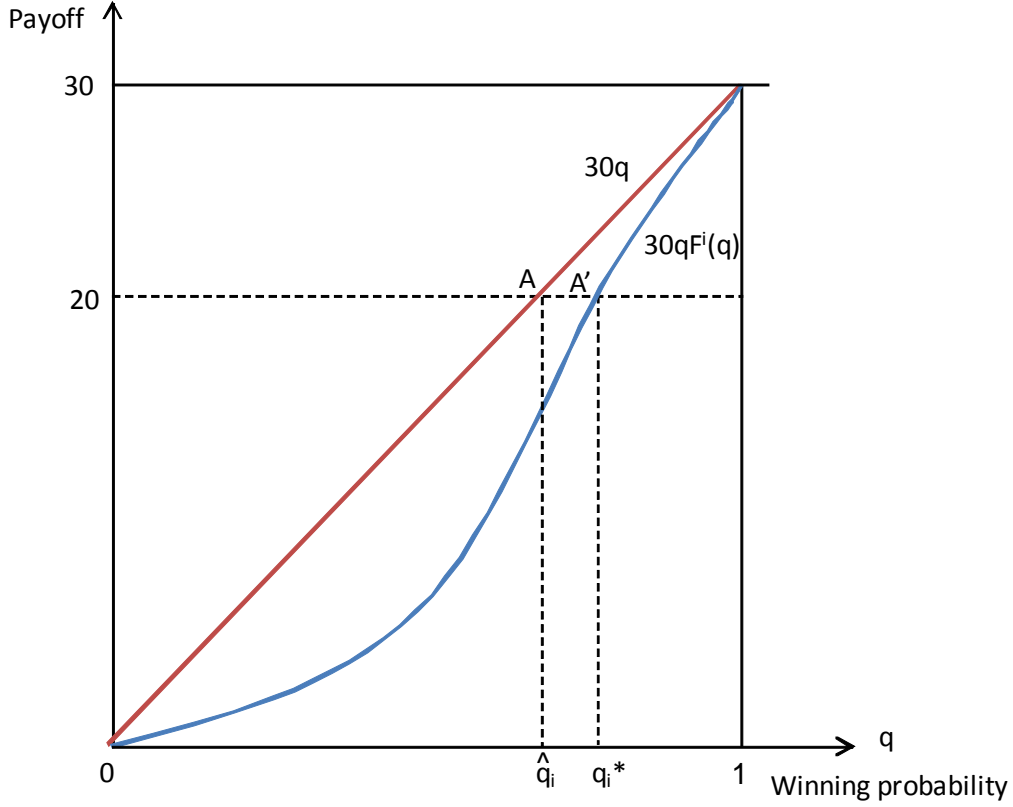


Figure 5: Critical winning thresholds for individual  $i$

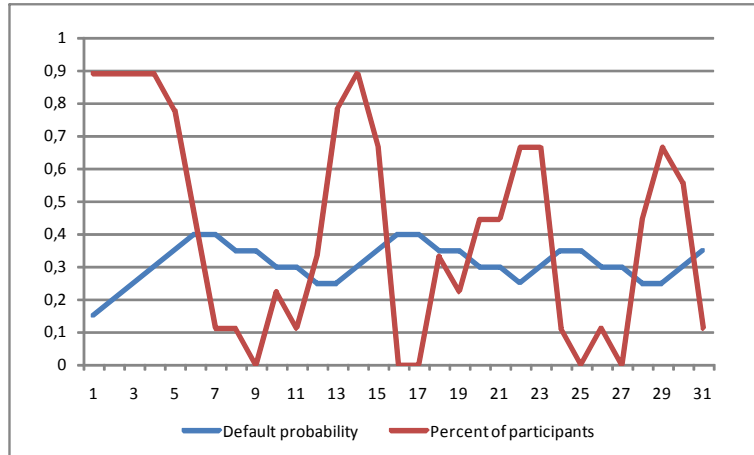
Furthermore, with homogenous, fully rational players the first occurrence of illiquidity default would reveal the true value of the threshold  $q^*$ . After the first default the distribution  $F^i(\cdot)$  would degenerate and players should coordinate their decision around this value (i.e., the threshold strategy, to use the concept submitted by Heinemann et al. 2004).

The experiment presented in the core text aims at analyzing how a group of "flesh and blood" decision makers behave within the former framework. The core issue is whether players do internalize the coordination risk, and, if they do, how fast. For sure, human subjects are not "homogenous"; they have their own psychological characteristics and biases (cognitive skills, various risk aversion, overconfidence/over prudence); in this case, the illiquidity default threshold would emerge at the term of a learning process.

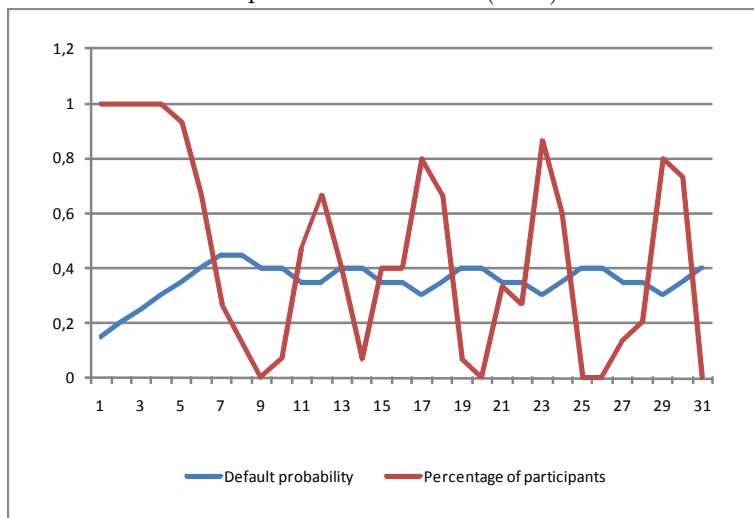
## 6 Appendix 2

The figures below indicate the evolution of illiquidity defaults depending on the level of risk. The computer chooses the level of risk according to the rule presented in Figure 2.

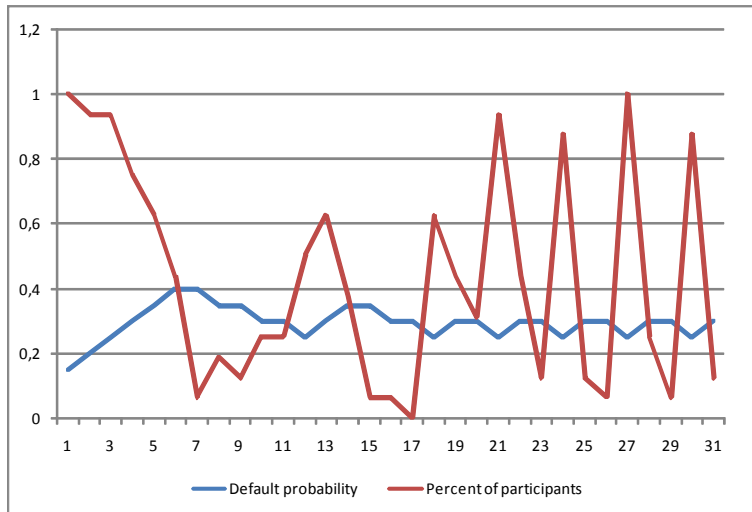
### 6.1 Data for the within-subjects experiments



Experience 26-05-2010 (N=9)

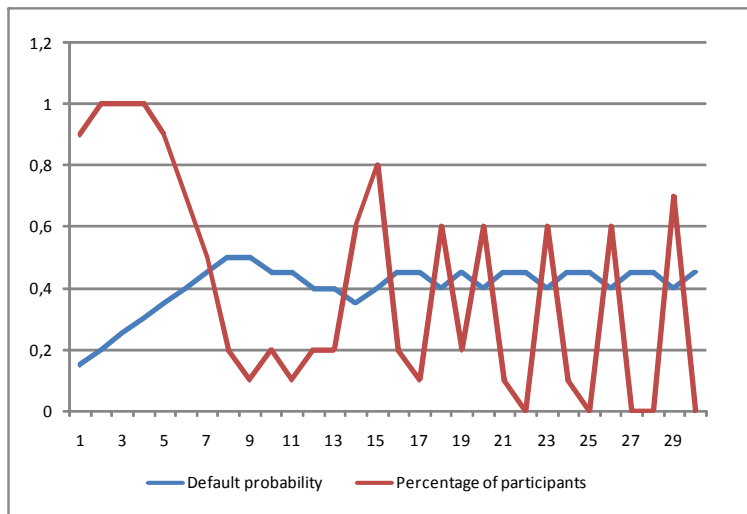


Experience 09-06-2010 (N=15)

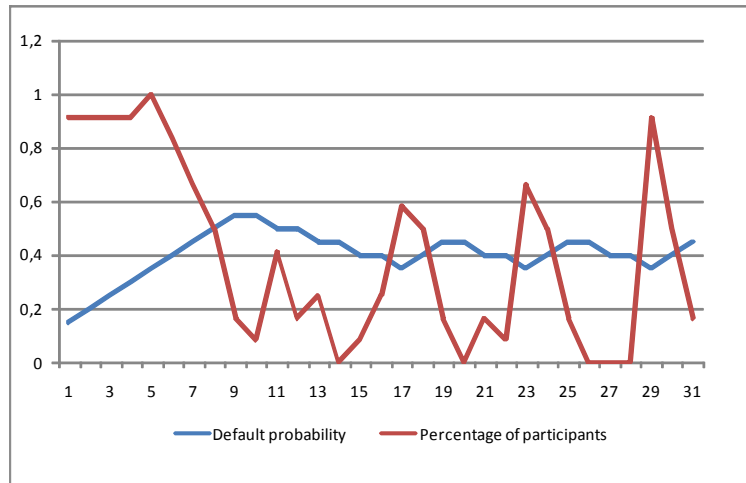


Experience 3-11-2010 (N=16)

## 6.2 Data for the "between-subjects" experiments



Experience 6-04-2011 (N=10)



Experience 18-05-2011 (N=12)



## 7 Appendix 3. Instructions for the within-subjects experiment<sup>12</sup>

**Screen 1.** Welcome to the ESSEC Experimental Laboratory. This experiment aims at studying the interaction between two risks and their consequences on the individuals' decisions. There will be two stages, one warming-up non-paid stage, and a paid stage. Pay attention please: the game progresses when the last player take his/her decision.

### THE WARMING-UP GAME

**Screen 2.** Lotteries. It costs you 20 cents to participate to a lottery. The lottery will allow you either to gain 30 cents or nothing.

**Screens 3-4-5.** Would you pay 20 cents to participate to a lottery that brings you 30 cents with a probability of 60% (50%, 40%) and 0 cents with a probability of 40% (50%, 60%) ? Yes/No.

### THE ELEMENTARY GAME

**Screen 6.** From now on the experiment will be paid. You receive the money at the beginning of each game and the decisions are material.

**Screen 7.** You will receive 20 cents at each round of the game. You can use them to buy the right to play a lottery. If you play the lottery, you lose and the gain is zero or you can win 30 cents. The loss probability will be displayed on the screen. This is the true probability used by the computer to pick the outcome. If you answer Yes to the question "do you accept to play the lottery" the participation fee is charged and you will benefit of the outcome of the lottery. Payment rule: if you do not play, the 20 cents are kept on your account. If you play and win, your account is credited of 30 cents. If you play and lose, your account is credited of 0 cents.

**Screens 8 and next.** Number of the actual round [1 to 14]. The loss probability is  $[1 - q]$ .<sup>13</sup> "Do you accept to play this lottery ?" Yes/No.

**Screens 8' and next.** Outcome of the round. You decided not to play; your gain is [20]. OR You decided to play; you gain is [0 or 30].

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<sup>12</sup> Original instructions in French.

<sup>13</sup> From one round to another,  $1 - q$  will be increased by 0.05, from 0.05 to 0.70.

## THE ILLIQUIDITY GAME

**Screen 9.** In this game there is an additional risk stemming from group behavior.

As before, you get 20 cents at each round. You can use them to buy the right to play a lottery that delivers either 30 cents or 0 cents. As before, this external probability of the zero payoff is indicated at each round.

At difference with the previous game:

- if at least [50%] of the players in the group participate, the loss / win outcome depends only on this external probability.

- if less than [50%] of the players participate to the lottery, the gain is [zero] for all players who participated to the lottery.

**Slide 10.** Examples

*Example 1.* There are 20 subjects. The displayed probability of loss is  $[1 - q]$ . For this level of risk, 6 players participate, 14 do not. Less than [50%] participate.

Outcome: All those who participate get zero, all those who did not keep the 20 cents.

*Example 2.* There are 20 subjects. The displayed probability of loss is  $[1 - q]$ . For this level of risk, 18 players participate, 2 do not. More than [50%] participate.

Outcome: Those who did not participate keep the 20 cents. Those who participate get 30 cents with a probability  $[q]$  and zero with a probability  $[1 - q]$ .

**Screens 11 and next.** Number of the actual round [1 to 31]. The loss probability is  $[1 - q]$ .<sup>14</sup> At the former round, the percentage of subjects that participated to the lottery was of  $[y\%]$ . "Do you accept to play the lottery ?" Yes/No.

**Screens 11' and next.** Outcome of the lottery. The loss probability was  $[1 - q]$ . You decided to participate (not to participate). The percentage of players is  $[z\%]$ , i.e. more (less) than [50%]. If "less" - your gain is zero. If "more": you earn 30 cents (or you get zero).

**Screen 12.** Your total gain is [A] euros. Thank you for your participation to this experiment.

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<sup>14</sup> From one round to another, this probability will vary starting from 0.15 according to the rule described in Section 2.