# The Strategies of New Technology Adoption under Real Options: Laboratory Experiment

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## Abstract

In this paper we test, by organizing experimental economics sessions, the main results of real-option theory on the strategies of new technology adoption. Thus, we verify, in a first game, the results of Grenadier and Weiss (GW) (1997) concerning the different strategies that the firm can undertake. In a second game of duopoly, we consider the models of Smit and Trigeorgis (2004, Chapter 5) and Huissman and Kort (HK) (2004). We evaluate risk aversion (RA) through Holt and Laury's (2002) lottery and the cognitive reflection test (CRT) through Frederick (2005). Then, we investigate whether risk aversion and /or cognitive ability reinforces cooperation and thus waiting behavior.

**Keywords:** technology adoption, real options, game theory, experimental economics

## I - Theoretical model and concept of experience

Under the RO approach, optimal investment behavior changes if the decision maker considers that the decision to invest may be delayed for at least one period. The postponement of the investment decision is useful as new information on the expected current value may be available in the following period. It is considered that a rational decision-maker would invest immediately only if the expected NPV is greater than the expected NPV a period later.

## I-1-Theoretical model and hypothesis formulation

This model is closely related to Dixit and Pindyck (1994). Suppose agents maximize their profits and are offered a contract to exercise it now or wait until period 1 when all uncertainties about the results are revealed before making the investment decision.

The way we operate the flows of projects today affects not only the profits of today, but also those of tomorrow, because the stock that remains at the end of period 0 is only the one on

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which we leave in period 1. In fact, optimal management cannot be achieved period by period, as if these periods were independent of each other. Since current decisions have an impact on future outcomes, the entire sequence of optimal decisions, at all times, must be resolved at once. It is the mathematical tool that provides us with the appropriate method to accomplish this feat: it is the dynamic programming founded by Bellman.

We are considering an ANT project with a limited lifespan and currently generating annual cash flow. This flow follows an MBG.

$$dX_t = \alpha X_t dt + \sigma X_t Z_t$$

$\alpha$ and represents drift and volatility respectively and $\sigma dZ_t \sim N(0, dt)$.

The risk-neutral version of a DP MBG (1994) is:[3]

$$dX_t = (\alpha - \lambda) X_t dt + \sigma X_t Z_t$$

We can therefore deduce that:

$$E(X_t) = X_0 e^{(\alpha-\lambda)t} \qquad (1)$$

$$V(X_t) = X_0^2 e^{2(\alpha-\lambda)t}\left(e^{\sigma^2 t} - 1\right) \approx X_0^2 \sigma^2 \Delta t \qquad (2)$$

In this case of MBG, it is possible to deduct closed solutions for the value of the option. This case can be considered the borderline case where the decision period is so long that it can reasonably be addressed by the assumption of unlimited maturity. In other words, the expiration time of the option tends to infinity. However, technological obsolescence or technological progress limits project life, the analysis had to be modified to take into account the case where the lifespan is over. Or T this lifespan, for which production ensures cash flows over T years. In continuous time, cash flows grow at a $(\boldsymbol{\alpha - \lambda})$**rate,** this amount received at the moment t must be discounted at the rate **r:** So the current value of the annuity between two dates and is:$\tau_1 \tau_2$

$$VA(X_t) = \int_{\tau_1}^{\tau_2} E(X_t)\, e^{-rt} dt = \frac{\left[e^{(\alpha-\lambda-r)\tau_2} - e^{(\alpha-\lambda-r)\tau_1}\right]}{(\alpha-\lambda-r)} X_0 \ = xX_0 \qquad (3)$$

U.S. options, which can be exercised at any time until expiry, are an example of cash flows that depend on future information. A rational decision in such circumstances must consider not only past information, but also expectations regarding future events. This required drawing up a

[3] Remember that in a risk-neutral context, all individuals are supposed to be risk-neutral. As such, they are only concerned with average or expected values and not with the dispersion around these values.

diagram that would sum up all the possibilities that might arise as the future presented itself, and then make the best decision in each case. To do this, several methods exist, including binomial networks. Their basic premise is that uncertainty can at any time be represented by two alternative states. A binary distribution (or Bernoulli distribution) is a discrete distribution that can take up two values, with probabilities (p) and (1-p). This is the binomial approximation CCR that we use to check the inputs of MBG. The CCR model is another simpler writing of the B&S model.

To do this, suppose that the value of cash flows ($X$), over a unit of time $\Delta t$, can:

- either increase (up) to reach $X^{+} = uX_0$ with a probability ($p$)where $u > 1$
- either decrease (down) to reach $X^{-} = dX_0$ with a probability $(1-p)$, where $d < 1$

The expectation and variance in this discrete case are then:

$$E(X) = \sum_{i=1}^{n} x_i\, p_i = p\, uX_0 + (1-p)dX_0 \quad (4)$$

$$V(X) = E(X^2) - (E(X))^2 = (pu^2X_0^2 + (1-p)d^2X_0^2) - (p\, uX_0 + (1-p)dX_0)^2 \quad (5)$$

The CCR model aims to match as closely as possible to the probability distribution in the case of the ongoing MBG process. To do this, it is enough to equalize the two expectations (2) and (4) and the two variances (3) and (5) (respectively of the two continuous and discrete cases). This equality should allow us to deduce the unknown parameters of the CCR model which are: $p, u \text{ and } d$

However, since we only have two equations, there is no one-stop solution. We can initially force one variable to take a certain value and then solve the other two. A practical choice of the third condition is the hypothesis of the symmetry of the binomial tree: , this condition has the property that an "up" [4]$u = \frac{1}{d}$ followed by a *"down"* , or vice versa, leaves the fixed value: .$udX_0 = duX_0 = X_0$

We get three equations with three strangers. Using a certain approximation, we deduce the following solutions:[5]

$$p = \frac{e^{(\alpha-\lambda)\Delta t} - d}{u - d}; u = e^{\sigma\sqrt{\Delta t}};\ d = e^{-\sigma\sqrt{\Delta t}}$$

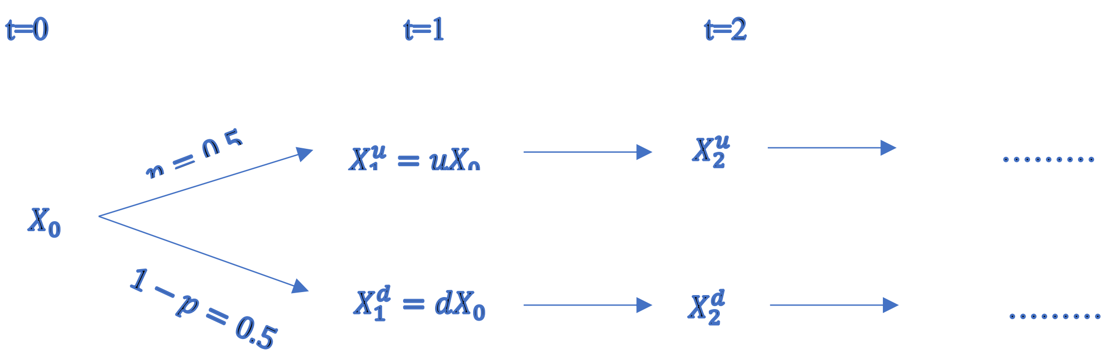
[4] Indeed, the trellis or binomial tree recombines: an increase followed by a decrease leads to the same asset price as a decrease followed by an increase (otherwise the number of knots would be significantly higher)

[5] A good simple but profound explanation on the website of the University of Taiwan:https://www.ntu.edu.tw/

Options are valued at the end of the network (at the T expiration date), as their earnings at that time are known. From these terminal gains, *backward induction* allows the current value of the option to be calculated.

Below is an investment situation that deduces the NPV approach and the OR approach. Suppose a company plans to invest, over a period, in two ANT projects. The company must choose between four projects, one of which represents an old technology. Investment in the three NT is uncertain and modeled by a binomial approximation of the geometric Brownian motion in discrete times (Dixit and Pindyck, 1994). However, the investment in the old technology is certain and therefore poses no risk.

**Figure 1 The Evolution of Flows**




First, we consider a risk-neutral decision-maker who must decide, in the case of uncertain projects, either to adopt the NT at $t_0$, or to postpone the decision at $t_1$, or not to invest. Currently, the project, which costs $I$ generates a flow $X_0$, but this value can either increase to $X^+ = uX_0$ with a probability $p$ or decrease to $X^- = dX_0$ with a probability $(1-p)$ in the first year, according to Figure 1. Both flows grow each year at the rate $(\alpha - \lambda)$ of project life. These flows will then be discounted at the rate $r$. The evaluation of options according to the binomial tree approach begins with, *the termination payoff:* TP," the present value of the option is deduced by the backward induction approach. We know that according to the RO approach, and in our simple case, both TP are either positive or zero (but never negative), thus using the equation (3):

$$TP^+ = \max\,(VA(X_T^+) - I; 0)\ ,\ TP^- = \max\,(VA(X_T^-) - I; 0)$$

The waiting area or "the continuation value: **CV",** in other words, is the updated expectation of TP (or investment region) is:

$$CV = e^{-r\Delta t}(pTP^{+} + (1-p)TP^{-})$$

In case the decision maker invested in , the NPV is then (using the equation (3)):$T_0$

$$VAN = VA(X_0) - I$$

At date $t_0$, the optimal decision is:

$$\begin{cases} Wait\ (and\ invest\ the\ following\ year) & if\ CV > VAN \\ investing\ immediately & if\ CV \leq VAN \end{cases}$$

In this binomial lattice, there is therefore a value ensuring that the immediate exercise value is greater or equal to the continuation value. This is the optimal exercise price$X^*$ that is a point on the border between the "investment region" and the "waiting area." The decision is simply a comparison between the two alternatives: the value of TP if we invest now and the continuation value if we decide to wait until the next period to invest. The optimal value, $X^*$above which it is optimal to invest immediately, is as follows:

$$CV = VAN \Rightarrow X^* = \frac{I(e^{-r\Delta t} - 1)}{x(e^{-r\Delta t}(up - d(1-p)) - 1)}$$

## I-2-The Design of the Experience

Laboratory experiments are natural solutions to fill the scarcity of empirical studies. All relevant variables are both observable and controllable.

It should be noted briefly that the reasoning by the actual options applies whenever future flows present a risk, the costs are at least partially irreversible and where there is some flexibility over time. Our experience has been formulated in the spirit of the reasoning of the actual options, while maintaining the decision situation somewhat realistic. By associating this situation with a degree of complexity at a level that can be applied in the laboratory.

Experimental studies on OR confirm the neglect of the benefit of waiting. There is usually either an investment too early or players eventually learn to wait until the uncertainty is sufficiently resolved (Morreale et al., 2019). Our experience also captures the conflict between choosing a less valuable but safe alternative or giving it up. In renouncing it, we must choose a risky but potentially more interesting alternative. While the two games in the experiment deal with decisions in the presence of uncertainty, the first will address the importance of the optimal timing of the investment (deferring a decision), while the second will examine the effect of a competitor's existence on the investment decision.

The experiment consists of four parts. The first part of the experiment consists of two ANT treatments. In the first game: it is the adoption of NT in a monopoly structure. In the second game, it is the adoption of an NT in a monopoly structure. In the second part, we use a lotteries session of Holt and Laury (2002) to identify the risk attitudes of investors. The third part is devoted to Frederick's Cognitive Reflection Test (2005). In the fourth part we collect socio-demographic and game-specific information to supplement the experimental data.

To choose our parameters of the binomial tree we refer on the one hand to Hauschild and Reimsbach (2014) who applied this method for the enhancement of a new drug, to Kellogg and Charnes (2000) and to Cox et al. (1979). These authors used the following values: u -1.30, d - 0.77 and the risk-free rate r - 7.09%. On the other hand, according to Castellion and Markham (2013), the study carried out by the Product Development and Management Association[6] *(PDMA)* in 2004 revealed differences in failure rates between industries adopting new products ranging from 35% for healthcare (healthcare) to 49% for consumer products. Thus, the assumption of a probability of an "up" of a NT, $p = 0.5$, seems reasonable. We also assume that NT are becoming more efficient, in the sense that the same investment cost generates $X_0$ ever-increasing flows. During each treatment, the subjects repeat the same decision task but with different values of $X_0$. To ensure consistency between the values of the binomial tree mentioned above, student payment and different values of $X_0$ , we chose the following adjustment along the experimental game:

$$u = 1.3; d = 0.77; p = 0.5; r = 0.1; \alpha = 0.035\ ; T = 4\ et\ I = 100$$

### I-2-1- Design of game 1

The NT that appears in T0, i.e. in the first period of the game is considered the adoption of the current NT if it is accepted by the company as a first investment. While the project is working, the decision maker must choose the next (or future) NT adoption. We assume that technologies are becoming more efficient, in the sense that they are $X_0^{NT1} < X_0^{NT2} < X_0^{NT3}$at the same cost. According to the theory of OR when $X_0$ tends towards $X^*$ (all things equal otherwise), in our case, the two values of CV and NPV tend to equalize for $X^* \approx 43$. From this value $X^*$, the optimal decision is to invest immediately. These NT appear successively in the following order:

[6] The common claim that 80-90% of products fail is an "urban legend". Empirical literature does not support this popular belief. No matter how many times this is claimed or how many people believe it, the idea that 80% of products fail is as common as it is wrong. The actual failure rate of the product is about 40%.

**Table 1: NT Adoption Projects**

| | | NT1 | NT2 | NT3 | Old technology (with certainty) |
|---|---|---|---|---|---|
| Adopt at T1 ( by coin toss) | TP+ expected | 16.86 | 21.02 | 27.26 | |
| | TP- expected | 0 | 0 | 0 | |
| CV | | 16.86 | 21.02 | 27.26 | |
| Adopt at $T_0$: NPV[7] | | 5.67 | 12.71 | 23.28 | 4.3 |
| The decision according to the RO | | Wait | Wait | Wait | Invest |

For each project and given the requirement to choose only two of the four projects, the decision maker must respond with one of three answers (e.g. for NT1):

D1: adopt NT1 to T0 and receive 5.67.

D2: adopt NT1 to T1 and receive 16.86 if stack or receive 0 if face and move on to the next project (if the decision maker has not exhausted all possibilities).

D3: Do not adopt NT1.

Based on this game where the decision maker takes the position of a monopoly, in other words he is not constrained in his decision-making by the behavior of a competitor, we propose to test the following hypotheses.

However, before testing these hypotheses, we need to clarify two points that emphasize the importance, whether theoretical or real, of this market structure and its usefulness in our experience. While we have believed in a deterioration of the monopoly structure, through the privatization of state-owned enterprises, we have recently seen a return of this phenomenon, particularly in the ICT sector where monopoly appears to be the result of a significant accumulation of innovations. For example, Microsoft's Windows monopolizes the operating system market on PCs and desktops with an average market share of more than 85% between 2010 and 2019. Facebook (with its four giants: Facebook, Facebook Messenger, WhatsApp and Instagram) monopolizes, over ten years (2010-2019),[8] the communication and social

[7] That is, the initial date of the corresponding period.
[8] https://gs.statcounter.com/os-market-share/desktop/worldwide/#monthly-201001-202008

networking applications. Undoubtedly, we cannot pass without mentioning Google with a 92% share of the search engine market in the world[9]. The second point stems from the design of the monopoly structure as a benchmarking experience in a first treatment without the waiting option. This option is introduced in a second treatment.[10]

The first hypothesis addresses the optimal timing of the adoption of NT in the face of uncertainty and in the absence of a strategy to help overcome this risk. In this regard, we refer to the founding fathers of experimental economics through their theory of perspectives, Kahneman and Tversky (1979, 1992). If these authors are, the annoyance of losing a sum of money is greater than the pleasure of earning the same amount. In other words, the pain of losing this amount of money could only be compensated by the pleasure of winning double or sometimes triple: this is the hypothesis that the authors call aversion to losses. We limit the choices in this first treatment to two projects whose investment decisions can be made either immediately or within a year. Our first hypothesis is:

***H 1:* individuals opt for the least risky decisions and therefore choose the NPV criterion (since it is positive) even if there is an opportunity for a significant gain.**

The second hypothesis relates to the ANT strategy presented in the GW model (1996) in Chapter II. While we omit assumptions about adoption costs, we make other assumptions about the flows generated from the NT. Once the technology is available but its gains are uncertain, what strategy will the company adopt: will it immediately adopt the current technology and the next, or will it opt for another uncertain future technology or decide to adopt a certain conventional technology. To answer this question, we have increased the number of projects available during the game. Players are thus reduced to choose only two between four projects. Referring to the results of GW (1996), we hypothesize:

***H 2:* in an uncertain environment and with the increase in the number of projects, the dominant strategy is the compulsive strategy without option and the "leap*frog*" strategy with waiting option.**

We specify that this hypothesis is tested without and with the waiting option.

We also focus on three other independent variables that are deemed to influence the behavior of investment decision makers. First, we study the impact of risk aversion on decisions made

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9 https://www.lesnumeriques.com/

10 https://gs.statcounter.com/search-engine-market-share

by individuals., Along the theoretical side, we have demonstrated the importance of risk aversion. Understanding the risk preferences of economic agents is useful in understanding risky behavioral decisions, particularly in predicting this behavior even in the context of various policy interventions (Bhattamishra and Barrett, 2010).

Alexy et al (2016), Ihli et al (2016) and Charness and Viceisza (2016) examine the ability of different methods to measure the degree of risk aversion. The common denominator between these four works is the analysis and evaluation of the Holt and Laury method (2002). It is one of the most answered methods for measuring risk tolerance in the laboratory. In this experiment, subjects are asked to make a series of binary choices about lottery pairs with increasing odds, where one of the lottery pairs is the safest choice. The fame of this method lies in its simplicity with regard to subjects (easy to explain and implement) and the possibility of easily linking it to other experiences where risk aversion can have an influence.

***H 3:*** **the "AR" variable is a measure of individual-specific risk preferences. We adopt the standard Holt and Laury protocol (2002). Higher HL values correspond to a decision maker less likely to take risks. Generally, studies such as Kroll and Viscusi (2011) claim that risk-fearing subjects make less investment. This could also be seen as a reluctance to invest.**

***H 4:*** **the variable "TRC" or the cognitive reflection test developed by Frederick (2005) is a short measure (three questions) of a person's ability to resist intuitive response trends and produce a normative response based on effortful reasoning, Primi et al (2014).** According to Frederick (2005), it is intended to measure the willingness or ability to engage in reflexive thinking, since it requires, among other things, that respondents replace intuitively attractive but incorrect responses. TRC has become a reference because of its strong correlation to the theoretical results of Kahneman and Frederick's (2002) dual processes on the one hand and on the other because of its ability to predict important real-life behaviors, such as patience, time preference, risk tolerance, willingness to admit ignorance and the ability to differentiate between real news and fake news, Meyer et al (2018).

***H 5:*** **the "gender" dummy variable is used as an independent variable. Previous gender research has shown that women make more conservative investment decisions (Tubetov, 2013 and Coleman, 2003).**

We emphasize that the effects of these three variables are also retained in the next game.

### I-2-2- Option game design: game 2

Under uncertain conditions, the optimal timing of the ANT is a major challenge for a monopoly. In a competitive situation, the decision becomes more and more difficult, but certainly the optimal adoption strategy can differ considerably from that of a monopoly. Rivals can preempt, which reduces the incentive to postpone the decision. In other situations, competitors may prefer to conduct a war of attrition in the hope that their rival will withdraw more quickly (Huissman and Kort, 2004). The presence of competition generally pushes companies to invest rather than a monopoly and erodes the value of the company's deferral option. However, any company considering a decision to adopt a capital-intensive or high-cost, unrecoverable NT must compromise between investing early to create a competitive advantage over the competitor, or delay investment to acquire more information and mitigate the potentially adverse consequences of market uncertainty.

The objective of this experiment is to introduce competition into the decision-making of ANT whose revenues evolve stochastically. For this, we consider a two-player game, similar to that of Morreale et al (2019).

The interdependence of player decisions is the foundation of game theory. These models are often based on the fundamental principle of physics: each action has a reaction. These interactions occur in two ways: either sequential or simultaneous.

Sequential interaction occurs when each player takes action in a sequence of tricks. During his turn, the player is aware of the actions taken in previous rounds, is also aware that his current actions will affect the subsequent actions of other players, as well as his future actions during the game.

Simultaneous interaction occurs when players act simultaneously, ignoring the current actions of others. It is important to note that even if players do not know the specific actions of other players, they are aware of each other's interactions and expectations that can be realized.

On the other hand, simultaneous game interaction can be more difficult for players. This is because players need to anticipate what the other player is anticipating at this time, and react accordingly, because these actions affect the future results of the game.

Two methods are used to analyze sequential and simultaneous games: the winning or payment matrix and the decision tree.

In our experimental game, the approximation of MBG by discrete time involves a set of options that is an overlay of a binomial tree on a winning matrix, Smit and Trigeorgis (2004). Both players know that this is a simultaneous game. They also know that each of them has the same set of actions "immediately adopt the NT" or "wait". In addition, they have information about each other's earnings. Their goals are also to maximize their earnings.

Thus, we envisage, according to our numerical data, two types of games. A game representing a stable Nash balance where none of the players has a motivation to deviate from the situation of balance. A symmetrical prisoner dilemma game (players have the same elements in their information sets), with complete information (each company knows the other's possible strategies in the four possible scenarios), but imperfect (because each company is not aware of the other's decision at the time it takes its own). Thus, the three scenarios of the ANT played previously by monopolies give us a game of stable Nash balance and two games representing the dilemma of prisoners. Repeating a game between the same players does not necessarily involve repeating the balance of the initial (or static) game.

To characterize the three scenarios, we opt for the same approach of Smit and Trigeorgis (2004). First, the adoption of an NT by one company immediately cancels out the profit of the other company: it is the power of the patent that translates the *"business stealing effect*". If both companies immediately adopt the T0 NT and the market share of each is 50%, then their earnings are the value of the NPV halved. If, on the other hand, both companies choose to wait, they each receive half of the CV value.

The first scenario seems like a coordinated waiting strategy. It appears when the first stream has the lowest value thus ensuring a minimum gain if both companies invest immediately at the moment 0. In fact, in this case two situations of equilibrium arise (adopt, adopt) and (wait, wait). However, it is very clear that the balance of expectation ensures more profit for both companies. Therefore, none of them has a motivation to deviate from their strategy, given the strategies of other players. It's a stable Nash balance. This usually occurs when the market is volatile: there is some uncertainty about current and future demand. So, the hypothesis 6 corresponding to this session is:

***H 6*: Decision-makers are rational and therefore choose the best situation (maximum earnings).**

**Table 2  Scenario 1: Nash's Stable Balance (Wait, Wait)**

| | | *Player B* | |
|---|---|---|---|
| | | Adopt | Wait |
| *Player A* | Adopt | (2.83 ; 2.83) | (5.67 ; 0) |
| | Wait | (0 ; 5.67) | (8.43 ; 8.43) |

The second scenario occurs when the flows generated in the first-year increase. In this scenario, the earnings matrix allows us to observe several characteristics of the nature of the market and the nature of timing. The company that adopts the first one makes the highest gains: this is the advantage of FM. However, as shown in the matrix below, the state (adopt, wait) is not a state of equilibrium. The other company will rationally decide to compete by choosing the decision to adopt in all cases. Thus, adopting is the dominant strategy for both players. In addition, we also note that balance (adopt, adopt) does not yield the highest possible gains to both parties. Both companies can earn a higher gain by choosing to wait together during this period. This is the classic dilemma situation of the prisoner. However, this is not a stable state of equilibrium, as either company is always strongly encouraged to deviate to win the AFM. Can the repetition of this game bring us back to the same state of balance or can it lead us to the game *Tit for Tat:* it is the object of scenario 3. The game *Tit for Tat* or the strategy cooperation-*reciprocity-forgiveness* or more simply "giving *give"* means reacting to cooperation by cooperating and reacting to defection by defecting. According to its first formulator Anatol Rapoport (1979) and his successors Axelrod and Hamilton (1981), this is the most effective strategy of behavior towards others.

**Table 3:  Scenario 2: Prisoner's Dilemma 1**

| | | *Player B* | |
|---|---|---|---|
| | | Adopt | Wait |
| *Player A* | Adopt | (6.36 ; 6.36) | (12.71 ; 0) |
| | Wait | (0 ; 12.71) | (10.51 ; 10.51) |

**Table 4: Scenario 3: Prisoner's Dilemma 2**

| | | *Player B* | |
|---|---|---|---|
| | | Adopt | Wait |
| *Player A* | Adopt | (11.64 ; 11.64) | (23.28 ; 0) |
| | Wait | (0 ; 23.28) | (13.63 ; 13.63) |

***H 7*** : **if according to the first prisoner's dilemma (PD) decision-makers choose inefficient balance (adopt, adopt), then repetition in Scenario 3, can take us back to the game "Tit-for-Tat" where waiting is the best strategy**. In fact, subjects may realize that their simultaneous and uncoordinated individual actions can only assure them of a lose-lose collective result.

Another hypothesis worth trying to test is the relationship between risk aversion and cooperation in a PD game. To date, some researchers have reported negative correlations between risk aversion and cooperation in a PD. De Heus et al (2010) found a slightly negative and non-significant correlation in a one-shot set of PD with an average cooperation rate of 53%. Sabater-Grande and Georgantzis (2002) reported a significant negative correlation in an environment with an average cooperation rate of 47%. These studies were conducted in situations with medium to low co-operation rates. Gluckner and Hilbig (2012) have shown that risk aversion can also reinforce the cooperation in a game of PD, if the environment of the game is conducive to cooperation, so that cooperation constitutes the predominant and expected behavior. The authors hypothesize that the relationship between risk aversion and cooperation is reversed in an environment with high co-operation rates, as defection would lead to greater variability in outcomes in such environments. Also, risk aversion induces an incentive to avoid the subjective risk inherent in such variability. We then hypothesize:

**H 8: Risk aversion reinforces immediate adoption in a game of PD.**

The latter hypothesis compares ANT's behavior in both market structures. According to the RO theory, if companies tend to defer their adoption decision in a monopolistic structure, their decision may change when they are exposed to competition and a pre-emption balance appears, especially when it comes to the AFM. The game of "war of attrition" predominates if another NT will come (Huissman and Kort, 2004). As a result of competition, companies are rushing to exercise their options as soon as possible. The resulting rapid balance destroys the value of the waiting option and implies violent investment behavior (Arasteh, 2016). In our experience and in both market structures the expectation ensures the maximum gain in the market, but the individual gain reaches its maximum when a single firm hastens to adopt and therefore cancels the gains of the other company.

***H 9*: A preemption game governs scenarios 2 and 3.**

In parallel with game 1, we are also studying the effect of the increase in the number of projects on decisions that are made both simultaneously and sequentially. Subjects are reduced to choosing between two or three projects, a single project either A, B or C.

***H 10*: According to these assumptions and referring to the HK model (2004), the pre-emption game can be transformed either into an FM and SM game or into a "war of attrition" game when the number of NT increases.**

## II - Analysis of experimental results

The experimental sessions were conducted in January and February 2020 at the Tunis Graduate School of Business (ESCT, University of Manouba) and the Graduate Institute of Business Studies in Carthage (IHEC, University of Carthage). The experimental protocol was programmed with the software "z-tree" developed by [11]Fischbacher (2007). Fifty-four subjects participated in these experiments. The sample consists of 28 students and 26 students with an average age of about 22 years. Participants were mainly students from the Manouba Higher Institute of Multimedia Arts (28 students), ESCT (14 students) and IHEC (12 students). We note that students who participated in these experiments have no theoretical or practical training on actual options. We organized 6 sessions. Three sessions were devoted to Game 2, two sessions for game 1 and one session where 6 students played Game 1, then 6 other students joined the group for game 2. In game 1, we look at individual choices, the gains made depend solely on the participant's behaviour towards a choice conveying a certain level of uncertainty. For game 2, we study strategic interactions, the gains made depend on the choice of two players who decide simultaneously. Each session consists of at least one treatment. The whole treatment is a game with 10 repeated periods. Each session lasted between 30 minutes and 90 minutes depending on the number of treatments.

Upon arrival, participants are randomly assigned to a computer. Students are informed first, whether for Game 1 or Game 2, that the experience consists of four games. They first receive instructions (either from Game 1 or Game 2). All instructions are distributed and read publicly.

[11] As it was the first time and as it was the exam period, whether at the University of Manouba or Carthage, as these experimental games took place, it was not easy to convince and find students willing to participate.

These instructions do not provide any information on the rules governing the subsequent parties. The purpose of this procedure is to prevent players' decisions from being influenced by the rules of subsequent parties. We were reassured that these instructions were well understood by all subjects. They have been asked to raise their hands in case they have any question and the answers are given privately by the experimenter. In addition, before starting the game, participants complete a pre-experimental questionnaire to ensure that the rules of the game are properly understood.[12]

After the computerized experiment in the first part, the second is to measure the degree of risk aversion of the participants, replies the standard protocol of Holt and Laury (2002). In this test, participants make ten sequential choices between two lotteries: Option A and Option B. Each option can yield either a high gain or a small gain. For the ten decisions, the gains associated with the two options are unchanged, but it is the probabilities of obtaining the high gain that increase from one decision to the next. The high and low earnings amount to 2 DT and 1.6 DT for Option A. For Option B, the winnings are 3,850 DT and 0.1 DT. Option B is therefore riskier than Option A. For the last decision or the last choice, both options pay for the high gain for sure. Participants' degree of risk aversion is inferred from the decision to which they change their choice from Option A to Option B. Given the parameters associated with both options, risk-neutral subjects select Option B from the fifth decision. Subjects who change their decision earlier in the game have a taste for risk, while those who still select Option A in the fifth decision are risk averse.

The third part is devoted to the response to the cognitive reflection test. The session concludes with a post-experimental questionnaire to collect the socio-demographic characteristics of the subjects, as well as information on how the experiment works.

In order to eliminate the effects of wealth, it has become increasingly common in economic experiments to pay only for a randomly chosen decision, once all data is obtained, (Holt and Laury, 2002; Humphrey, 2004). This random payment method allows you to observe a large number of individual decisions without supporting a high payment of all choices, and without reducing gains to a level that subjects could not take seriously. The assumption is that subjects will give the same importance and attention to all scenarios, since they do not know the exact scenario that can be paid for (Laury, 2005). This decision is selected by lottery for each

[12] See appendix III, V et VI

participant at the end of the session. Earnings are estimated, for each period, actually in Tunisian dinar. Added to this win is the winning of the HL lottery (2002) and a participation fee of 5 dinars. Earnings are paid in cash and privately at the end of the experiment.

The distribution of subjects in different treatments is summarized in Table 4:

**Table 5: Summary of Experimental Treatments**

| Information/games | Game 1 | Game 2 |
|---|---|---|
| **Treatment** | 3 | 5 |
| **Group number** | 18 | 21 |
| **Participants/group** | 18 | 2 |
| **Periods** | 10 | 10 |
| **Observations** | 180 | 420 |

Using the results obtained in different treatments, we present successively an analysis of the results of game 1. We then look at an analysis of the results of game 2 and conclude in a third section.

### II-1-Analysis of results of game 1

While theoretical studies have rigorously proven the argument of real options, it is not clear whether investors would actually delay a plan to adopt a new technology with a positive net present value (NPV), on what condition does an investor agree to postpone his adoption decision to a future date and what is the strategy chosen in the face of an uncertain environment?

Game 1 allows us to reproduce an artificial situation to answer these questions and consequently *"speaking to theorists"* developed by GW (1997). Three treatments are developed. In a first treatment, participants must decide to adopt two products from two products, but they come on two different dates. In fact, it is a matter of deciding the timing of adoption of the two products, otherwise choosing two decisions from four choices. The control variable is the value of the project that increases offering more gain if the decision is postponed, while NPV of the investment was immediately positive. The second treatment increases the number of products, while still retaining the obligation to choose only two projects. In this case, participants must decide which projects to choose without resolving the uncertainty. This assumption is relaxed in the third treatment and the investment decision may be deferred to the first period until the uncertainty about future flows is resolved.

In this part of analysis, we opt for a graphic analysis, first graphic and then econometric, thus joining one of the founders of experimental economics (Vernon L. Smith). According to Montmarquette (2008): "I would say that Smith is right to insist on the value of a good graph to clearly present the results of an experiment." We also introduce an initial classification of our results according to the algorithm ID3 ("Iterative Dichotomiser 3") which is a classification algorithm in the form of a decision tree.

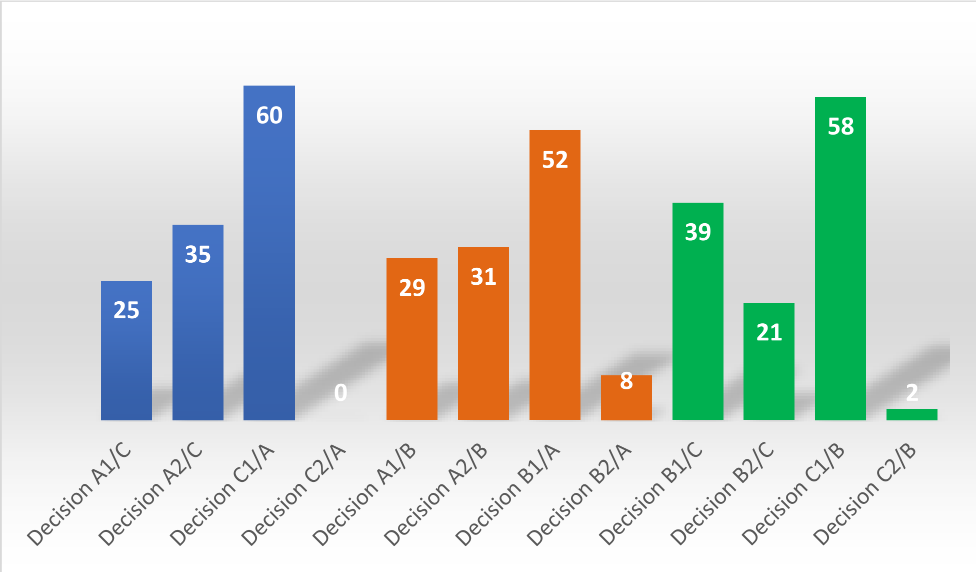
### II-1-a- The choice of two projects from four choices

In this treatment, participants must first decide to accept the acquisition of products A and B that are available either immediately (note 1) or in the following period (note 2) with different values. In other words, for products A and B (for example), the subject must choose either A1, A2 and B1 or B2. The same goes for product couples (A, C) and (B, C). We note these games respectively by: 1AB game, 1AC game and 1BC game.

***Result 1:*** Individuals are showers to losses, between 67.5% and 80% of the choices focus on certain decisions, which verifies hypothesis 1. However, the use of uncertain decisions was not negligible.

***Support 1:*** Figure 2 below represents aggregated data from six subjects over ten periods, 120 decisions. We note that in this decision-making process the use of immediate adoption (i.g. adoption in phase 1 for each project) increases from 67.5% in the 1AB game, to 70% in the 1AC game, to reach 80% in the 1BC game. On the other hand, the adoption percentage in the second phase decreases from 32.5% for the 1AB game to 30% for the 1AC game and will take its lowest value of 20% in the 1BC game. The subjects making the uncertain decisions, in the three games, are covered by the immediate decision ensuring a certain gain (B1 for the game 1AB and C1 for the game 1AC and BC) to be able to support "psychologically" risky decisions. The adoption of this strategy is all the more important when one project ensures significant value, while the other encloses a weak immediate NPV. Overall, decision A2 was more in demand than decision A1. In the same vein, the B2 decision had only 6% of the participants' interest in the AB game, however exceeded 17.5% in the 1BC game. This jump, which we think was important, was well below the adoption percentages of the A2 decision in the 1AB game with 26% and in the 1AC game with 29%. A large gap between project values can create an incentive to build a portfolio of risky and non-risky projects. It thus shows that intuitively and globally reasoning by real options may exist or may seem like a risk management tool for those looking for opportunities for a significant gain.[13]

**Figure 2: The distribution of decisions in T1**



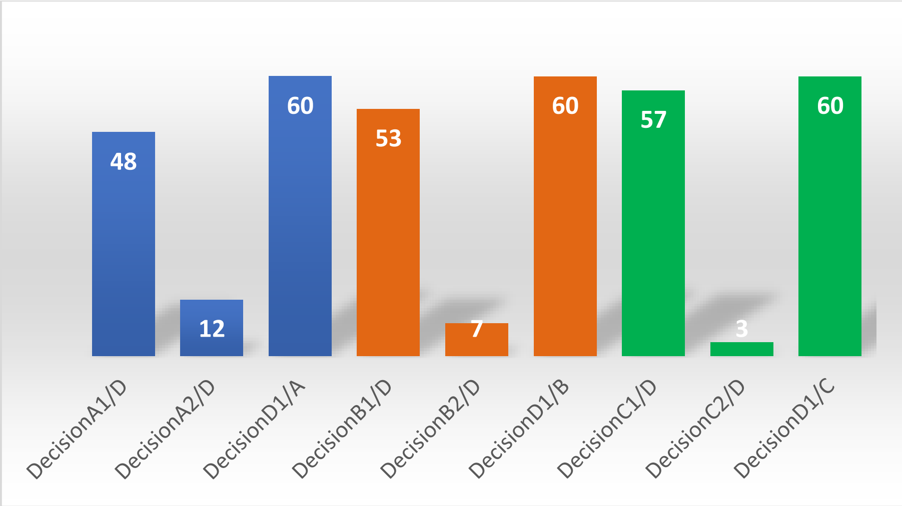

Based on this analysis, can we speak of a reasoning by the RO when it is a single project ? To answer this question, we introduced product D with a low value and that only comes up immediately. Product D takes the case of an old technology whose gain is well estimated. Participants are brought back to choose given the following couples (A, D), (B, D) and (C, D).

Figure 3 confirms the result already demonstrated. In the case of a single project, we agree, the majority of empirical research, whether experimental or econometric, confirming either the absence or a minority used the or analysis. While the percentages of B2 and C2 choices were negligible, the A2 decision with the lowest project value (A1) was only 10%. Risk-taking in this case does not seem to be a good strategy for participants, even though the value of Project A in the second period is almost tripled. Uncertain future incentive, even if it is important, cannot be effective or even acceptable unless a current minimum of satisfaction is assured. At this level an important question arises, if in itself the monetary incentive seems insufficient what other factors can hinder or induce individuals to overcome a risky decision? Most experimental research has focused on the importance of risk aversion and gender. Recently, the focus has been on a rather psychological factor of assessing the tendency to use intuitive or

[13] Montmarquette (2008).

analytical thinking, or the ability to delete a false intuitive answer and replace it with a correct answer. This is the Cognitive Reflection Test (TRC) developed by Frederick (2005).

**Figure 3: The distribution of T1-1 decisions**




### II-1-b- The choice of two projects between four projects without waiting

In order to answer the question of the last paragraph, we have developed a second treatment. In this treatment, the number of projects available is now four. These are both the three A, B, C products available over two periods and product D with a single period. This treatment aims to test the effect of a larger number of projects on the decision-making process. Twelve students participated in this treatment: the six participants of the first session who have already played the first treatment, and six new participants. The latter have directly played this treatment as we note 1ABCD game. During this treatment participants make adoption or non-adoption decisions before the true value of the project is revealed.

***Result 2:*** Many projects promote the adoption of projects with immediate high values. In this case, decision-makers do not intuitively recognize the value of waiting for the same project and generally opt for compulsive strategy. We confirm the first part of Hypothesis 2.

***Support 2:*** Before starting the analysis, it is important to check whether Group 1 has experienced a learning effect on these decisions in the 1ABCD game. To do this, we can chart below the distribution of the different decisions by group.

Figure 4: The distribution of decisions of game 1 ABCD/ Group 1

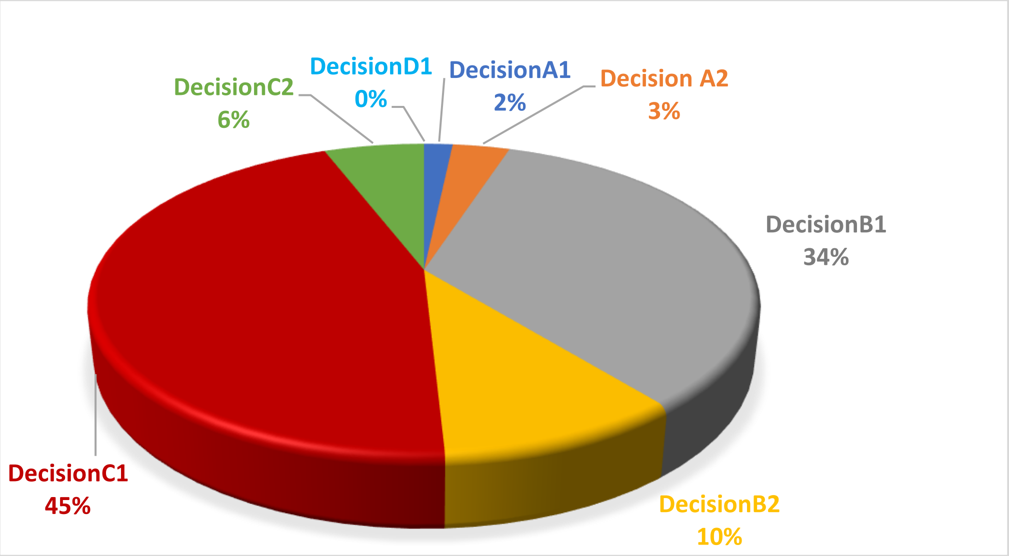
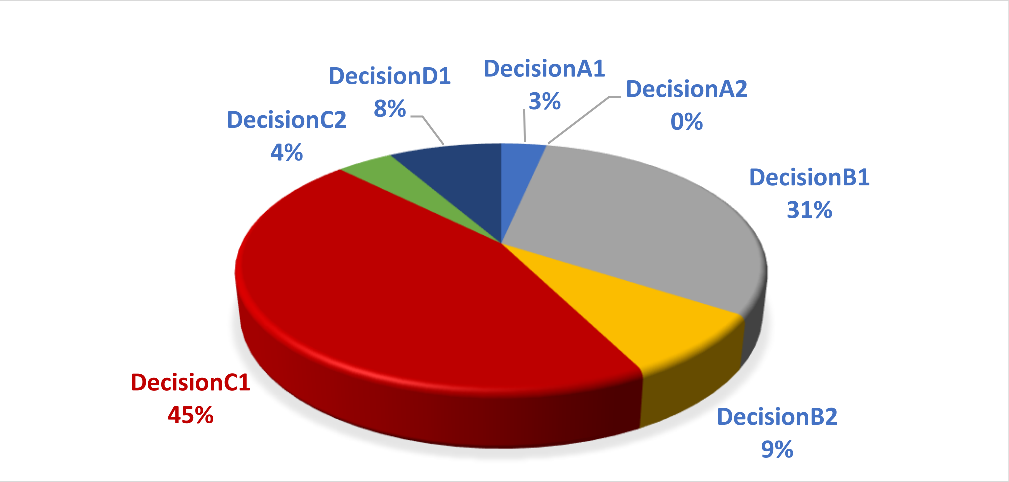



Figure 5: The distribution of decisions of game 1 ABCD/Group 2




We note that there is a very small difference between the two groups. The Wilcoxon[14] test confirms the null hypothesis involving the absence of a learning effect. The descriptive characteristics[15] of our sample, which consists of 42% female and 58% male, are summarized in Table 4:

[14] To do this, we add a binary variable indicating whether the subject has already played or if he is playing for the first time.

[15] See appendix for risk aversion classification and TRC responses.

## Table 6: Sample descriptive statistics

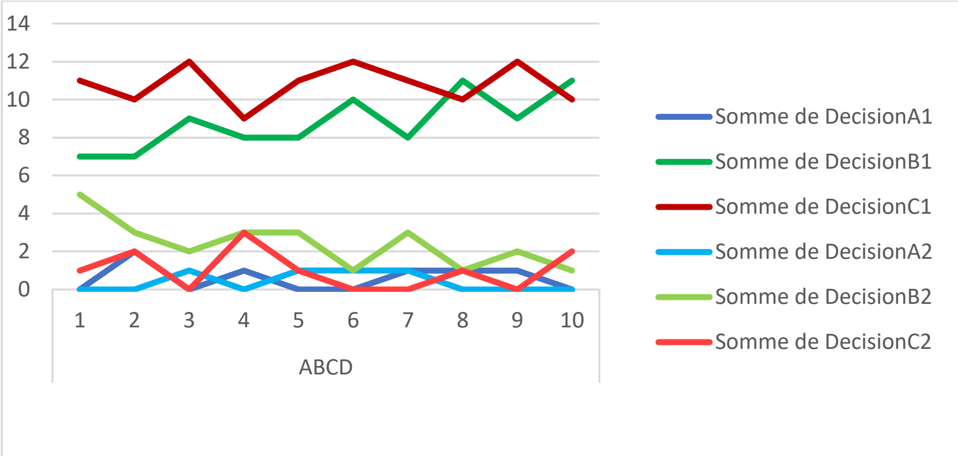
| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| TRC | 12 | 0.75 | 0.9251756 | 0 | 3 |
| AR | 12 | 6.25 | 1.480563 | 3 | 9 |

This table shows that the population studied is on average risk-averse and has a tendency to use system 1. This system in most cases provides quick and non-correct intuitive answers, rather than thought-provoking analytical answers. It should be noted that only 8% give three correct answers and 92% give at least one wrong answer. Frederick's (2005) study of a population of more than 3,000 Americans shows that 17% correctly answer the three TRC questions. De Neys et al (2013) find that 83% of subjects providing false answers to the first TRC question had total confidence in having correct answers. Regarding the AR variable, 8% are risk-seekings. The choices of this population over the ten periods are shown in Chart 5. A careful observation of this graph reveals the following information summarized in Figure 6.[16]

Decisions B1 and C1 are the most preferred for most subjects. While decisions are stable, other decisions have two different levels depending on whether one is at the beginning or the end of the period. The choice of C1 is relatively stable over the ten periods. On the other hand, the choice of B1, which did not attract the interest of most decisions at the beginning of the first and second period, ended up joining the values reached by the choice of C1. This phenomenon is known to experimental economists as the "end effect". This effect is defined as the change in subject behavior between the first and last periods. During these early periods, some participants tended to make risky decisions, which explain the evolution of the B2 curve. This decision, in contrast to decision B1, is on a downward trend at the end of the period. The choice of other A1, A2 and C2 decisions remains very limited, stable and sometimes takes zero value in certain periods.

[16] The choice of decision D1 is negligible over the ten periods compared to a total of 120 decisions and therefore strategies based on the adoption of old technologies are not included in our experimental results. We then neglected Project D, which only takes one period (which allows us to focus on two-period projects)

**Figure 6: The decisions of Sample 1**




In each period two decisions per subject are allowed. The cross table 5, helps us to understand the pairs of decisions made overall over the ten periods.

**Table 7: Adopted strategies**

| Strategies adopted | | Project B | | Project C | |
|---|---|---|---|---|---|
| | | B1 | B2 | C1 | C2 |
| Project A | A1 | 0.8% | 0% | 4% | 0% |
| | A2 | 0.8% | 0% | 4% | 0% |
| Project B | B1 | | | 68% | 3% |
| | B2 | | | 16% | 3% |

According to this table, 90% of decisions focus on the two projects B and C and 8% on projects A and C. Of the 92% of decisions based on the choice of C1, or the decision ensuring the highest immediate gain, 20% of the decisions are accompanied by risky decisions. This rate is considered generally acceptable for a risk-averse population. Based on this interpretation, we categorized the decisions made by participants in each period as strategies. This categorization is based on the most important percentages and the use of risky decisions. We identify two main strategies. The first is the compulsive strategy of choosing two projects successively such as A and B or B and C. The second is the *leap-frog* strategy when it comes to choosing a first project, rejecting the second but choosing the third, this is the case of A and C. We define four strategies:

- The *leap-frog* strategy (rated StrgLf1): corresponds to the choices of projects A and C. In this case, we focus on the "A2-C1" decisions. On the one hand this strategy contains a risky decision and on the other hand the choice of A1 is negligible along the 1ABCD game.[17]
- The risk-free compulsive strategy (rated StrgCp0): corresponds to the choices of projects B and C in their early phases. In other words, these are the "B1-C1" decisions. This strategy accounts for 68% of participants' decisions over the ten periods.
- The compulsive strategy with a risky project (rated StrgCp1): corresponds to the choices of projects B and C, but with the decisions "B2-C1" or "B1-C2". This strategy ranks as the second most chosen strategy and contains a risky project.
- The compulsive strategy with two risky projects (rated StrgCp2): corresponds to the choices of projects B and C but with two risky decisions that are "B2-C2", hence its peculiarity.

To understand the behavioral characteristics of the choices of these strategies, we opted for an econometric estimate. Each strategy is then equated with a binary variable taking value 1 if adopted and value 0 if it is not. Our experimental data is characterized on the one hand by a binary dependent variable and on the other hand players are led to decide between several choices over ten periods. The appropriate model for these characteristics is mixed-effect logistic regression in panel data. Mixed logistic regression is also seen as an extension of generalized linear models to include both fixed and random effects (i.e. mixed models). In the case of panel data the integration of the random effect is very important to avoid the problems of self-correction and take into account the different sources of variability. The peculiarity of this method of regression stems from its ability to take into account the different distributions other than Gaussian distribution; such is our case of binary logistic distribution. We briefly outline his formulation assumptions. The method is based on the introduction of a function known as the "link". By posing that there is a linear predictor noted [18]$\eta$ which is the combination of fixed and random effects excluding residues:$\varepsilon$

$$\eta = X\beta + Zu$$

[17] The values used (0.1.2) in policy abbreviations indicate the number of risky projects for any strategy.

[18] To see Vermunt (2005) and Rabe-Hesketh And Skrondal (2012) for more analytical details on the model. Econometric estimates are made on Stata 16.0 software.

And by posing that there is a function $g(.)$called a link function that connects the dependent binary variable involving the predictor $p = P(Y = 1)\eta$, then the conditional expectation of our model is:

$$g[E(Y)] = \eta$$

$$\Rightarrow E(Y) = g^{-1}(\eta) = \mu$$

And of course: $Y = \mu + \varepsilon$ . Our link function is therefore the logistic function where Y and u follow Bernoulli's law of expectation $p$**:**

$$logit(p) = g(p) = ln\frac{p}{1-p} = \eta \Rightarrow Y^{*} = \mu + \varepsilon$$

$$\Rightarrow g^{-1} = \frac{p}{1-p} = e^{\eta} \Rightarrow p = \frac{e^{\eta}}{1+e^{\eta}}$$

The quantity $\frac{p}{1-p}$ defines what is commonly called *"odds ratio"*, in other words a chance ratio and so $Y^{*}$ is a latent variable. Thus, in our first estimate in panel data we assume $p_{it} = P(Y_{it} = 1)$: which refers to the probability of choosing the compulsive strategy by an individual i at the period t. The Likert scale at least risk-seeking at most risk-averse is used to assess the independent variable of risk aversion (RA). For the Cognitive Reflection Test (CRT), it is evaluated based on the number of correct responses. The estimate of this method in Table 6 shows that behavioral and gender variables significantly affect the decision to adopt the risk-free compulsive strategy. While the choice of this strategy increases with risk aversion, it decreases with the increase in test score of cognitive and female gender thinking. Although results on risk aversion and CRT are expected, such results do not support the majority of findings. In other words, it is women's decision-makers who prefer non-risky decisions more. Montmarquette (2008) suggests that in order to decide such a debate, which is not the objective of our study, sessions with similar participants were required.

**Table 8: Results of regression 1**

| | StrgCp0 (b/se) | StrgCp1 (b/se) |
|---|---|---|
| TRC | -0.487* | 0.538 |
| | (0.24) | (0.28) |
| AR | 0.293*** | -0.385*** |
| | (0.06) | (0.08) |
| GenderF1 | -1.298*** | 0.803 |
| | (0.38) | (0.43) |
| N | 120 | 120 |
| Wald chi2(3) | 24.050 | 32.892 |
| Prob > chi2 | 0.000 | 0.000 |

* p<0.05, ** p<0.01, *** p<0.001

Table 6 also shows a regression such that the compulsive strategy with a single risky project is the dependent variable. This estimate shows a reversal of the signs of the explanatory variables. The results also confirm that risk aversion is an important determinant that negatively affects risky decisions. Indeed, the investment in risky activity decreases significantly with the degree of risk aversion of the individual. However, it increases with the level of CRT and when the decision-makers are more likely to be women. Although the decisions of StrgCp1 do not exceed 19%, the estimate is of significant significance. This allows us to compare the effects of the variation of independent variables on the two strategies.

However, as explained above in the non-linear logistic regression model, it is difficult to interpret the coefficients of the explanatory variables. Indeed, the dependent variable is a latent variable: it is the logarithm of *"odds"*. What we want to see for interpretation are the effects on results such as probabilities (which measure the degree of certainty of the realization of an event) and not on the "*odds ratio"*. To do this, we move on to the analysis of marginal effects. This analysis shows, from Tables 7 and 8, that a subject with a single correct TRC answer has a 20% chance of choosing compulsive strategy with a risky project, compared to 66% for choosing the risk-free compulsive strategy. When all TRC responses are correct, the probability of opting for a strategy containing a risky project will reach 40%. On the other hand, it is the risk-seekings, only, who have a 40% chance to opt for the said strategy. This probability increases to 10% for high-risk-averse individuals, while 78% decide for a non-risky compulsive strategy.

**Table 9: Marginal effects for the dependent variable: StrgCp0**

```
. margins,  at(AR=(3 5 8)) at(TRC=(1 2 3))

Predictive margins                              Number of obs     =        120
Model VCE    : OIM

Expression   : Predicted mean, predict()

1._at        : AR              =           3

2._at        : AR              =           5

3._at        : AR              =           8

4._at        : TRC             =           1

5._at        : TRC             =           2

6._at        : TRC             =           3
```

| _at | Margin | Delta-method Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| 1 | .4957793 | .0296074 | 16.75 | 0.000 | .4377499 | .5538087 |
| 2 | .6201337 | .0369856 | 16.77 | 0.000 | .5476434 | .6926241 |
| 3 | .7803074 | .0461529 | 16.91 | 0.000 | .6898494 | .8707654 |
| 4 | .6625725 | .0391625 | 16.92 | 0.000 | .5858155 | .7393295 |
| 5 | .5691064 | .0640445 | 8.89 | 0.000 | .4435816 | .6946312 |
| 6 | .4703907 | .1063053 | 4.42 | 0.000 | .2620361 | .6787452 |

This econometric study shows the importance of the explanatory variables chosen for decisions in an uncertain environment. In fact, several questions arise as a result of this estimate. Are all the decisions of the risk-averse far from containing a certain level of risk? What about a risk-averse decision but with a high CRR score or what about a risk-averse decision maker but with a low CRR score. In our sample, the gender variable is significant; can we say that regardless of their RA and CRT, women tend to be in favor of an uncertain decision?

**Table 10: Marginal Effects for the Dependent Variable StrgCp1**

```
. margins,  at(AR=(3 5 8)) at(TRC=(1 2 3))

Predictive margins                              Number of obs     =        120
Model VCE    : OIM

Expression   : Predicted mean, predict()

1._at        : AR              =           3

2._at        : AR              =           5

3._at        : AR              =           8

4._at        : TRC             =           1

5._at        : TRC             =           2

6._at        : TRC             =           3

------------------------------------------------------------------------------
             |            Delta-method
             |     Margin   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         _at |
          1  |   .4055196   .0367938    11.02   0.000      .333405    .4776342
          2  |   .2525976   .0361215     6.99   0.000     .1818008    .3233945
          3  |   .1023877   .0310153     3.30   0.001     .0415988    .1631765
          4  |   .2094254   .0343086     6.10   0.000     .1421819     .276669
          5  |    .297026   .0642996     4.62   0.000     .1710011     .423051
          6  |   .4007686    .120151     3.34   0.001     .1652769    .6362603
------------------------------------------------------------------------------
```

To deepen our analysis, we propose an attempt to classify our sample by applying the ID3 algorithm, which is widely used in the field of "Data mining". With this algorithm we aim to partition our sample into groups, as homogeneous as possible, in the form of a tree. To build such a tree, we usually start with the choice of an attribute and then the choice of a number of criteria for its node. For each criterion, we create a node for the data that verifies that criterion. The algorithm continues recursively until the nodes of the data of each class are completed. This algorithm uses the concepts of entropy and information gain to choose the nodes of the decision tree. The most well-known entropy is Shannon's. It first defines the amount of information provided by an event: the lower the probability of an event, the greater the amount of information it brings. Thus, entropy E for a given set is calculated on the basis of the classification of the class of the fixed samples. The information gain is calculated by the following formula:[19]

$$G(D,A) = E(D) - I(D,A)$$

With: $$E(D) = -\sum_{i=1}^{k} p_i log_2(p_i)$$

[19] See Andrew Oleksy (2018)

$$I(D,A) = \sum_j \frac{|D_j|}{|D|} E(D_j)$$

In our case, since a good majority of the decisions taken were in favor of the absence of uncertainty, the classification is to divide decision-makers, either as risk-taking decision-makers (regardless of number of risky projects) that are noted DR1, or as non-risk decision-makers (with zero risky projects) that are noted DR0. So D is represented by either DR1 or DR0. The probability of class *i* in D is noted by $p_i$. $|D_j|$ represents the number of j value cases for feature A. $|D|$ refers to the number of all cases. $E(D_j)$ is entropy for the subset of the entire dataset having the j value for feature A. Our data results are:

**Table 11: Applying the ID3 algorithm**

| | $E(D)$ | $I(D,A)$ | $G(D,A)$ |
|---|---|---|---|
| **A=AR** | 1 | 0.42 | 0.58 |
| **A=TRC** | 1 | 0.8 | 0.2 |
| **A=Gender** | 1 | 0.98 | 0.02 |

We note from Table 9 that the risk aversion variable reports the highest information gain. Therefore, it appears as the root of our decision tree. We then build the branches of the tree according to the different values of the root variable. The D data set is divided into as many subsets as the discrete values of the chosen variable. For each subset must correspond to it a single value of the D class and that represents the sheet. The values for which the assignment of a decision is impossible, we take up the calculations of the information gains for the remaining variables. This process stops until it is no longer possible to create leaves.

The tree shown in Figure 7 summarizes the characteristics of our sample. They show that all those who are risk-seeking make risky decisions in most cases regardless of their CRTs. However, for those who are risk-averse, it is their CRT scores that will determine their involvement in strategies characterized by the absence of uncertainty. When decision-makers are both, either risk-averse, risk-averse or very risk-averse, and have a CRT of at least one point, they do approve of risky choices. Only the highly risk-averse make the least uncertain decisions even with low gains. They also reveal that the gender variable only occurs at the last level. Female decision-makers, who are risk-averse and have a TRC of one point, adhere to risk-free strategies.

To reduce the effects of uncertainty in decision-making, we assume in the following treatment that decision makers can wait for the uncertainty to be resolved after a period of time. Can this reasoning by the RO method lead to a change in the strategies adopted?

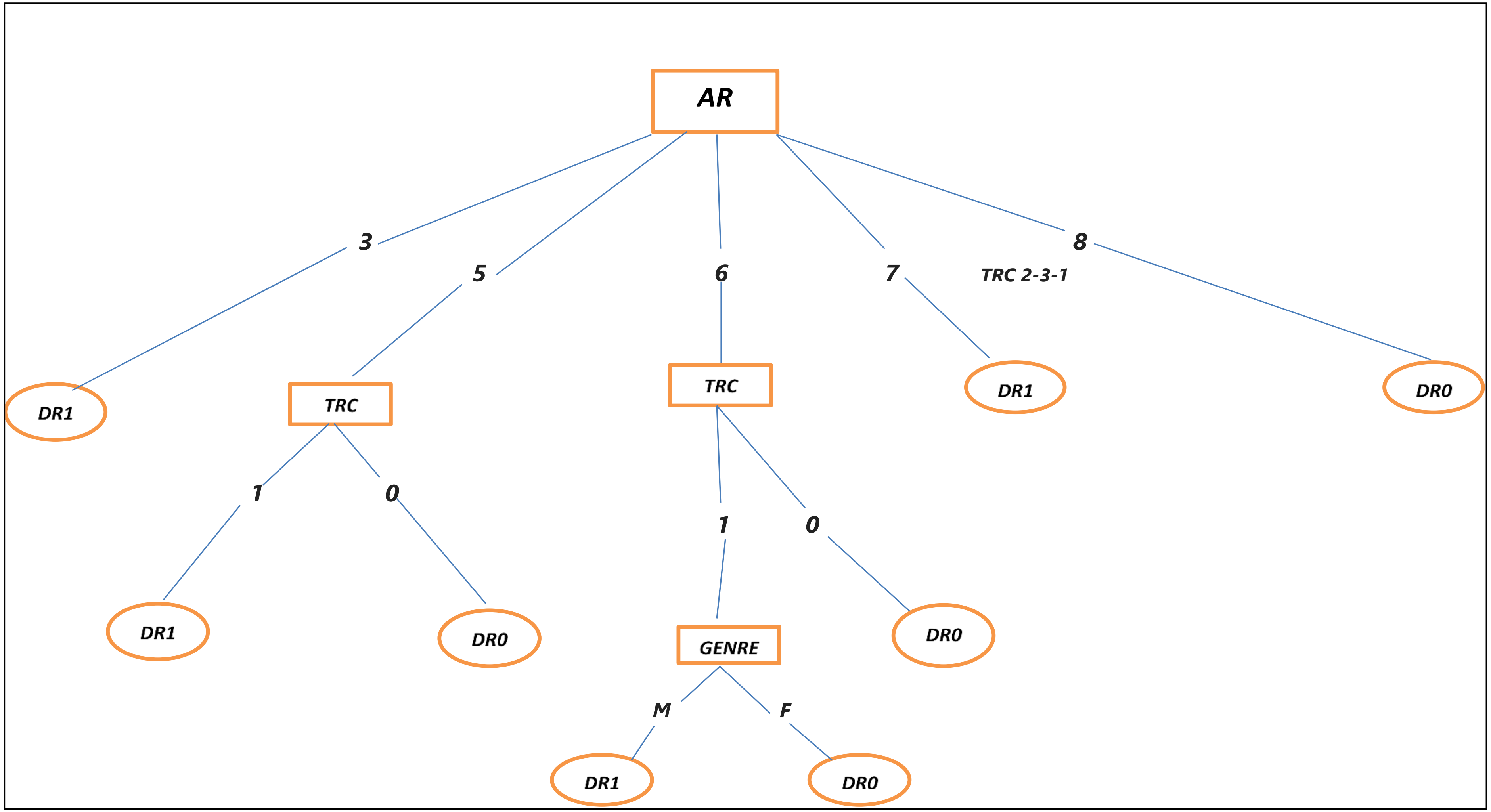



Figure 7: Applying the ID3 algorithm on decision-making

### II-1-c- The choice of two projects between four projects with waiting

We wonder in this treatment if the introduction of the wait can affect the strategies of the players. Always with the constraint of choosing two projects, participants, unlike the first treatments, can see the result of the coin toss and then they make the decision whether to adopt the project.

***Result 3:*** The OR approach strengthens the *leap-frog* strategy and therefore increases the gain. Those who opt for the compulsive strategy are the risk-averse. Risk-seeking decision-makers tend to adopt the *leap-frog* strategy.

***Support 3:*** Comparison of Figure 8 with the two Figures 4 and 5 shows stability in decisions A1, B2 and C2 against a very significant increase in the choice of decision A2. The choice of this decision goes back to 21% at the expense of decision B1 and C1. Although their shares, over the ten periods and for all participants, would still occupy the front rows. In addition we notice that all participants accepted project A2 when the positive gain. This mutation necessarily implies a new distribution of different strategies.

**Figure 8: The distribution of decisions with expectation**

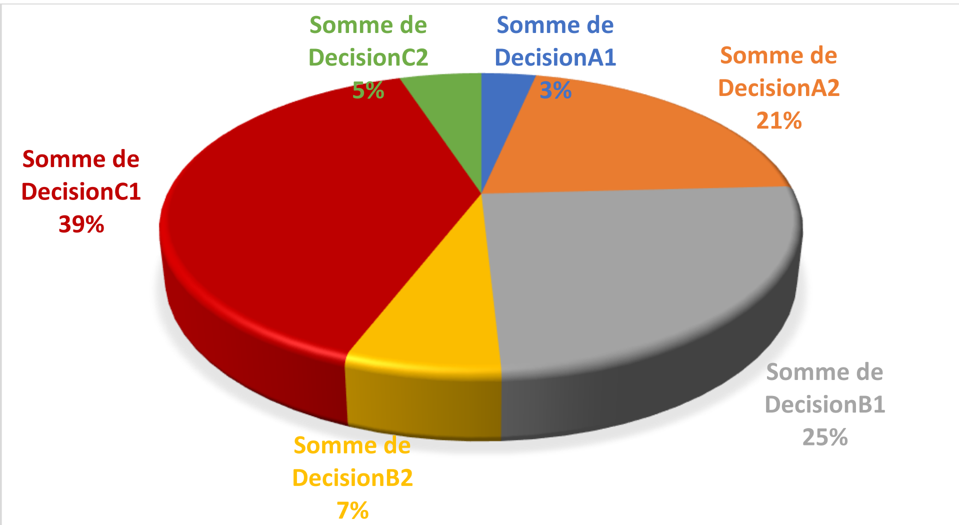


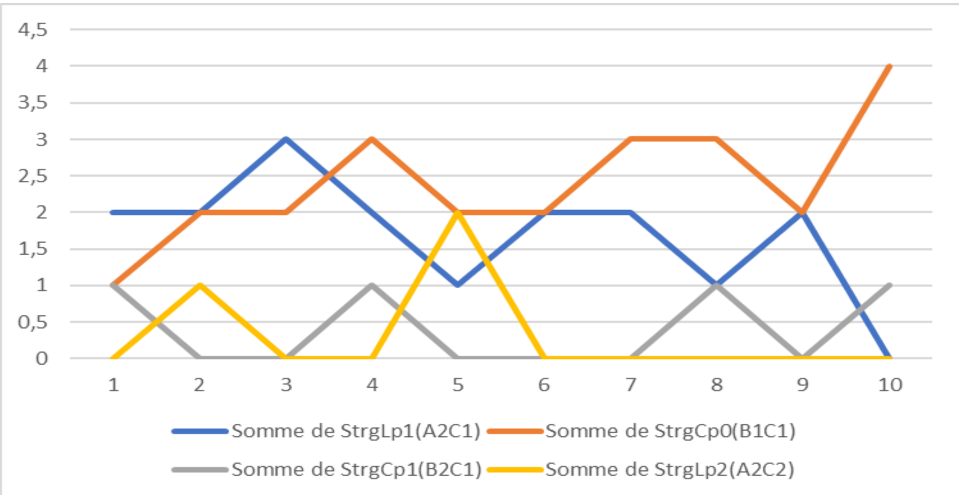

Table 10, compared to table 5, shows a marked increase in adoptions of strategies containing one or two risky projects. In fact, it is the wait-and-see strategy that can make risky decisions more apprehensive, resulting in a more controlled flexibility in accepting or rejecting projects.

**Table 12: The breakdown of the different strategies adopted**

| Strategies adopted | | Project B | | Project C | |
|---|---|---|---|---|---|
| | | B1 | B2 | C1 | C2 |
| **Project A** | A1 | 3% | 0% | 3% | 0% |
| | A2 | 5% | 3% | 28% | 5% |
| **Project B** | B1 | | | 40% | 2% |
| | B2 | | | 7% | 3% |

Figure 9 describes the evolution of the choice of different strategies over the ten periods. Individuals have a tendency to take the risk just in the early periods which explains the increase in the adoption of the *leap-frog* strategy. Rather, the end-of-period phenomenon is characterized by the dominance of risk-free compulsive strategy. It seems that this phenomenon (already existing in the previous game) is independent of the behavioral characteristics of the subjects. Compared to the previous sample, our sample in this treatment is more homogeneous with AR, but with a higher CRT as shown in table 11.

**Figure 9: The evolution of different strategies over ten periods**




Estimates have already been made that we can predict greater recourse to strategies that contain risky decisions, particularly because this uncertainty is partly resolved. Compared to the GW(1997) model, the dominant strategies are: first, the compulsive strategy and second, the *leap-frog*strategy. Members of the *leap-frog* strategy on one or two risky projects have a risk aversion of between 0.68 and 0.97 and have an average of 1 higher CRT.

## Table 13: Descriptive statistics on RA and CRT for different strategies.

| _chosen_alternative | AR | TRC |
|---|---|---|
| StrgCp0(B1C1) | 7.458333 | 1 |
| StrgCp1(B2C1) | 8 | 1.75 |
| StrgLp1(A2C1) | 7.058824 | 1.588235 |
| StrgLp2(A2C2) | 7.333333 | 1.666667 |
| Total | 7.354167 | 1.3125 |

For the following econometric estimate, we opted for the *panel-data-mixed-logit-choice model*. This model allows us to understand the choice of different strategies as a whole or in relation to a basic alternative (strategy). Mixed logit models have the distinction of using random coefficients to model the correlation of choices between alternatives. These random coefficients allow us to relax the independence of the irrelevant alternative hypothesis that is required by some other choice models. In addition, [20]the use of the mixed-effect logit model in panel data allows us to model the probability of selecting each alternative for each period rather than modeling a single probability to select each alternative (which is the case with cross-sectional data).

The results of table 12 significantly confirm the previous estimate for RA and CRT. An increase in CRT makes it more likely to choose riskier strategies either for compulsive or leap-frog strategies, rather than certain compulsive strategy. Conversely, an increase in RA makes it less likely that decisions are made uncertain, but of course encourages the implementation of a risk-free compulsive strategy. For *leap-frog1*strategy, the gender variable is positive, ensuring that female gender individuals are more likely to choose or proceed with such a strategy, rather than to compulsive strategy without risk.

[20] For more technical details see Han et al (2020).

## Table 14: Econometric estimate of "*Choice Models*"

```
Integration points:            0             Wald chi2(9)     =      30.64
Log likelihood =       -41.176045            Prob > chi2      =     0.0003
```

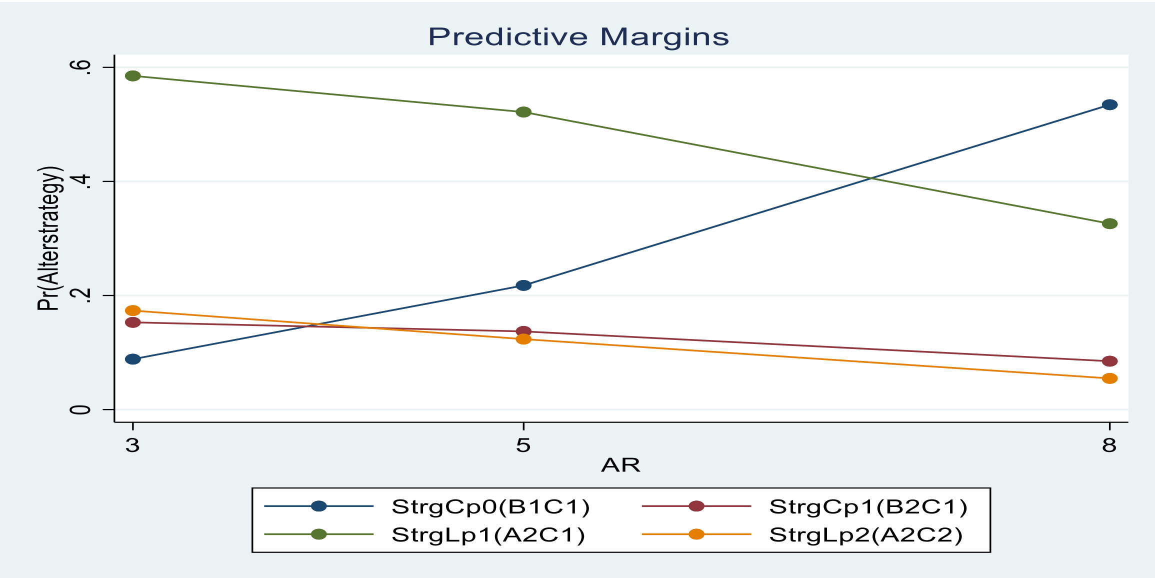
| decision | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| StrgCp0_B1C1_ | (base alternative) | | | | | |
| StrgCp1_B2C1_ | | | | | | |
| AR | -.5807847 | .2419698 | -2.40 | 0.016 | -1.055037 | -.1065325 |
| TRC | 2.376362 | 1.149509 | 2.07 | 0.039 | .1233664 | 4.629358 |
| Genre1F | -1.14717 | 1.280401 | -0.90 | 0.370 | -3.656709 | 1.362369 |
| StrgLp1_A2C1_ | | | | | | |
| AR | -.6042621 | .1839182 | -3.29 | 0.001 | -.9647352 | -.2437889 |
| TRC | 2.342811 | .8513193 | 2.75 | 0.006 | .6742558 | 4.011366 |
| Genre1F | 1.768588 | .8630271 | 2.05 | 0.040 | .0770856 | 3.46009 |
| StrgLp2_A2C2_ | | | | | | |
| AR | -.7072021 | .2654694 | -2.66 | 0.008 | -1.227512 | -.1868917 |
| TRC | 2.348121 | 1.190289 | 1.97 | 0.049 | .0151975 | 4.681044 |
| Genre1F | .4298158 | 1.248899 | 0.34 | 0.731 | -2.017982 | 2.877613 |

Post-estimate predictions show that, depending on the characteristics of our sample, 48% opt for the certain compulsive strategy and 36% opt for the *leap-frog* strategy according to the approach by the actual options. Compulsive strategy1 and *leap-frog2* strategy benefited by 8.7% and 6.5% respectively.

When all decision-makers are women, the choice of certain compulsive strategy represents 42% versus 58% when all decision makers are male. The latter choose the *leap-frog* strategy only in 15% of cases, while this same strategy will have a 48% probability of being adopted if all decision makers are women. However, predictions show that the riskiest B2C1 compulsive strategy, which at the same time can provide a significant gain over other strategies, represents a 19% probability for male decision-makers, compared to 3% for female decision-makers.

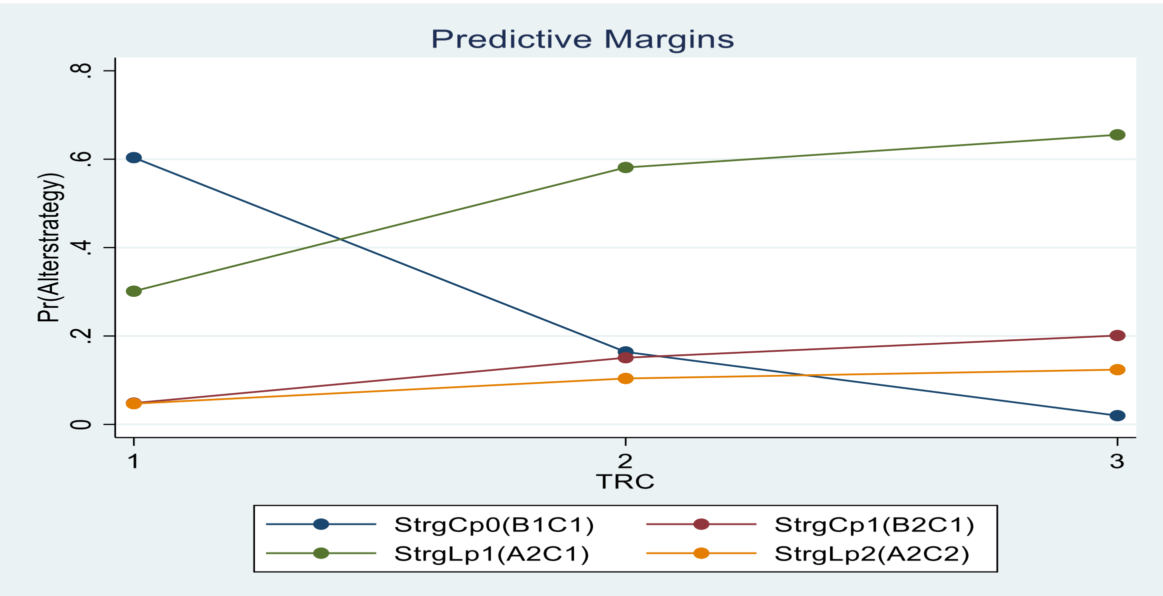
Figure 10 shows that the increase in RA increases the adoption of the compulsive strategy by 53% for risk-averse individuals, but it decreases the adoption of the *leap-frog* strategy. Risk-seekings choose this strategy in 58% of cases. Thus, we confirm the theoretical findings put forward by Chronopoulos and Lumbreras (2016) and Alexander and Chen (2019).

**Figure 10: Prediction between the evolution of RA and different strategies**




Conversely, this strategy is in increasing relation to the CRT. Those with the highest CRT value choose this strategy with a 65% probability.

**Figure 11: The effect of CRT variation on different strategies**




To conclude this first part, we can say that in the absence of a competitor in the market, the subjects choose to adopt, in most cases, projects with relatively large values, some and immediate. They project the expectation or practice of the method by the actual options for projects with low immediate values (with the aim of increasing their values). Thus, it seems that the real options approach promotes the *leap-frog* strategy that increases the gain by minimizing uncertainty. The RA itself is not a constraint for the choice of risky projects unless it is coupled with a zero CRT.

### II-2-Analysis of results of game 2

To configure the effect of competition on the adoption of new technologies as part of the real options approach, we consider that the decision made by one individual is affected by the decision of another individual. Their decisions are thus made simultaneously. We are drawing a competition of the monopoly; each group is then composed of two students. Students play in *"strangers"* mode where group members change after each period randomly. Compared to the *"partners"* mode whereby each group keeps the same members during all periods of the experiment, Weimann (1994) shows that *"partners"* and *"strangers"* generally behave similarly. Below we first show the results of the 2A, 2B and 2C games. Secondly, we analyze the results of the game 2AB and the game 2ABC.

#### II-2-a-Results of games 2A, 2B and 2C

During this treatment, the subjects were randomly matched with another participant and were asked to choose either "adopt" or "wait". In other words, both subjects are in a position to invest now, but they also have the option of deferring investment. We note that all participants are informed about the underlying assumptions and values, as well as financial incentives prior to the launch of the investment experience. However, to keep the information asymmetry hypothesis, subjects were not informed of the other person's choice prior to decision-making. It also reflects the idea that the company will make the decision without knowing what other companies will do and how they will react to its decision to invest.

In this context, we have developed two types of the game. The first game, 2A, is a simple stable Nash balance game. The second type of games, 2B and 2C, are two games of the prisoner dilemma.

Thus, the increase in the value of projects on the three treatments (2A, 2B and 2C) allows us to assess the effect of such an increase on the decision of subjects in other words on the waiting strategy. Thirty students played the 2A, 2B and 2C games. A first group of fourteen students, played in *"strangers"* mode and a second group of sixteen students, played in *"partners"* mode. We note that the subjects were not informed of the nature of the relationship with the other player.

### II-2-a-i- Game 2A Results

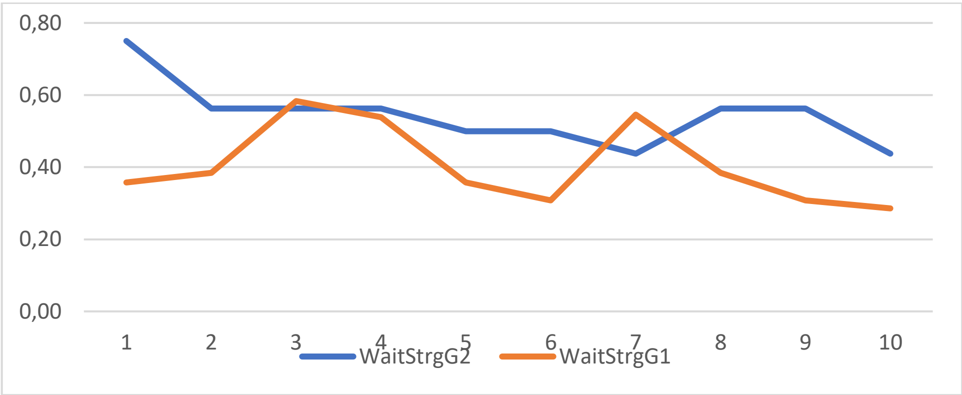
This first game, 2A, is a simple stable Nash balance game. In this game, theoretically speaking, none of the players has a motivation to deviate from the situation of balance. This scenario appears to be a coordinated strategy. Recalling, as we have already explained, that in this case, two situations of equilibrium arise: either (adopt, adopt) or (wait, wait). However, it is clear that the balance of expectation ensures more profit for both companies. In fact, can we expect such a result?

Regardless of the validity of Nash's equilibrium, we confirm Holt&Roth (2005) postulate: " *The Nash equilibrium is useful not just when it is itself an accurate predictor of how people will behave in a game but also when it is not, because then it identifies situations in which there is a tension between individual incentives and other motivations*".

***Result*** 4: The waiting strategy representing the stable Nash balance is not experimentally verified. The pre-emption game dominates from the fifth period. Assumption 6 is not verified.

***Support 4:*** It is clear from the observation of figures 12 and 13 that the maximum value of the choice of the waiting strategy peaked at 75% in the first period for the G2. This group that played in *"partner"* mode shows a waiting rate, on average 54%, significantly higher than the G1 with an average of 41%. While the decisions of both groups diverged in the first, second and seventh periods, both treatments experienced their lowest levels towards the end of the period. The G1 boxplot shows instability (distribution is more extensive) in making the waiting decision, in contrast to G2 decisions where decisions were more stable. Generally, in the majority of experiences and regardless of the mode of the game, individuals have a tendency to start by seeing if cooperation is possible. The G2 subjects sought this cooperation from the first period, while the G1 participants sought it a little later, in the third period. Often, individuals avoid starting a repeated game with uncooperative behavior in order not to jeopardize the chances of possible cooperation during the remaining periods of the game. However, at the end of the game we move further and further away from Nash's balance, even if Nash's balance is dominant. The fact that the subjects' decisions are different from Nash's balance revives the idea that experimental results do not verify theoretical predictions. These are therefore called into question and new explanations are advanced by the experimental method. This deviation from balance raises the question of the rationality of individuals. Waiting or adopting immediately is directly related to the risk aversion of the subjects. The waiter takes the risk of having his winnings equal to zero if the other player makes the decision to adopt immediately. This risk aversion is generally less present at the beginning and middle of the game, as the scenario described above can be repaired during the remaining periods of the game. The decrease in the choice of waiting strategy at the end of the game could therefore be due to the increasing distrust of the players and their risk aversion.

**Figure 12: The evolution of the wait strategy of G1 and G2**




Thus, to fully understand this irrational behaviour, we set out in the following table the psychological-behavioural characteristics of subjects in terms of risk aversion, TCR and gender.

**Figure 13: Boxplots of G1 and G2**

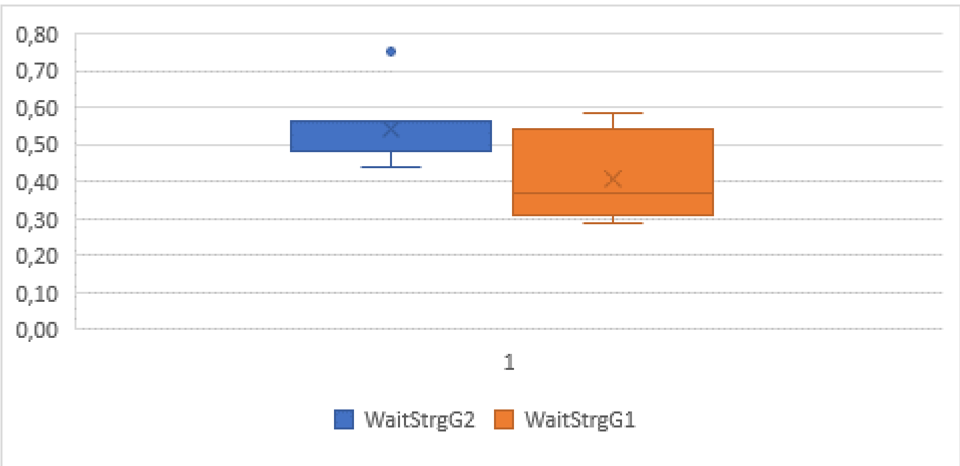



Table 13 shows fundamental differences in the characteristics of the G1 and G2. Indeed, the G2 enjoyed a higher CRT, at least risk-averse, more risk-seeking and more male gender with a game in *"partner"* mode. These characteristics lead to expectation strategies that tend more toward Nash's balance, without this trend being straightforward. This finding can confirm the results from Game 1. Those who make risky and wait-and-see decisions, in the case of a single decision maker, are either risk-seeking or risk-averse with at least one correct answer. It is also those who decide to opt for the waiting strategy when it is a dominant strategy.

**Table 15: The behavioral characteristics of G1 and G2**

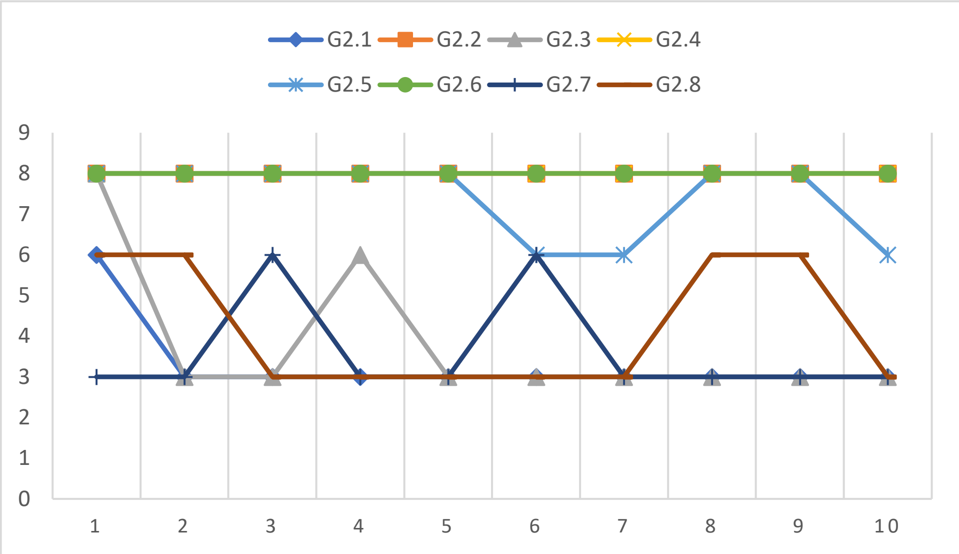
| | | Group 1 | Group 2 | Group 3 |
|---|---|---|---|---|
| **Kind** | Female | 50% | 31% | 75% |
| | Masculin | 50% | 69% | 25% |
| **TRC** | 0 correct answer | 79% | 25% | 41.5% |
| | 1 correct answer | 14% | 62.5% | 41.5% |
| | 2 correct answers | 0% | 0% | 17% |
| | 3 correct answers | 7% | 12.5% | 0% |
| **Ar**[21] | Risk-seeking | 14% | 25% | 8% |
| | Risk neutral | 21% | 25% | 8% |
| | Risk-averse | 65% | 50% | 84% |

It also turns out, however, that risk-averse with zero CRT have rather aggressive competitive behavior resulting, in most cases, in balance (Adopt, Adopter) and thus achieving the lowest gain. We then use a group behavior analysis that could clarify the details of this outcome.

Since the G1 has played in *"stranger"*mode, it is therefore impossible to report the decisions of these days. We represent in the graph following the G2, whose participants played *"partner"*.

**Figure 14: The evolution of the different gains of the subgroups G2 over ten periods**

[21] HL - 0-3: risk-seekings, HLL - 4: risk neutral, HLL - 5-10: risk-averse ( Holt and Laury (2002))




To represent this graph, we have opted for the following procedure:

- Value 3 represents the gain when both individuals in the same group opt for the immediate adoption strategy.
- Value 6 represents the gain when one of the two individuals in the same group opts to adopt immediately, while the other opts for waiting.
- Value 8 represents the gain when the two individuals in the same group decide to wait.

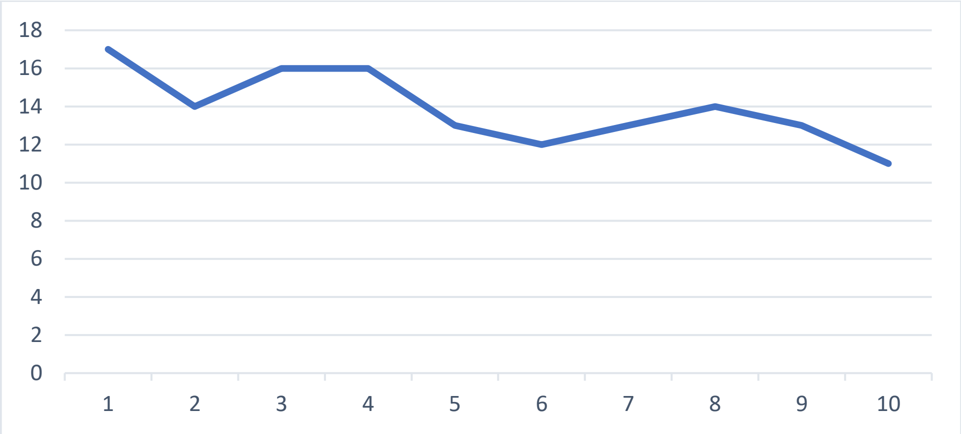
Figure 14 shows three types of subgroups in the G2:

- Groups 2.2, 2.3, 2.4, 2.5 and 2.6 started the game with the waiting strategy. However, it is groups 2.2, 2.4 and 2.6 that check Nash's stable balance over the ten periods. These groups consist of couples who are both risk-seeking or a risk-averse and has a CRT with one or three correct answers. This observation confirms at least in part our interpretation above.
- While for groups 2.1 and 2.8 only one individual who adopted the waiting strategy during the first period.
- The two subjects in group 2.7 opted for immediate adoption in the first period, and they kept the same strategy over eight periods, with the exception of periods 3 and 6. Groups 2.1, 2.3 and 2.8 also engage in this aggressive competition and opt in at least 80% of balanced choices (Adopt, Adopt).

An important question at this level is whether one player's previous strategy will affect the other player's current decision. To do this, we hypothesize that the mode of the game *"partner"* or *"stranger"* does not have a significant influence on the strategies of the players. For this purpose of estimation we create a new variable that allows us to take into account the other player's previous strategy for each group. This variable therefore reflects, for a player, the effect of an opponent's previous decision on his reaction function in terms of waiting strategy.

Over the ten periods, the evolution of individual choices for the waiting strategy for the thirty subjects is presented in Figure 15:

**Figure 15: The evolution of the waiting strategy**




In accordance with the experimental literature in this context, particularly with regard to cooperation in the game of public goods, the expectation decreases throughout the game. It starts at 57%, in the first period, on average 46% in rounds 2 to 9, and drops to 37% in the final period. This decline throughout the game leads us to believe that this learning could exist and that the ten periods of the game may not be enough to allow players to understand the strategic outcome of the game. Would the learning process then be a long enough process that requires a lot of repetition and additional information to be successful?

Econometric analysis of individual behaviors could inform us about this questioning. By incorporating the two groups of thirty individuals over the ten periods, we get Table 37. While the signs of variables reflecting aversion and cognitive ability (TRC) confirm the interpretations already deduced in Games 1 regarding the adoption of the waiting strategy, the sign of the gender variable is not stable compared to the previous games. The new variable built: "$OthStrg_{t-1}$"may reflect the notion of reciprocity.

According to Fehr and Gochter (2000), the founders of behavioral game theory, this reciprocal behaviour is explained by Fehr and Gochter (2000), that in response to good deeds or cooperative actions, individuals are often much more cooperative than the conventional model of self-interest predicts. Conversely, in response to hostile or unfavorable actions, they are often much more cruel and even aggressive. This description of player behavior allows us the following inference: remembering that the average rate of adoption of the waiting strategy in this game could not exceed 46.7% for a stable Nash balance. We can thus conclude that the minority, who opt for the waiting strategy, ensuring more profit, could not compel the majority who are in most cases risk-averse or have zero CRTs to choose the right strategy. On the contrary, in order to join the explanation of Fehr and Gochter (2000), this majority pushed the minority to be more aggressive.

The most recognized example of this aggressive competition in the monopoly sector is that in the aviation industry between the two major global companies Boeing and Airbus. Since 2006, Boeing has been talking about replacing Boeing 737 with a totally innovative design called "Boeing Y1". The pressure exerted by the airlines, for more energy-intensive aircraft, and the commissioning of the A320Neo by its competitor Airbus, which was originally scheduled for mid-2016 and was advanced to October 2015, have prompted Boeing to continue improving the 737 with new engines rather than embark on the new design of the "Boeing Y1". While Boeing's Research and Development Program has predicted that the 737 Max will offer 16% less fuel consumption than the current Airbus A320, and 4% lower than the Airbus A320neo, the 737 Max has completed two crashes with the death of 346 people.

**Table 16: Game 2A regression**

| | WaitStrg(M1) | WaitStrg(M2) |
|---|---|---|
| | b/se | b/se |
| AR | -0.264*** | -0.296*** |
| | (0.05) | (0.05) |
| OthStrgt1 | 0.275*** | 0.236*** |
| | (0.04) | (0.04) |
| Gender1F | -0.427 | |
| | (0.26) | |
| TRC | | 0.309 |
| | | (0.16) |
| N | 270 | 270 |
| Wald chi2 | 43.029 | 43.811 |
| p | 0.000 | 0.000 |

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

On December 16, 2019, Boeing announced that production of the 737 Max would be discontinued from January 2020. The final report of the U.S. Congressional Transport Committee "highlights five themes, starting with the strong financial pressure put on Boeing and the 737 Max program to move as quickly as possible in order to better compete with the Airbus A320Neo. This pressure has prompted Boeing to cut spending and maintain the production schedule at all costs." In 2019, Airbus replaced Boeing as the largest aerospace company and the 737 Max crisis has already cost it [22]nearly $20 billion.

In this game, with a theoretically stable balance, the adopters of the waiting strategy were 46.7%. What adoption rate can we expect if the game turns into a prisoner's dilemma game? The following section allows us to resolve this issue.

### II-2-a-ii- The Prisoner's Dilemma: Games 2B and 2C

The second type of game is the symmetrical prisoner's dilemma game, with complete and imperfect information. This type of game, 2B and 2C, illustrate that rational individual behaviours can go against the collective interest. In fact, this game is a dilemma since on the one hand, each player would find his interest in an orderly and simultaneous cooperation, but on the other hand, unilaterally deviating from the latter is profitable, which induces behaviors of the type stowaway. In Game 2A, the gain from the wait was on the one hand much greater than the win without expectation if both players decide to adopt immediately and on the other hand more than the gain of a single player if the other decides to postpone his decision of adoption. On the other hand, in Game 2C the gain of the wait, if both players decide to wait, is significantly less than the gain of a single player if he decides to adopt immediately and the other postpones his decision. This differential of winning in Game 2B is small, but it is more important than the immediate adoption gain by both players. This characterization helps us to measure the magnitude of the risk and the degree of claim of the waiting strategy in both games, according to Rapoport (1967), Au et al (2012).

***Result 5-1:*** the pre-emption strategy is most played especially for projects that are less risky and by the most risk-averse. This result confirms assumptions 8 and 9.

***Result 5-2:*** the repetition of the DP, for games 2A and 2B, does not induce the game "Tit for *Tat"*. Assumption 7 is not verified. However, we note that the waiting strategy is more adopted when the project is riskier and decision makers are less risky.

[22]*https://www.lemonde.fr/economie/article/2020/09/16/boeing-737-max-le-constructeur-et-le-regulateur-vertement-blames-par-le-congres-americain_6052451_3234.html *https://fr.wikipedia.org/wiki/Boeing_737_Max#cite_ref-18

***Support 5:*** Compared to Game 2A, the two groups maintained significant differences in their decision-making, although they recorded a decreasing rate of adoption of the wait policy (see four charts below) over the ten periods. Contrary to our expectations, both groups opted for the waiting strategy with a rate exceeding 50% but only during the first and second period of Game 2B. We then see a continuous and stable reluctance to choose this strategy for the 2B and 2C games, thus excluding the game *"Tit for Tat"*. However, this decrease was more significant for Group 1. The choice of waiting strategy has increased from 27% for game 2B to 12% for the 2C game. It should be remembered that group 1 is more risk-averse with a low CRT. Group 2 tried to keep the waiting strategy at an average level exceeding 50% for game 2B, also started the 2C game with this high optimism, although the expectation in this game does not bring a significant gain compared to the immediate adoption strategy, since this gain value (12) is very close to the optimal level of adoption. Overall, for both groups and both games, the preemption strategy is the most played. However, we note from the following graphs, that the choice of this strategy is more important in the 2C game. To explain this decrease in the involvement of each group in

**Figure 16: The choice of the Waiting Strategy by G2 for 2A, 2B and 2C Games**

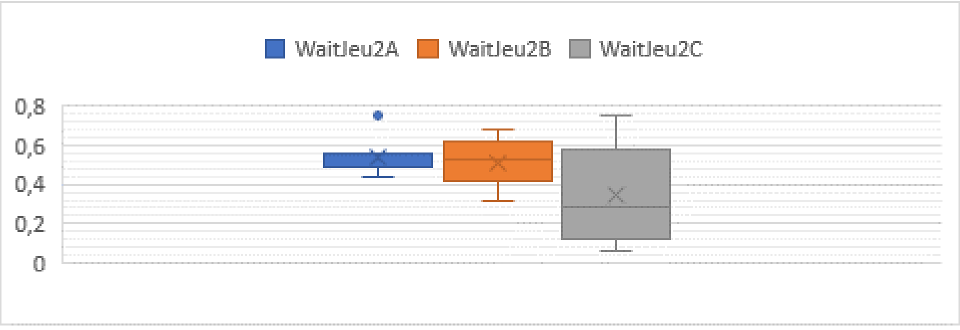



**Figure 17: The evolution of the waiting strategy by G2 for 2A, 2B and 2C games**

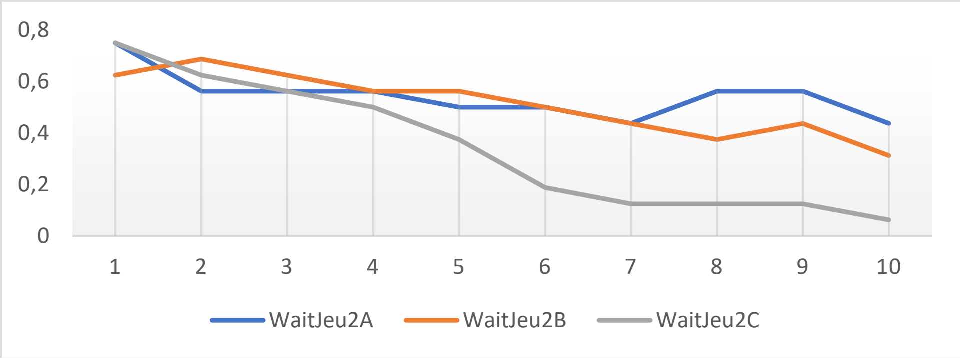



**Figure 18: The choice of waiting Strategy by G1 for 2A, 2B and 2C Games**

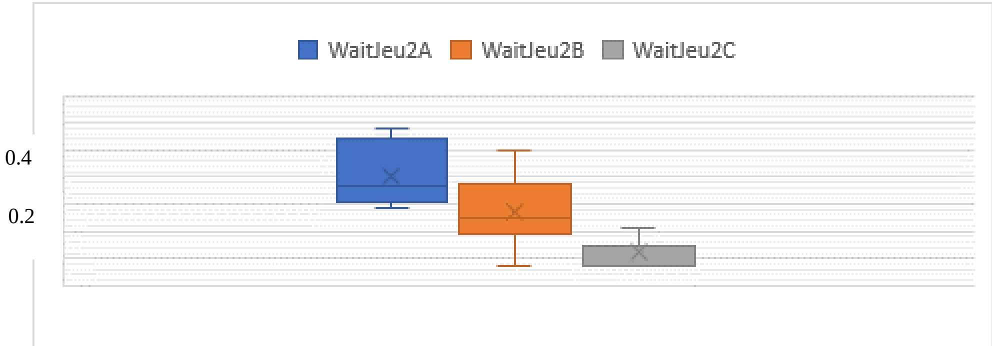
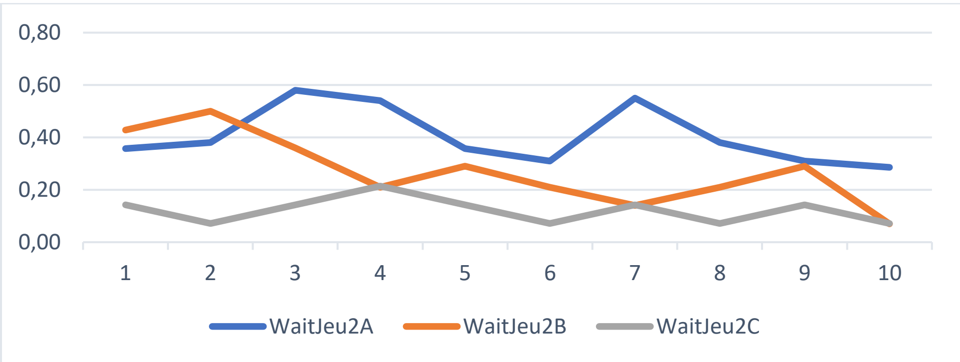



**Figure 19: The evolution of the waiting strategy by G1 for 2A, 2B and 2C games**




their choices in the two games of the prisoner's dilemma, we use the approach of Ng and Au (2015) which is based on the classic model of Rapoport (1967) and the coefficient of Au et al. (2011). According to Repoport, the prisoner's dilemma exists when the values in the table below verify the following relationship:

**Table 17: Repoport's Prisoner Dilemma Table**

| | | ***P1*** | |
|---|---|---|---|
| | | A | In |
| *P2* | A | (P, P) | (T, S) |
| | In | (S, T) | (R, R) |

The choice of the waiting or immediate adoption strategy exposes the decision maker to uncertain gains. However, and as explained above, the magnitude of the risk depends largely on the values of each of the strategies chosen. In other words, what is the riskiest strategy or what is the most appropriate strategy for each project? The choice of the waiting strategy exposes us to the uncertainty of having either S or R as a gain. In fact, the expectation leads to a very large variation in earnings, while the choice of adoption strategy exposes us to the uncertainty of obtaining either P or T. Using project values B and C, we calculated The Rapoport indices to determine the project for which the waiting strategy is more beneficial and the Au et al index (2012) to determine the riskiest project.

**Table 18: Rapoport and Au et al Indices of Projects B and C**

| **Projects** / **Index** | **Project B** | **Project C** |
|---|---|---|
| **Rapoport Index** | $K_B = \frac{R_B - P_B}{T_B - S_B} = 0.3$ | $K_C = \frac{R_C - P_C}{T_C - S_C} = 0.08$ |
| **Au et al index** | $r_B = \frac{R_B - S_B}{(R_B - S_B) + (T_B - P_B)} \approx 0.6$ | $r_C = \frac{R_C - S_C}{(R_C - S_C) + (T_C - P_C)} \approx 0.56$ |

Table 15 shows that Project B is the riskiest: $r_B > r_C$, therefore, the appropriate strategy is that of waiting since $K_B > K_C$ . This result explains at least in part the interest in the waiting strategy in Game 2B, especially for group 2 which is less risk-averse. While the commitment of risk-averse to the choice of waiting is limited and tends to disappear for less risky projects, risk-seeking are more committed to the waiting strategy when projects are more risky. However, they are experiencing a significant and rapid decline in the choice for Project C, which is less risky. This behavior could be a revision of the strategies played or learning over time. Players are led to understand that their dominant strategy is to adopt immediately, avoiding on the one hand having a zero gain and thus achieving a gain close to the optimal situation (for the game 2C).

Games 2A, 2B and 2C study the behavior of competitors when it comes to investing or postponing adoption in the presence of a single NT. With the increase in the number of projects available, can we expect a further deterioration or a strengthening in the choice of the waiting strategy? Can the FM and SM structure be foreseen or rather a more aggressive competition structure such as *the "war of attrition"?*

### II-2-b-Results of 2AB and 2ABC

Through the 2AB and 2ABC games, we want to study the behavior of competitors when two or three NT are available respectively. In the DP game, in the presence of an NT, companies are much more forced to choose immediately to avoid zero profit. In fact, several sectors, such as the ICT sector, are characterized by a rapid rate of the emergence of NT. All companies in this case have more likelihood or chance to make positive profits. The values of these two games partly reflect the tree in Figure 28 but with the existence of two projects and eliminating the possibility of rejection over both periods. The player, taking into account the behavior of his partner must decide only to buy a single project, either immediately or while waiting for the second period. Each player can understand the other's decision by observing their winnings for each choice. In this game (also the game 2ABC), the subjects play both simultaneously and sequentially. In other words, when making a decision about Project A, no player can see the other's decision. Once the choices are made, each player can see on the screen the decision of the other. This is a non-zero-sum game where each company can improve its profit without ousting the other's profit. Participants in these games are G2 subjects who have previously played 2A, 2B and 2C and twelve other topics that we call G3. The latter group started the 2AB game directly and they played the *"partner"* mode for the 2AB game, which makes it easier for us to compare the results of the two groups and the evolution of their decisions over the ten periods. For the game 2ABC, the same group played in *"stranger" mode.*

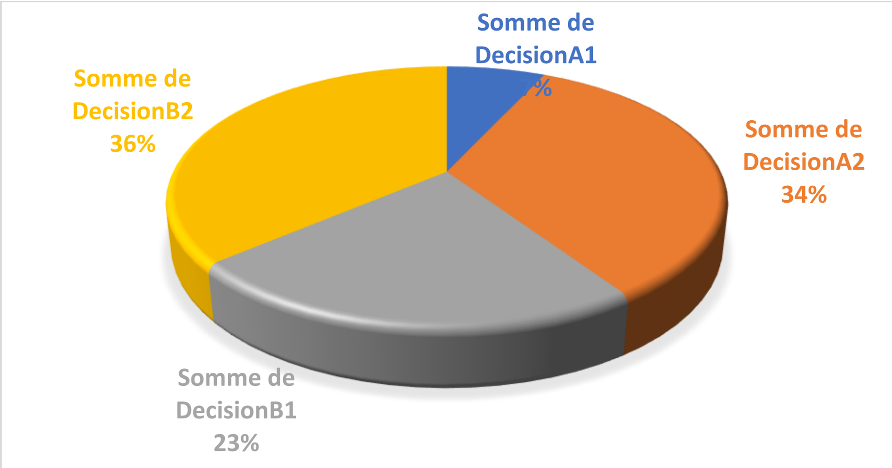
### II-2-b-i- 2AB Game Result

While in the DP game, no player has the opportunity to take advantage of the observation of the behavior of his competitor, in this game such luck may exist. Is it possible, therefore, to achieve a new, less aggressive competition structure? What behaviour can arise if the number of available technologies increases?

***Result 6:*** when the number of technology available increases the choice of waiting strategy can reach more than 70% on average. The deviation from the waiting strategy does not appear to be beneficial.

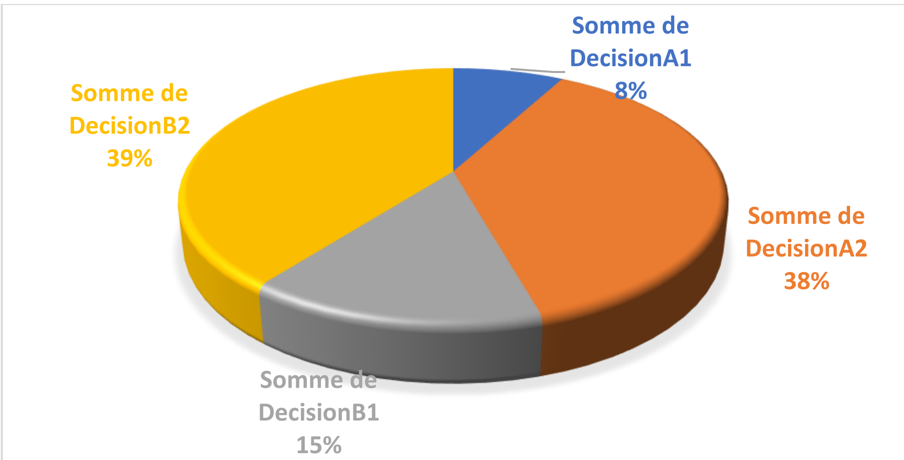
***Support 6:*** The choice of the immediate adoption strategy, whether for Project A or B, does not expose its decision maker to the risk of zero profit. However, the choice of the waiting strategy locks up such a risk but with a lower probability than the DP. The choice of waiting strategy was well maintained over the ten periods and there was no end-of-period phenomenon of previous games. In this game, the subject who decides to postpone his investment and wait will be able to observe what others will do. This will give him the advantage of having more information on which to base his decision. The characteristics of the subjects of both groups are summarized in Table 12. Group 3 is more risk-averse, with a low TRC below group 2 and with more female subjects. Figures 20 and 21 represent the results of the decisions of both groups. Because the results of the two groups are not different, we can see that group 2 has not experienced a learning effect.

**Figure 20: The results of Group 2 decisions**




As the two figures, 20 and 21, shows, the increased choice of waiting strategy suggests that the use of aggressive competition was limited. Players have, in most cases, opted either for *the Tit for Tat* strategy game or for the FM and SM strategy game. Through the *Tit for Tat* strategy we mean that players have imitated the action of their opponents after cooperating in the first round in the sense that the competitive reactions are reciprocal. Moreover, through the strategy of FM and SM we mean that the players have retained the same behaviors throughout the game. This game can also be considered a sex *battle* game where both players are encouraged to align their waiting strategies to avoid having lower winnings.

**Figure 21: The results of Group 3 decisions**

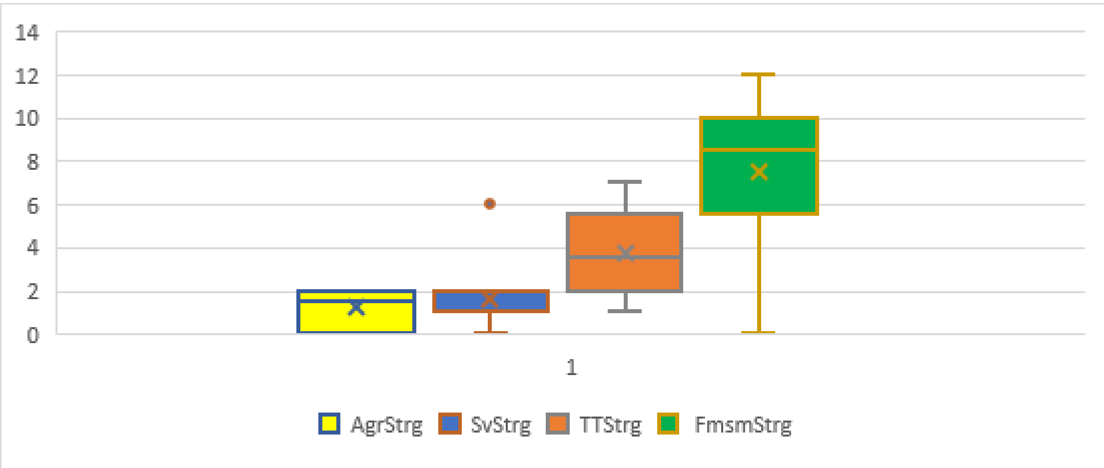


***Result 7:*** the waiting strategy arises in the FM and SM games: each company enjoyed a profit from the monopoly. This result confirms hypothesis 10. Thus the two results 5-1 and 7 check cases 1 and 2 of the Model Huissman and Kort (2004).

***Support 7:*** To demonstrate this result, we define the following strategies associated with the different decisions made by each subject at the fourteen group level over the ten periods since the groups are in *"partner"* mode:

- SvStrg: This strategy, which we call a rescue, occurs when both players reject Project A and both decide to immediately adopt Project B to avoid a possible cancellation of the gain of one of the days.
- AgrStrg: This strategy, which we describe as aggressive, is the opposite of the previous strategy. The gain of one of the players, when Project A is not adopted, is necessarily zero. The game, according to this strategy, appears as a game of war of attrition where each company must decide to reduce its losses and exit, or to solve it in the hope that the competitor will leave the market soon.
- TTStrg: This strategy is an attempt to request the cooperation or play of Tit for Tat following an aggressive strategy.
- FmsmStrg: This FM and SM strategy usually occurs as a result of the TTStrg strategy and one player maintains to have the highest gain, resulting from the B2 decision, and the other player accepts the winning of the A2 decision several times. In most cases, this game continues until the tenth period. We call FM the one who makes the decision B2.

**Figure 22: boxplots for different strategies**

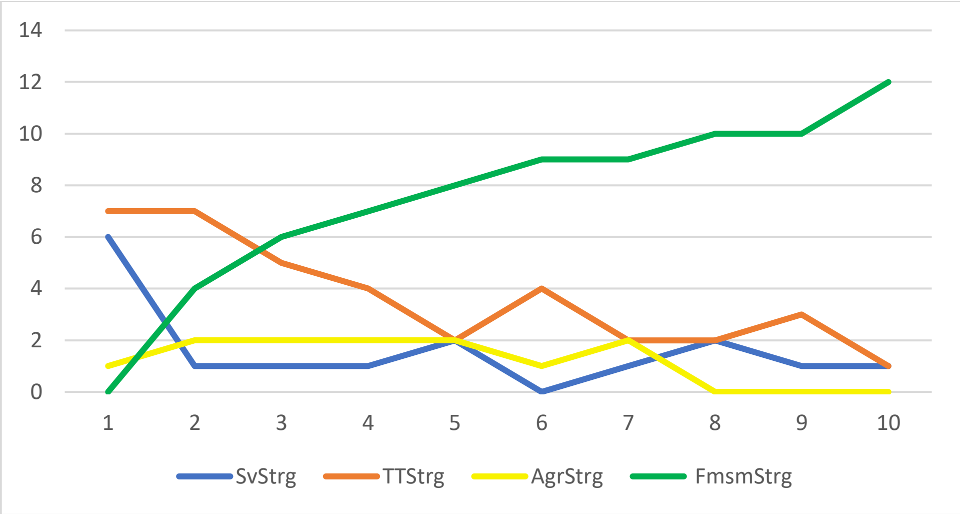


Overall, the dominant strategy of FM and SM took the largest share of 53%, and then it is the strategy announcing a possible game of *Tit for Tat* with 27%. The aggressive strategy is the latest with a rate of 9% that is not far enough from the 11% rescue strategy. Over the ten periods, each subject has on average the chance to play seven times the strategy of FM and SM, while he can propose cooperation three times and only or fortunately he can play only once, fortunately, aggressive strategy or rescue.

With more detail, Figure 23 represents the evolution of these strategies for the fourteen groups over the ten periods. The first period is characterized by two dominant strategies. Knowing that 50% of the players began to offer their optimism of the game *Tit for Tat*, while 40% opted for the immediate adoption of Project B. Only 10% of the players chose the aggressive strategy that has also disappeared during the last three periods. As the game repeats itself, SvStrg and TTStrg's strategies are transformed into FM and SM strategies. Some players maintained their choices for decision B2 which forced their partners to reject the proposals for the change of role and accept a lower but certain gain. It was this behavior that made the game of FM and SM appear, whose curve has seen a steady increase over the ten periods. While two groups still refused to align with their opponents, this strategy was the choice of twelve out of fourteen groups in the last period. Indeed, the deviation to such a strategy exposes both players to a probability of having a lower gain. In particular, the SM can make a higher gain but only if the other player agrees to play the *Tit for Tat*. This condition seems quite difficult if not impossible to achieve. The SM therefore accepts this situation, in particular, perhaps, that the gain made by the FM is not significant enough in relation to its gain. Can we explain why such a strategy was so attractive to the majority? And what are the characteristics of the minority subjects who were resistant and could not accept to play the role of SM or that they looked instead for the game *Tit for Tat?*

At the individual level and before answering this question, the database shows that groups 12, 6 and 7 opted respectively for the FM and SM strategy, zero times, once and twice, while they opted for the aggressive strategy, three times, twice and only once. It is the TTStrg strategy that dominates their choices. Also these groups are composed of female gender subjects. This remark helped us to develop our variables for the following econometric estimate and to understand the behavior of the subjects in choosing a particular strategy.

**Figure 23: The Evolution of different Strategies**




***Result*** 8: the choice of FM and SM strategy is more solicited, when the risk aversion gap is significant with a high CRT.

***Support:*** To make the group estimate and answer our question, we created two new variables. The RAgap variable that measures the difference between the risk aversion of the two subjects and the TRCmoy variable that measures their average CRTs. The results of table 16 show that the larger the AR gap and the higher the TRC, the greater the chance of choosing FM and SM strategy, to the detriment of the other three strategies. An average TRC with three correct answers implies that 97% of players decide to play FM and SM while 75% of players will choose the same strategy if the game takes place between a risk-seeking and a risk-averse. This choice can be negatively affected when both players are of the same gender. Conversely to FM and SM's strategy, those who opt for the Tit for *Tat* or Rescue strategy are characterized by closer levels of risk aversion and low CRT. The aggressive strategy, on the other hand, appears to be mainly due to a weak CRT.

**Table 19: Results of 2AB game strategies regression**

| | Variables dépendantes | | | |
|---|---|---|---|---|
| | FmsmStrg | AgrStrg | TTStrg | SvStrg |
| **RAgap** | 0.2856794<br>(0.1293725)<br><br>2.21 | -0.0975538<br>(0.205001)<br><br>-0.48 | -0.2886339<br>(0.1291871)<br><br>-2.23 | -.3403723<br>(0.1456159)<br><br>-2.34 |
| **TRCmoy** | 1.744954<br>(0.3592809)<br><br>4.86 | -3.425013<br>(0.9947671)<br><br>-3.44 | -1.203339<br>(0.3666384)<br><br>-3.28 | -1.203004<br>(0.3464663)<br><br>-3.47 |
| **Gender(Same=1)** | -2.130565<br>(0.5057696)<br><br>-4.21 | -0.1968751<br>(0.5380752)<br><br>-0.37 | 0.5732113<br>(0.4374597)<br><br>1.31 | _ |
| **N** | 140 | 140 | 140 | 140 |
| **Prob>chi2** | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

### II-2-b-ii- 2ABC Game Result

In the latter game, we introduce Project C, which is characterized by a significantly higher gain compared to projects A and B. We want to test whether a higher gain, which generally characterizes drastic or radical innovations, can deteriorate the nature of the competition that has been characterized by the stabilization of the FM and SM structure, when existing projects are close in terms of gains.

***Result 9:*** With a higher number of projects, the waiting strategy is maintained. The game of FM and SM does not turn into a war of attrition despite the rise of competitive threats.

***Support 9:*** Group 2 still plays in *"partner"* mode but the group 3 plays in *"stranger"* mode. For partners, as for foreigners, more than 50% of the choices focus on the three decisions of A2, B2 and C2. The increase in the choice of C1 in relation to the B2 decision shows an increase in competition. For Group 3, this choice reached 40%. Partners, however, start their games more aggressively than strangers, but finish their games with more stability. Overall and inversely to the results of the 2AB game, the decisions of the two groups differ.

**Figure 24: The results of decisions for group 2 for the 2ABC game**

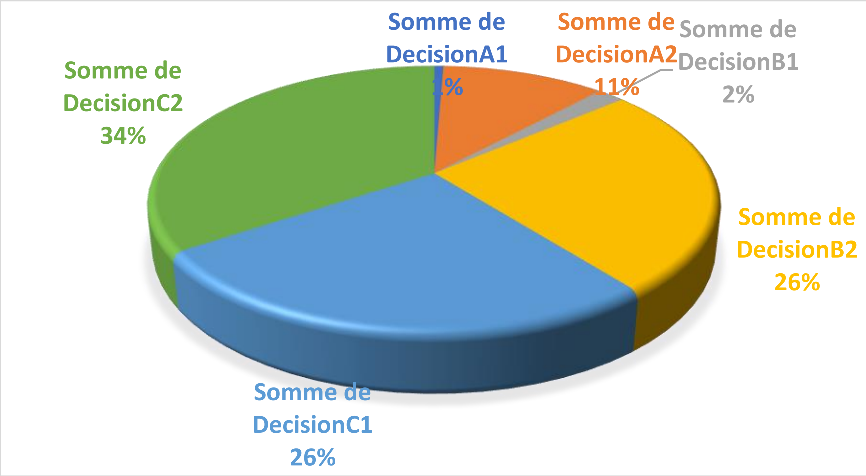
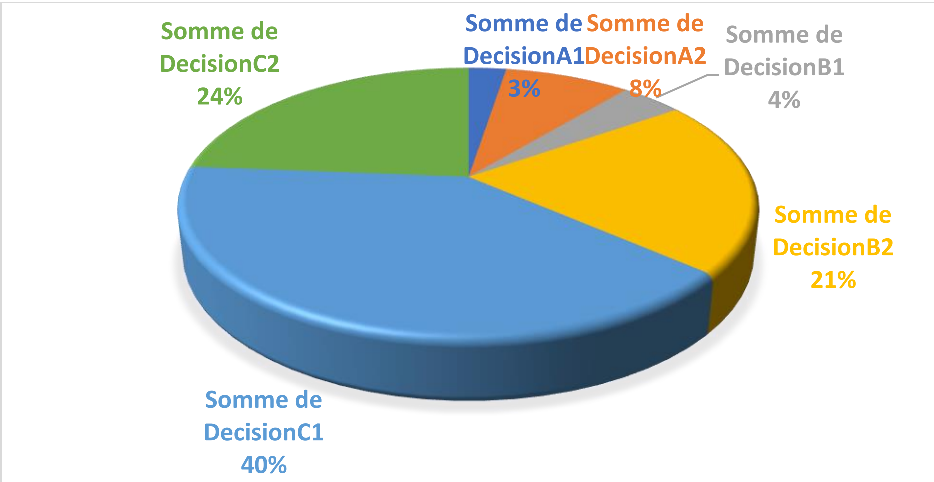
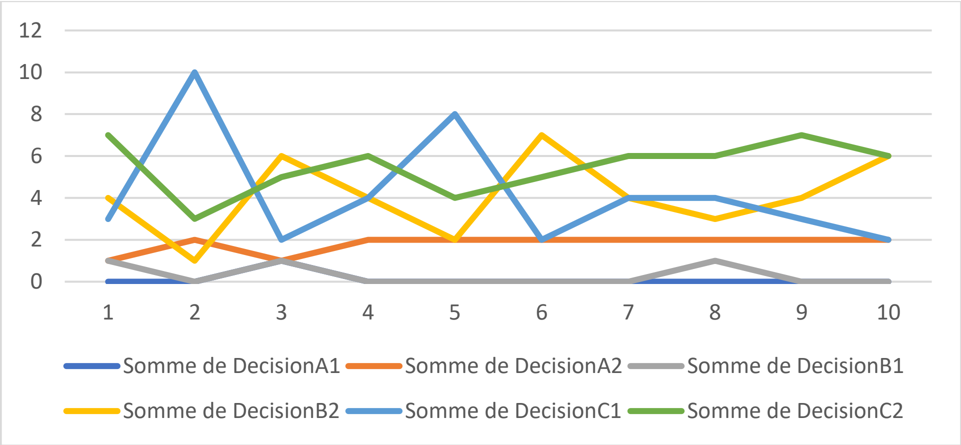



**Figure 25: The results of decisions for group 3 for the 2ABC game**

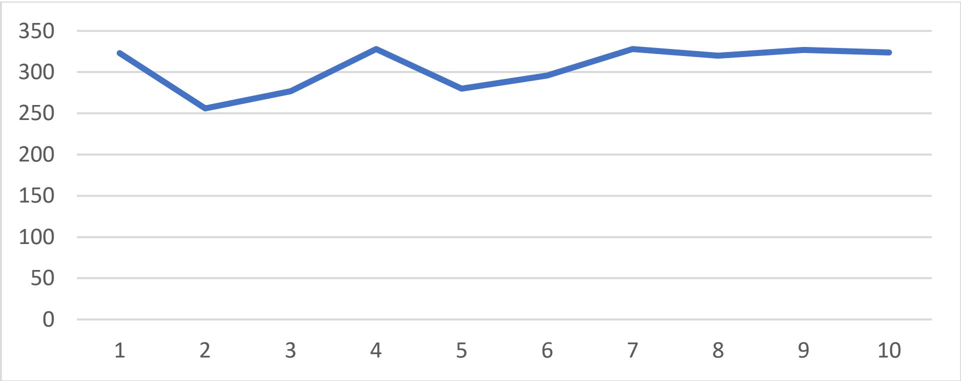



Figures 26, 27, 28 and 29 show the decisions of each group and the evolution of their profits over the ten periods. It appears that the majority of the subjects of both groups during the first period tried to keep the same dominant strategy of FM and SM of the game 2AB. In fact, for FM, this strategy ensures a significant gain. At the same time, SM's commitment to this strategy minimizes the risk of zero payout, but hope that FM will recognize their cooperation during the 2AB game. That's why this behavior suddenly deteriorated in the second period. Especially for partners who make the lowest profit corresponding to a concentration of choices on Project C with more than 81% of the decisions of the subjects. Looking at the data, it appears that those who have been FM want to keep their positions, on the other hand those who were the SM sought, by immigrating from decision B2 to C1 or C2, either reciprocity or threatening the position of FM.

## Figure 26: The evolution of the choice of group 2 for the 2ABC game




## Figure 27: The evolution of group 2 total profit for the 2ABC game




## Figure 28: The evolution of group 3 choices for the 2ABC game

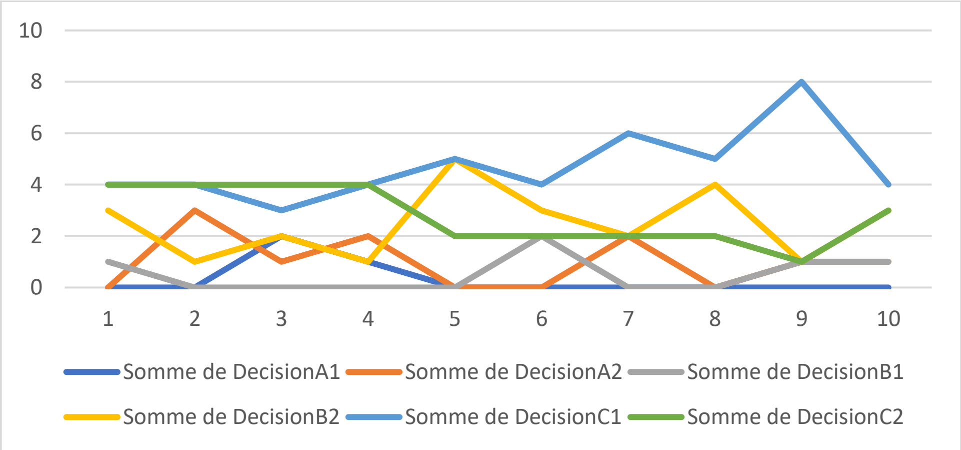
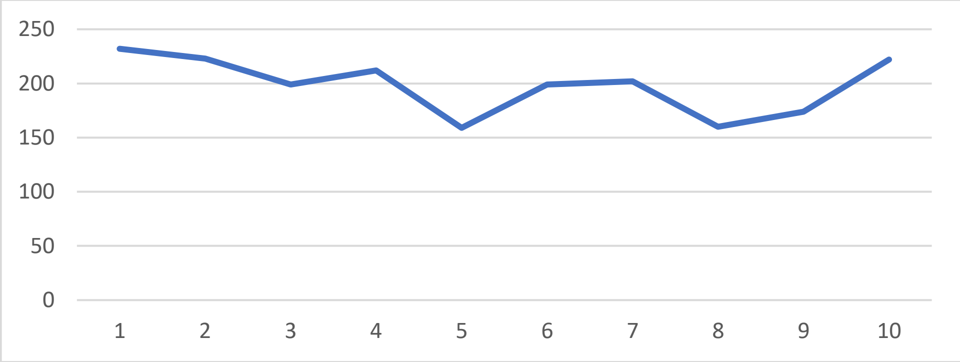


**Figure 29: The evolution of total profit for the 2ABC game /group 3**




The role change proposals that continued, but less aggressively, during the third and fourth periods end in the fifth period. From this round, the total profit steadily grows and stabilizes during the last periods implying that the partners have found the balance by joining the FM and SM structure. Group 3, on the other hand, fails to reach such a compromise. In fact, 66% of their choices during the first four periods were for Project C. This choice heralds the strategy of the war of attrition. Each of the players, maintaining his decision for Project C hopes that whoever wins zero will leave to make another different choice. From the fifth to the ninth period, there has been a diversion of FM and SM's strategy, resulting in the decline and non-stability of the value of profits. It is in the last period that the subjects resume their cooperative decisions by choosing less C1 but more C2 and B2.

An important finding implies that despite the instability of the choices experienced by the partner group during the first periods and by the group of foreigners during the next five periods, both groups have come to recognize the importance of waiting in accordance with the approach of real options.

***Result 10:*** Driven by the achievement of high earnings, the FM strategy is adopted by risk-seekings with high CRT. On the other hand, those who pursue a threat strategy are risk-averse with low CRTs and low gains. SM has a low CRT.

***Support 10:*** In the previous game the analysis was conducted in terms of "market structure". In other words, the analysis was at the group level. It is proposed in this part, and given such an increase in competition with the increase in the profit of Project C, to categorize the strategies adopted by each of the subjects. Using data from 2AB, we can identify three strategies:

- FmStrg strategy: This is the dominant strategy adopted by the player in most periods of the 2AB and 2ABC games. These players seek to appropriate the highest gain, even if the threat of other players sometimes forces them to have a zero win. They maintain their decisions for Project C.
- The SM (SmStrg) strategy: this is the dominant strategy adopted by the player in most periods of the 2AB and 2ABC games. These players do not seek the FM position and sometimes choose the adoption of the A2, even in the 2ABC game, to avoid a possible competitive situation.
- The Threat Strategy (MnStrg): This is the dominant strategy adopted by the player who seeks to have a *Tit for Tat* game and refuses to cede the FM position to the other player. The game of the war of attrition, which ended quickly in the first periods in the game 2AB (for both groups), could not end in the game 2ABC for group 3.

Table 17 shows that the FM strategy adopted by risk-seeking individuals, who have significant CRT and are influenced by significant profits. This confirms our conclusion in Chapter 3 that when firms are symmetrical, the least risk averse is FM. The simulations made show that an increase in profit from 25 to 35 implies an increase of 53% to 80% of the adoption of this strategy. However, the adoption of the threat strategy decreased enormously from 11% to 2%. While an improvement in TRC, from 1 to 3, does not induce a significant variation for the takers of this strategy, which stagnates at 33%, but results in a significant variation from 32% to 51% for those who adopt the FM strategy. When players are increasingly risk averse, there is a 26% to 43% increase in the chance of choosing the threat strategy. On the other hand, there is a 37% to 23% decrease in the probability of conducting the FM strategy. Moreover, this variation in risk aversion does not induce a significant variation in the choices of the SM strategy.

**Table 20: Econometric Estimation of the Different Strategies of the 2ABC Game**

| | Variables dépendantes | | | | |
|---|---|---|---|---|---|
| | FmStrg(1) | FmStrg(2) | SmStrg(1) | SmStrg(2) | MnStrg |
| **AR** | -0.17<br>(0.045)<br>-3.87 | -0.619<br>(0.084)<br>-7.33 | -0.003<br>(0.042)<br>-0.07 | -0.007<br>(0.048)<br>-0.15 | 0.269<br>(0.069)<br>3.88 |
| **TRC** | 0.410<br>(0.16)<br>2.83 | _ | -0.35<br>(0.17)<br>-2.02 | _ | 0.106<br>(0.228)<br>0.47 |
| **Gender(F=1)** | -0.41<br>(0.261)<br>-1.57 | -1.114<br>(0.3)<br>-3.69 | -0.640<br>(0.254)<br>-2.53 | -0.46<br>(0.24)<br>-1.91 | 1.017<br>(0.304)<br>3.35 |
| **Profit** | _ | 0.16<br>(0.022)<br>7.19 | _ | -0.021<br>(0.013)<br>-1.56 | -0.173<br>(0.022)<br>-7.88 |
| **N** | 280 | 280 | 280 | 280 | 280 |
| **Prob>chi2** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

The takers of this strategy have a low TRC and they are satisfied by achieving a minimum of profit and therefore do not seek to maximize their earnings.

## Conclusion

In recent years, we have seen a proliferation of the use of the experimental method in economics. In contemporary research, experimental economics has moved from a marginal place to a fundamental and irreplaceable place. Behavioral economics is based, moreover, in particular on experimental results. While the three main fields of analysis are decision theory, game theory and industrial organization theory, the application of this method for the analysis of the strategy of adoption of NT by RO is still in its embryonic phase. Most of the experiments that have been studied in the literature review focus on the theory of decision-making as part of an investment project. A minority of the work focuses either on innovation or on RO theory. We did not identify experimental work studying ANT's strategy through options games. Our goal in this chapter is to develop a first simple essay to predict the different theoretical results developed with RO approach. Our experience shows the important role that the psychological dimension plays in determining the ANT's strategy. The results deduced from this experiment are summarized in the following points:

1. Individuals are showers to losses, between 67.5% and 80% of choices focus on certain decisions. However, the use of uncertain decisions was not negligible. In the absence of the waiting option, a large number of projects favor the adoption of projects with immediate high values. In this case, decision makers do not intuitively recognize the value of waiting for the same project and generally opt for compulsive strategy.

2. The RO approach reinforces the leap-frog strategy and therefore increases the gain. This confirms the theoretical result of the GW model, according to which the probability of choosing the leap-frog strategy increases with the increase in the speed of arrival of NT. In addition, it shows that those who opt for the compulsive strategy are risk-averse. Risk-seeking decision-makers tend to adopt the *leap-frog* strategy. This deduction is consistent with the models of Chronopoulos and Lumbreras (2016) and Alexander and Chen (2019).

3. In the context of options games, the waiting strategy representing the stable Nash balance is not experimentally verified. The pre-emption game dominates from the fifth period. This result confirms the theoretical inferences of HK (case 1). In particular, it seems that the pre-emption strategy is the most played, especially for projects that are less risky and by the most risk-averse.

4. The repetition of the PD, in the case of a single project, does not induce the game *"Tit for Tat*". However, we note that the waiting strategy is more adopted when the project is more risky and decision makers are less risky.

5. When the number of technology available increases the choice of waiting strategy can reach more than 70% on average. The deviation from the waiting strategy does not appear to be beneficial. The waiting strategy arises in the FM and SM games: each company enjoyed a monopoly profit. Thus, these results verify the predictions of the HK model (case 2).

6. The choice of the FM and SM strategy is applied when the difference of risk aversion and TRC are significant.

7. With a higher number of the project, the waiting strategy is maintained. The game of FM and SM does not turn into *a war of attrition* despite the rise of competitive threats. This preliminary finding contradicts the HK model (case 3) and thus requires further investigation.

**8.** Driven by the achievement of high gains, the FM strategy is adopted by risk-seeking who have a good ability to think cognitively. On the other hand, those who pursue a threat strategy are risk-averse with low CRTs and low gains. SM has a low CRT.

These preliminary results work towards a new research axis incorporating the psychological dimension when evaluating the adoption of NT by the RO approach. An extension of the ID3 algorithm, already developed as part of decision theory, to the framework of option game theory can be a powerful tool for predicting ANT's proper strategy.