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« When Allais meets Ulysses: Dynamic axioms and the Common Ratio Effect »

Antoine NEBOUT

Dimitri DUBOIS

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Unite de Formation et de Recherche d'Economie
Avenue Raymond DUGRAND C.S. 79606
3 4 9 6 0 MONTPELLIER Cedex 2

E-mail : lameta@lameta.univ-montp1.fr
web : www.lameta.univ-montp1.fr

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When Allais meets Ulysses: Dynamic axioms and the Common Ratio Effect

Nebout, A. and Dubois, D.

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Abstract We report experimental findings about subjects' behavior in dynamic decision problems involving multistage lotteries with different timings of resolution of uncertainty. Our within-subject design allows us to study violations of the Independence axiom and of the dynamic axioms: Dynamic Consistency, Consequentialism and Reduction of Compound Lotteries. More precisely we investigate the extensions in a dynamic framework of the pattern of choices observed in the Common Ratio Effect (CRE). We study the effects of changes in probability and outcomes over CRE-like violations of each dynamic axiom as well as the eventual association between the independence axiom and each dynamic axiom. We find that, although probability and outcomes do not have an impact on general violation levels of the dynamic axioms, each of these parameter dimensions play an important role when it comes to CRE-like violations of the axioms: the probability level for Reduction of Compound Lottery and Dynamic Consistency and the outcomes levels for Consequentialism. Moreover, we find that an important proportion of our subjects verify the Independence axiom but violate some dynamic axioms in a systematic manner. This accounts for the fact that dynamic axioms are not only extensions of the Independence axiom to a dynamic framework but also capture preferences that are independent of those observed with single stage lotteries.

Keywords Decision Theory, Experiment, Independence Axiom, Dynamic Consistency, Consequentialism
JEL: C91, D81

Nebout, A., Corresponding author,
LAMETA - CNRS, UMR5474 LAMETA, F-34000 Montpellier & GREG-HEC - CNRS, UMR2959, F-78351 Jouy en Josas. E-mail: nebout@greg-hec.com

Dubois, D.
LAMETA - CNRS, UMR5474 LAMETA, F-34000 Montpellier, France, E-mail: dimitri.dubois@lameta.univ-montp1.fr

1 Introduction

One of the most robust violations of Expected Utility Theory (EUT) is the Common Ratio Effect (CRE). CRE, exhibited in the pattern of choices shown in Figure 1, is one of the main effects (with Common Consequence Effect) related to the Allais paradoxes[1] (Allais 1953, McCrimmon & Larsson 1979, Kahneman & Tversky 1979, Starmer & Sugden 1989) which cast doubt upon the descriptive adequacy of the independence axiom[2] (IND). These violations of EUT led to new models of decision under risk (non-EU models) which account for these effects and thus have stronger descriptive power in a static set up.

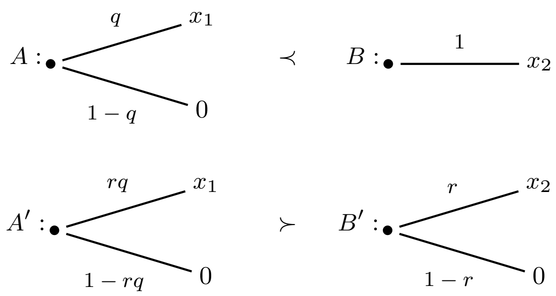

Fig. 1: Common Ratio Effect pattern of choices (Allais 1953)

In fact, IND is a property of preferences over one stage lotteries. It has however been connected with choice behavior in dynamic decision problems. The mixture operation involved in IND was originally interpreted in terms of composition of lotteries (von Neumann & Morgenstern 1947). Dynamically there are several ways of composing two lotteries. One can consider the compound lottery prior to the resolution of any uncertainty, or after the resolution of the uncertainty of the first lottery. This allows us to define the three dynamic axioms that are studied in this paper. Figure 2 (p5) gives a graphical representation of these axioms (see Cubitt et al. 1998 and Wakker 1999) namely *Consequentialism*, *Dynamic Consistency* and *Reduction of Compound Lotteries*. Formally, Burks (1977) and later Karni & Schmeidler (1991) showed that one satisfies these three dynamic principles only if the induced preference relation over one stage lotteries satisfies IND. Reciprocally, Volij (1994) made it clear that a Non-EU model of decision under risk that relaxes IND must specify which one of the three dynamic axioms mentioned above is not satisfied. Indeed, he showed that if two of the three aforementioned dynamic axioms are verified, then the remaining one is equivalent to the independence axiom[3]. In these theorems, one makes the hypothesis that only one dynamic axiom can be violated at a time. From a descriptive perspective, it is however

[1] The original parameters proposed by Allais are the following : $x_1 = 5M€$, $x_2 = 1M€$, $q = 0.9$ and $r = 0.1$.
[2] The choice pattern $A \succ B$ and $B' \succ A'$ is also a violation of IND called reverse common ratio effect (RCRE).
[3] Logically, it means:
- If RCL and CON hold then DC $\Leftrightarrow$ IND. (Karni & Schmeidler 1991)

possible to observe simultaneous violations of the dynamic axioms in a way that do not necessarily imply violations of the independence axiom.

In this paper, we build on the work of Cubitt et al. (1998) who provided valuable empirical information[4] about Consequentialism (CON), Dynamic Consistency (DC)[5] and Reduction of Compound Lotteries (RCL) using a between-subject design. We propose an experimental design that allows two main innovations ; first we test each dynamic axiom at an individual level (within-subject design), second we perform these within-subject tests for different values of the parameters. We can therefore determine which dynamic principle is more prone to be violated and the direction of violation depending on the outcome and the ratio levels. We can also account for simultaneous violations of the dynamic axioms and test the association between IND and each axiom. We provide new insights about how the type of rejection of each axiom depends on the outcomes and probability (ratio) levels. Our results and findings are relevant in order to further our understanding of risky decisions in a dynamic context and of the impact of the timing of resolution of uncertainty on individual decision behavior. More precisely, we connect standard findings of choices between one stage lotteries to new observations of choice behavior in more sophisticated dynamic contexts. Because the timing and the probability of resolution of uncertainty as well as its consequences have strong behavioral implications and differ in many real-life situations, the results of our study should deepen our interpretation of many existing stylized facts concerning choice under risk.

Notably, we reproduce the benchmark results of Cubitt et al. (1998) and of McCrimmon & Larsson (1979). We confirm that for the independence axiom the smaller the probability level (ratio) and the higher the outcomes, the more frequently CRE is observed. For the dynamic axioms, we find that for RCL and DC, the rate of CRE violations is higher for small ratio values, but is not affected by the outcome level; whereas for CON, CRE violations are more frequently observed with high outcomes. These results are confirmed when subjects who violate more than one dynamic axioms are excluded from our sample. This category of subjects is of particular interest and is composed in a grand majority of individuals who satisfy IND but violate two dynamic axioms in an opposite direction. Interestingly, more than 75% of them exhibits CRE violations of CON and RCRE violations of RCL. This systematic pattern of violations constitutes an empirical contradiction to the implicit normative hypothesis (Karni & Schmeidler 1991, Volij 1994) that violations of dynamic axioms are necessarily connected to violations of independence. Finally, we find that CON is the

- If RCL and DC hold then CON ⇔ IND. (Volij 1994)
- If DC and CON hold then RCL ⇔ IND. (Volij 1994)

[4] The first experimental investigation of the decomposition of the independence axiom in a dynamic set up is due to Kahneman & Tversky (1979). Indeed, the *isolation effect* comes from the decomposition of IND between CON and DC+RCL.

[5] In this study the authors refer to separability and timing independence for what we call consequentialism and dynamic consistency.

best candidate as a dynamic version of independence (as suggested by Machina 1989) since we find a significant association only between IND and CON.

Our paper proceeds as follows. Section 2 presents our notation, the tasks used in the experiment, and the way to detect acceptance or rejection of dynamic axioms from the patterns of choices on these tasks. It also discusses the relationship between the terminology used for the axioms and existing literature. Section 3 describes our experimental design. The results of the study are presented in section 4. Finally section 5 summarizes and discusses the experimental findings.

2 Preliminaries

We now present the three dynamic axioms. The terminology we use is in strict accordance with Karni & Schmeidler (1991).

2.1 Notation and decision problems

Let us introduce the decision tasks we used in the experiment. We restrict ourselves to the set L of two-outcome lotteries where outcomes can be three monetary values taken from $\{x_1, x_2, 0\}$ such that $x_1 > x_2 > 0$. Let $\succcurlyeq$ be a preference relation over L. We identify four types of choice problems (Cubitt et al. 1998) : scaled down, scaled up, prior lottery and two-stage. In figure 2, they are represented following standard notation where circles correspond to chance nodes and squares to decision nodes. For decision nodes, we note by U_k (resp. D_k) the choice of up (resp. down) in problem S_k, $k = 1, \ldots, 4$.

First, in the scaled down and the scaled up problems, the choice patterns $[D_1/U_4]$ and $[U_1/D_4]$ contradict the independence axiom[6]. Similarly, in the scaled up and the prior lottery problems, choice patterns $[D_1/U_2]$ and $[U_1/D_2]$ contradict CON. In the prior lottery and the two stage lottery problems, the choice patterns $[D_2/U_3]$ and $[U_2/D_3]$ are violations of DC. In the two stage lottery and scaled down problems, choice patterns $[D_3/U_4]$ and $[U_3/D_4]$ contradict RCL. More specifically, the pattern $[D_1/U_4]$ corresponds to the common ratio effect. So we call the patterns $[D_1/U_2]$, $[D_2/U_3]$ and $[D_3/U_4]$ CRE violations (in opposition to the RCRE violations) of, respectively, CON, DC and RCL that correspond to CRE in a dynamic set up. By contrast, choice patterns $[D_i/D_j]$ and $[U_i/U_j]$ respect the corresponding axiom depending on i and j and are therefore acceptance patterns. These dynamic axioms can therefore be tested within the revealed preference paradigm in order to complement the existing theoretical research into these concepts.

[6] Indeed, with $P = (x_2; 1)$, $Q = (x_1, 0; q)$, $R = (0; 1) \in L$ these patterns imply that: $\exists\ P, Q, R \in L, \exists\, r \in [0, 1]\ s.t.\ P \succ Q \not\Leftrightarrow rP + (1-r)R \succ rQ + (1-r)R$ which is the negation of IND which is formally stated as : $\forall\ P, Q, R \in L, \forall\, r \in [0, 1],\ P \succcurlyeq Q \Leftrightarrow rP + (1-r)R \succcurlyeq rQ + (1-r)R$. Subsequently, r is called ratio to recall the common ratio effect that contradicts this axiom ($r = 0.1$ in the original paradox of Allais 1953).

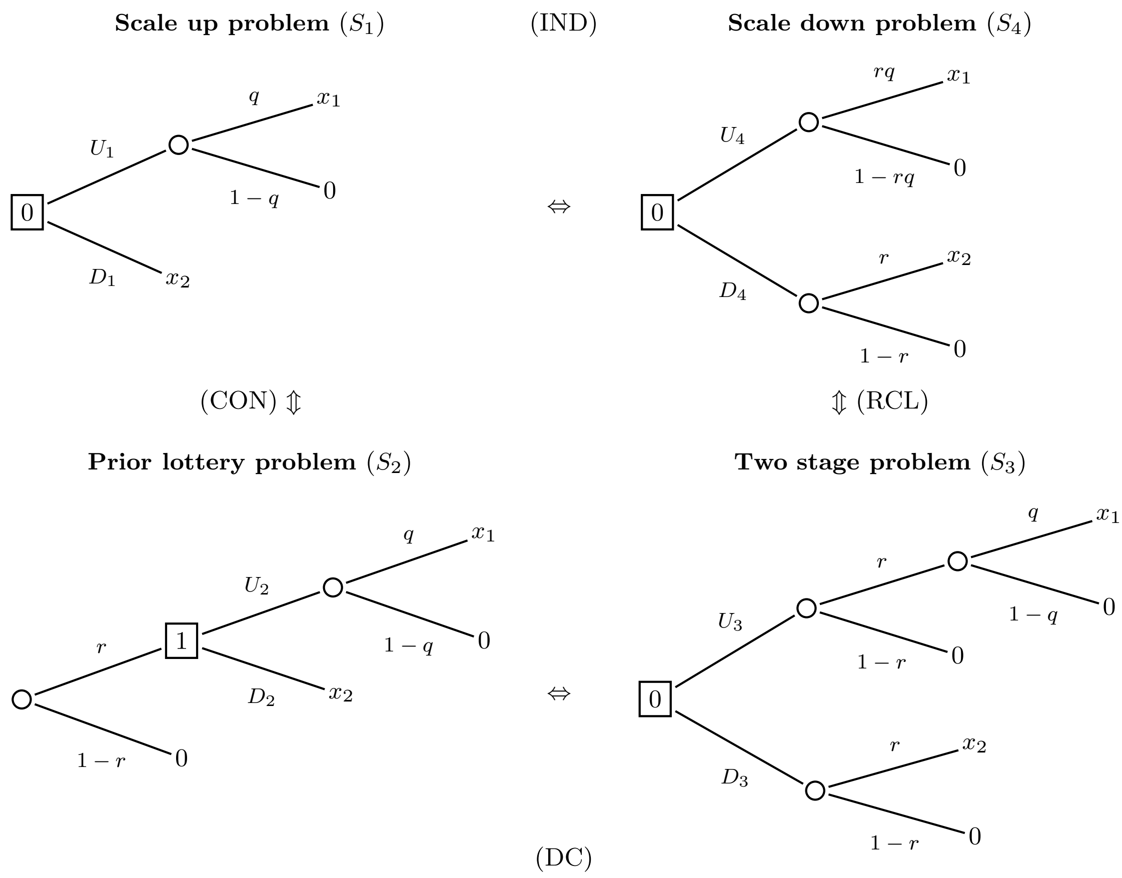

Fig. 2: Dynamic axioms and independence axiom for two outcomes lotteries

2.2 Consequentialism (CON)

This term was first introduced in the formal Decision Theory literature by Hammond (1988, 1989) and refers to the idea that acts are only valued by their consequences[7]. Formulated in terms of decision trees, consequentialism "would be false if missed opportunities, regrets, sunk costs, etc. affected behaviour and yet were excluded from the domain of consequences". In this paper, we define consequentialism as shown in figure 2. This is a special case of Hammond's (1988) notion[8]. In fact, it corresponds to the separability condition in Machina (1989), Cubitt et al. (1998) and McClennen (1990) and to forgone event independence in Wakker (1999). We argue that CON means that choice behavior should not be influenced by an uncertainty already resolved. If CON is abandoned, then behavior is affected by events that are known not to have happened at the moment of decision and therefore involves counterfactual reasoning about outcomes that could have occurred but are revealed not to. Machina (1989) and McClennen (1990) argued that CON

[7] In ethics, the term "consequentialism" was first used by Anscombe (1958)

[8] Consequentialism in the sense of Hammond is the conjunction of the two axioms we call CON and RCL.

is an inappropriate property to impose on a Non-EU model because it is a dynamic version of separability which constitutes, for them, the core of the independence axiom.

2.3 Dynamic consistency (DC)

Karni & Safra (1989, 1990) used the term Dynamic Consistency for strategies in a sequential decision problem. A strategy is dynamically consistent if the ex-ante plan is actually implemented at each step (decision node) of the sequential problem. We restrict this definition to preferences towards dynamic single decision problems and consider that, when ex-post and ex-ante preferences relative to the resolution of an uncertainty correspond, DC is verified. This is motivated by the approach used by Cubitt et al. (1998) with the difference being that we merge what they called "timing independence" and context independence under the same axiom, dynamic consistency (DC). Violation of DC has great implications when dealing with sequential decision problems because it renders the use of backward induction reasoning ineffective and therefore requires the use of alternative sequential strategies. There exists more empirical research into violations of DC than for CON (Busemeyer et al. 2000, Barkan & Busemeyer 2003, Hey & Panaccione 2011).

2.4 Reduction of Compound Lotteries (RCL)

There is a consensus about the definition of Reduction of Compound Lotteries in the literature. This axiom describes the ability to compute probabilities according to the definition of conditional probability. Segal (1987, 1990) argued that multiple stage gambles should be distinguished from single stage gambles and described the dynamic behavior of an individual who does not satisfy this axiom. Bar-Hillel (1973), Carlin (1992), Budescu & Fischer (2001) provide empirical evidence of violation of RCL where, most of the time, the multiple stage gamble is preferred to the reduced single stage one. Therefore according to this axiom the preferences observed in a choice between a two stage prospects and another option should be the same than the one observed if this two stage gamble is replaced by its reduced single stage counterpart. Therefore, if choices in the two-stage and in the scale down problem are not the same, then RCL is not satisfied.

3 Experimental design

3.1 Architecture

The experiment was conducted at the LEEM[9] experimental lab in Montpellier (France). A total of 114 participants[10], graduate and undergraduate students from various disciplines took part in a computerized experiment. A typical session lasted for about 1 hour and was composed of 30 questions of 4 different kinds[11](presented as S_i in figure 2). We opt for a 2×2×2 design in order to control and test for the effects of the following three dimensions:

– We fixed two levels for the ratio: $r^L = 0.3$ and $r^H = 0.7$. For r^L, we choose a value close but slightly higher than the one ($r = 0.25$) used by Cubitt et al. (1998). For r^H, we choose a value slightly higher than the one ($r = 0.6$) used by Starmer & Sugden (1989) and for which they observe more RCRE than CRE[12].
– We fixed two levels for the sure outcome $x_2 = 15€$ and $x_2 = 60€$. McCrimmon & Larsson (1979) found an increase in violations of the independence axiom, specifically CRE rejection, for smaller ratios and higher outcomes. Therefore, we decided to control for the effects of the ratio and outcomes levels over the rate of acceptance/rejection of dynamic axioms.
– For each of these two levels of x_2, we fixed two levels of maximal gain x_1. For $x_2 = 15€$, we choose $x_1 = 20€$ and $x_1 = 24€$ and for $x_2 = 60€$, we choose $x_1 = 80€$ and $x_1 = 95€$. We introduce this additional dimension in order to control for the heterogeneity of risk attitudes in our sample and to gain in statistical discriminative power.

With $q = 0.8$ for all the questions, this makes 8 questions per type of problem except for S_1 where there is no r. To sum up, the experiment[13] was divided as follows:

(i) 4 scaled up problem (S_1) questions involving a choice between a sure amount of money $(x_2; 1)$ and a lottery $(x_1, 0; q)$
(ii) 8+2 scaled down problem (S_4) questions involving a choice between 2 lotteries : $((x_2, 0; r)$, and lottery $(x_1, 0; rq))$. We added two questions to test for first-order stochastic dominance by proposing a choice between lottery $(x, 0; q)$ and lottery $(x^*, 0; q)$ with $x^* > x$.
(iii) 8 two-stage problem (S_3) questions involving a choice between a simple lottery $(x_2, x_3; r)$, and the two-stage lottery $((x_1, 0; q), 0; r)$.

[9] Laboratoire d'Economie Expérimentale de Montpellier (France)
[10] We ran 6 sessions of 19 participants each.
[11] For every problem type, participants were given instructions and a short questionnaire to check their understanding of the task.
[12] With the aim to study exclusively CRE violations of IND and of the dynamic axioms, it would have been more adequate to use ratio values between 0.1 and 0.5. This is exactly what is done in Nebout & Willinger (2012). However, in this study we are interested in both CRE and RCRE violations, so it is useful to have a ratio value over one half.
[13] Screenshots of each problem type are available in the appendix B.

(iv) 8 Prior lottery problem (S_2) questions where, first, participants had to activate manually a prior lottery. Then further instructions were displayed: depending on the outcome of the prior lottery, either (with probability $1-r$) they get nothing and they was no choice to be made or (with probability r) they were told to choose between a sure amount $(x_2; 1)$ and a lottery $(x_1, 0; q)$. From an experimental point of view, an important aspect of this task is that $1-r$ is the probability that the subject fails to reach the second stage and therefore the proportion of missing data for this question.

As explained in section 2, our design allows us to test which, if any, axiom is violated for each participant and each combination of parameters: for the independence axiom we compare S_1 and S_4, for CON we compare S_1 and S_2, for DC we compare S_2 and S_3 and for RCL we compare S_3 and S_4.

A pilot study revealed that subjects had difficulties in answering questions involving multi-stage lotteries, because of misunderstandings or task complexity. We therefore decided to introduce such lotteries step by step, starting with simple choices between a lottery and a sure outcome (S_1) followed by choices between two lotteries (S_4). For the question types S_2 and S_3, we control for possible order effects[14] as follows : half of the subjects were confronted with the task sequence $S_1/S_4/S_2/S_3$ and the other half with $S_1/S_4/S_3/S_2$.

3.2 Incentive system

The use of monetary incentives is the topic of an active debate among behavioral economists. Depending on the type of experiment, the chosen incentive scheme might have a significant impact on the results (Camerer & Hogarth 1999, Read 2005, Bardsley et al. 2010, chapter 6). The nature of our experimental design (multiple binary choices for each subject) raised the issue of the most appropriate incentive schemes. In this section, we present the advantages and drawbacks of each possible schemes and justify the choice of hypothetical payment that we implemented in our experiment.

We identified four possible incentive schedules: "play one pay one", "play all pay all", random incentive system (RIS) and hypothetical payment. There is no doubt that the "play one pay one" solution is more appropriate for an experimental protocol investigating dynamic preferences (Bardsley et al. 2010, p280). This requires forming several groups of subjects, each of them facing one problem for real and in isolation. This solution, chosen by Cubitt et al. (1998), is ideal in terms of incentives because it involves no risk of contamination between different choice tasks and no *prediction failure*. However such protocol consumes an important amount of time, money and

[14] We do not found such effect in our sample so we do not evoke this feature later in the paper.

subjects. Futhermore, with only one question asked to one subject, this methodology restricts the analysis to a between-subject design and, by consequence, rules out any study of violations of dynamic axioms at an individual level. For such a study, multiple questions per subject are required and the following criticism, anticipated by Cubitt et al. (1998), can be made : "If a subject faces more than one decision problem in an experiment, then the experiment as a whole can be understood as a single problem of dynamic choice. In order to interpret the subject's responses to such an experiment as revealing her preferences over the options in the individual problems, it would be necessary to assume the truth of at least one of the dynamic choice principles which we wish to test." (p1372). This possibility of contamination is a risk that has to be taken in order to obtain results about dynamic preferences at an individual level. For this purpose three incentive schemes were available.

A first idea would be to incentivize all the questions of the experiment and thus to pay the cumulative gain at the end. In order to keep the payments reasonable, it would be necessary to reduce the gain associated to each question or to introduce an exchange rate. That would force us to use maximal gains between 0.5 € and 2 € in each lottery. Such amounts of money are unlikely to motivate subjects. In addition, the difference between the outcome levels might be too small to detect any effect on the outcome dimension. There are also several drawbacks in incentivizing each question like contamination, income and house money effects. Since few studies use this method, it would hinder comparison of our results with the existing literature. We therefore discarded this solution.

Random incentive system (RIS) was another option. It consists in paying only one question randomly selected from the set of answered questions at the end of the experiment. For our purposes, Cubitt et al. (1998) argued that this option was not appropriate because the assumption justifying RIS is isolation which is exactly what is investigated here[15]. Although several studies show that RIS does not prevent subjects separating questions in a multiple tasks experiment (Hey & Lee 2005), we thought that this scheme was not adequate for the critical issues investigated in this paper.

We decided to use hypothetical incentives following Kahneman & Tversky (1979) who claimed that: "the method of hypothetical choices emerges as the simplest procedure by which a large number of theoretical questions can be investigated. The use of the method relies on the assumption that people often know how they would behave in actual situations of choice, and on the

[15] "Since the random lottery incentive system is widely used in experimental economics this points to a further motivation for testing dynamic choice principles. In any random lottery design, the subject makes precommitments to actions to be taken conditional on a chance event. Timing independence implies that these precommitments are in line with the actions which would be taken after the realisation of nature's move. Separability implies that the latter actions are identical to those which would have been taken at the relevant decision problems been faced in isolation and for real. Thus, timing independence (DC) and separability (CON) are jointly sufficient for the validity of the random lottery incentive system."

further assumption that the subjects have no special reason to disguise their true preferences". Thus, we payed subject a flat fee of 15€ and compensated for travel costs with 5€ or 10€ depending on the journey required. Nevertheless, there are potential problems raised by this scheme. A first drawback is that it could bias participants' attitude towards risk in reducing their level of risk aversion (Beattie & Loomes 1997, Holt & Laury 2002). This effect is not critical in our protocol since the detection of violations of dynamic axioms is independent of the subjects' risk attitude. A second objection could be that the effect of the resolution of uncertainty in the prior lottery problems might have a limited impact on individuals' state of mind given the fact that these questions will not be payed. Subjects may not experience the disappointment or the relief related to the resolution of the prior uncertainty. This could undermine our findings concerning CON and DC. In fact, this "prediction failure" phenomenon might induce the subjects to give more thought to their answers rather than to give an answer whilst in the grip of their emotions or as a reaction to a "gut feeling". Consequently, we expect our subjects to satisfy DC and CON more frequently than they would do with real incentives. In addition, it is likely that "prediction failure" will also occur with RIS because each question has a low probability of being selected which could dilute the emotions due to the resolution of uncertainty in a particular prior lottery problem.

In conclusion, given that there is probably no perfect incentive scheme that goes with our within-subject protocol, we opted for the one that, in our opinion, minimizes the impact of all possible detrimental effects.

3.3 Statistical methodology of analysis

We present the method of aggregation of our data along two parameter dimensions which aims to improve the clarity and the statistical power of our study. First, we merge the samples for parameter combinations with a similar level of outcomes. More specifically, we define x^L as the merging of the samples for outcomes $(20, 15, 0)\&(24, 15, 0)$ and x^H as the merging for the samples for outcomes $(80, 60, 0)\&(95, 60, 0)$. Then, in order to investigate the influence of one dimension (ratio: r^L and r^H or outcome levels : x^L and x^H) on the rate of acceptance/rejection of a dynamic axiom, we merge the samples along the other dimension. Finally, we merge all 8 samples to obtain the most aggregated level of results. This aggregation is a convenient tool for dealing with the scarce data resulting from the loss of observations for CON and DC. For each axiom, we first study the acceptance versus rejection rates then we refine our understanding of the rejection behavior by testing the two possible types of rejection (CRE versus RCRE) against each other. In this part, we first compare our results to existing evidence in the literature, then we provide new results for each of the 3 dynamic axioms. We further exploit the within-subject characteristic of our data by studying the number of dynamic axioms violated by a subject within the same parameter set. Finally, we investigate the links between the independence axiom and each of these dynamic axioms.

4 Results

3 subjects out of 114 (2.6%) chose a strictly dominated lottery at least once. We therefore excluded them from the analysis. In Tables 1 and 2, we give the overall experimental results for the remaining 111 subjects. Table 1 presents the rates of choices between U and D for each decision problem and each parameter set. As explained in the previous section, we choose two values for x_1 for the same x_2 in order to control for different levels of risk aversion in our sample. In fact, we observe more choice of the riskiest option, U, for the high levels of x_1 (24€ and 95€) than for the small levels (20€ and 80€). There is only one exception for S_1 where U is more frequently observed for 20€ than for 24€.

		CSS	$r^L = 0.3$				$r^H = 0.7$			
			x^L		x^H		x^L		x^H	
			20€	24€	80€	95€	20€	24€	80€	95€
S_1	U_1	19	56	37	17	47	56	37	17	47
		38.00	*50.45*	*33.33*	*15.32*	*42.34*	*50.45*	*33.33*	*15.32*	*42.34*
	D_1	31	55	74	94	64	55	74	94	64
		62.00	*49.55*	*66.67*	*84.68*	*57.66*	*49.55*	*66.67*	*84.68*	*57.66*
S_2	U_2	13	8	15	12	34	28	53	36	60
		28.90	*28.57*	*42.86*	*31.58*	*68*	*32.94*	*51.46*	*39.13*	*66.67*
	D_2	32	20	20	26	16	57	50	56	30
		71.10	*71.43*	*57.14*	*68.42*	*32*	*67.06*	*48.54*	*60.87*	*33.33*
S_3	U_3	32	43	64	57	80	34	57	53	81
		66.70	*38.74*	*57.66*	*51.35*	*72.07*	*30.63*	*51.35*	*47.75*	*72.97*
	D_3	16	68	47	54	31	77	54	58	30
		33.30	*61.26*	*42.34*	*48.65*	*27.93*	*69.37*	*48.65*	*52.25*	*27.03*
S_4	U_4	25	45	62	70	68	23	30	20	49
		48.10	*40.54*	*55.86*	*63.06*	*61.26*	*20.72*	*27.03*	*18.02*	*44.14*
	D_4	27	66	49	41	43	88	81	91	62
		61.90	*59.46*	*44.14*	*36.94*	*38.74*	*79.28*	*72.97*	*81.98*	*55.86*

Table 1: Effectives and frequencies of U and D for each problem.

There are no significant differences between the results of our experiment and the ones of Cubitt et al. (1998)[16]. The parameter profile ($r = 0.3$, $x_1 = 24$€, $x_2 = 15$€, $x_3 = 0$) is comparable with the one used by Cubitt et al. (1998) ($r = 0.25$, $x_1 = 16$£, $x_2 = 10$£, $x_3 = 0$). Let us note that in our design each subject answers each decision problem while this is not the case in Cubitt & al's

[16] S_1: $\chi^2 = 0.157$ p-value=0.692, S_2: $\chi^2 = 1.130$ p-value=0.288, S_3: $\chi^2 = 0.792$ p-value=0.374 and S_4: $\chi^2 = 0.577$ p-value=0.448

experiment. Hence we cannot use the same z-test in order to find a significant difference between the prior lottery and two-stage problems and to draw conclusion concerning the violation of DC. Table 2 presents the statistics of each pattern of choice for the independence and all the dynamic axioms. First, we compare the results of these two tables with the standard results of the experimental literature on the common ratio effect and its dynamic extensions.

		$r^L = 0.3$				$r^H = 0.7$			
		x^L		x^H		x^L		x^H	
		20€	24€	80€	95€	20€	24€	80€	95€
CON	Obs.	28	35	38	50	85	103	92	90
	U_1/U_2	4	8	3	15	19	25	8	29
		14.29	*22.86*	*7.89*	*30*	*22.35*	*24.27*	*8.7*	*32.22*
	D_1/D_2	9	18	24	13	30	39	50	22
		32.13	*51.43*	*63.17*	*26*	*35.29*	*37.86*	*54.35*	*24.44*
	U_1/D_2	11	2	2	3	27	11	6	8
		39.29	*5.71*	*5.26*	*6*	*31.76*	*10.68*	*6.52*	*8.89*
	D_1/U_2	4	7	9	19	9	28	28	31
		14.29	*20*	*23.68*	*38*	*10.59*	*27.19*	*30.43*	*34.45*
DC	U_2/U_3	6	13	9	24	12	35	20	50
		21.43	*37.14*	*23.68*	*48*	*14.12*	*33.98*	*21.74*	*55.56*
	D_2/D_3	11	10	10	7	42	34	31	17
		39.29	*28.57*	*26.32*	*14*	*49.41*	*33.01*	*33.70*	*18.89*
	U_2/D_3	2	2	3	10	16	18	16	10
		7.14	*5.71*	*7.89*	*20*	*18.82*	*17.48*	*17.39*	*11.11*
	D_2/U_3	9	10	16	9	15	16	25	13
		32.14	*28.57*	*42.11*	*18*	*17.65*	*15.53*	*27.17*	*14.44*
RCL	Obs.	111	111	111	111	111	111	111	111
	U_3/U_4	21	42	40	53	8	21	10	43
		18.92	*37.84*	*36.04*	*47.75*	*7.21*	*18.92*	*9.01*	*38.74*
	D_3/D_4	44	27	24	16	62	45	48	24
		39.64	*24.32*	*21.62*	*14.42*	*55.86*	*40.54*	*43.24*	*21.62*
	U_3/D_4	22	22	17	27	26	36	43	38
		19.82	*19.82*	*15.32*	*24.32*	*23.42*	*32.43*	*38.74*	*34.23*
	D_3/U_4	24	20	30	15	15	9	10	6
		21.62	*18.02*	*27.02*	*13.51*	*13.51*	*8.11*	*9.01*	*5.41*
IND	U_1/U_4	21	29	13	30	13	15	6	24
		18.92	*26.13*	*11.71*	*27.03*	*11.71*	*13.51*	*5.41*	*21.62*
	D_1/D_4	31	41	37	26	45	59	80	39
		27.93	*36.94*	*33.33*	*23.42*	*40.54*	*53.16*	*72.07*	*35.14*
	U_1/D_4	35	8	4	17	43	22	11	23
		31.53	*7.21*	*3.6*	*15.32*	*38.74*	*19.82*	*9.91*	*20.72*
	D_1/U_4	24	33	57	38	10	15	14	25
		21.62	*29.73*	*51.35*	*34.23*	*9.01*	*13.51*	*12.61*	*22.52*

Table 2: Effectives and frequencies of choice patterns for each axiom.

Result 1

(i) The value of the ratio affects the frequency of rejection of the independence axiom (IND),

(ii) The CRE violation of IND (D_1/U_4) is more frequently observed than RCRE with small ratio value and high outcome level whereas with high ratio value and low outcome level RCRE is more frequently observed.

		r^L	r^H
$x_1 = 20$	U_1/D_4	35	43
	D_1/U_4	24	10
$x_1 = 24$	U_1/D_4	8	22
	D_1/U_4	33	15
$x_1 = 80$	U_1/D_4	4	11
	D_1/U_4	57	14
$x_1 = 95$	U_1/D_4	17	23
	D_1/U_4	38	25
x^L	U_1/D_4	43	65
	D_1/U_4	57	25
x^H	U_1/D_4	21	34
	D_1/U_4	95	39
Total	U_1/D_4	64	99
	D_1/U_4	152	64

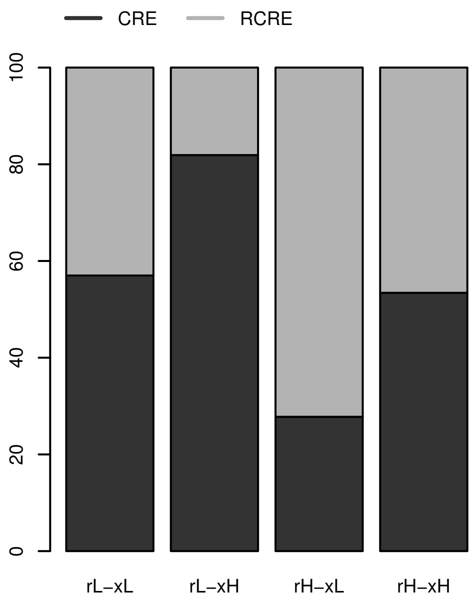

Table 3: Contingency table for IND rejection variable / Frequencies of CRE and RCRE types of rejection for IND axiom

At the aggregate level (table 2) the IND axiom is rejected in 48.65% of the cases for the small ratio and in 36.71% for the high ratio. The difference is significant ($\chi^2 = 12.447$, p-value< 0.001). If we focus on the type of rejection (table 3), D_1/U_4 is more frequently chosen than U_1/D_4 for r^L while the reverse is true for r^H. The difference between the two contexts is significant ($\chi^2 = 35.415$, p-value< 0.001). The difference is also significant at the low outcome level (for x^L, $\chi^2 = 15.319$ p-value< 0.001) and the higher one (for x^H, $\chi^2 = 16.251$ p-value< 0.001). If we consider the data at the x_1 level (with no merging), the frequency of $[D_1/U_4]$ choices for r^L is also significantly higher than for r^H, at all values except $x_1 = 95$ where the statistic is just above the 10% threshold (for $x_1 = 20$: $\chi^2 = 5.293$, p-value$= 0.021$, for $x_1 = 24$: $\chi^2 = 11.479$, p-value$= 0.001$, for $x_1 = 80$: $\chi^2 = 14.762$ p-value< 0.001, and for $x_1 = 95$: $\chi^2 = 2.446$ p-value$= 0.118$).

So, whatever level of aggregation is used, we find significantly more CRE violations for the small ratio value. For high ratio value, it is the other way around, we observe more frequently the U_1/D_4 pattern than D_1/U_4 which corresponds to the reverse common ratio effect[17]. This last result is less known but was already found in Starmer & Sugden (1989). On the outcome dimension, we find that the criterion $[D_1/U_4]$ is more frequently observed than $[U_1/D_4]$ for x^H than for x^L ($\chi^2 = 28.628$, p-value< 0.001) when aggregating the samples over the ratio dimension. These two results about the rate of CRE violations with regards to the ratio and the outcome levels are in line with McCrimmon & Larsson (1979). In conclusion, these first descriptive statistics of the data are consistent with the benchmark studies we are building our experiment on.

4.1 Acceptance versus rejection

In this section, we provide results comparing the rejection versus the acceptance rate for each of the dynamic axioms. Acceptance of the axiom is obtained for the choice patterns U_i/U_j and D_i/D_j, rejection of the axioms for U_i/D_j and U_j/D_i. Table 4 presents the descriptive results and allows to draw two conclusions. First, the rate of rejection does not differ among axioms. Second for all three dynamic axioms, the rate of rejection is affected neither by the ratio level nor by the outcome levels. This result is based on a composite measure which aggregates violations in opposite directions. The impact of the different parameter sets on the type of violations are more specifically studied in section 4.2.

		r^L		r^H	
		x^L	x^H	x^L	x^H
IND	*Accept* : U_1/U_4 - D_1/D_4	54.95	47.75	59.46	67.12
	Reject : U_1/D_4 - D_1/U_4	45.05	52.25	40.54	32.88
CON	*Accept* : U_1/U_2 - D_1/D_2	61.90	62.50	60.11	59.89
	Reject : U_1/D_2 - D_1/U_2	38.10	37.50	39.89	40.11
DC	*Accept* : U_2/U_3 - D_2/D_3	63.49	56.82	65.43	64.84
	Reject : U_2/D_3 - D_2/U_3	36.51	43.18	34.57	35.16
RCL	*Accept* : U_3/U_4 - D_3/D_4	60.36	59.91	61.26	56.31
	Reject : U_3/D_4 - D_3/U_4	39.64	40.09	38.74	43.69

Table 4: Aggregated frequencies.

Result 2 *The frequencies of rejection of CON, DCand RCL axioms:*

(i) are not significantly different from each other whatever level is considered.

(ii) are not affected neither by the ratio nor by the outcomes levels.

[17] This case where the risky option is chosen in the scale up problem and the safe option in the scale down problem. that has been accounted for theoretically by Blavatskyy (2010),

In table 4, we observe that the rate of rejection is similar among the dynamic axioms at each level. None of the Chi-square values of the two by two tests of independence between each dynamic axioms are significant (Table 12 in appendix A). We also observe that the rates of rejection are similar for each dynamic axioms at each level . Based on table 4 for proportions and table 13 in appendix A for chi-square values :

– CON is rejected (both criteria pooled) in 37.75% of the cases for r^L and 40.00% for r^H. This difference is not significant ($\chi^2 = 0.143$ p-value $= 0.705$). When we aggregate over the ratios in table 4, CON is rejected also in about 40% of the cases (more precisely 39.44% and 39.26% respectively for x^L and x^H, this difference being not significant, $\chi^2 = 0.002$ p-value=0.963).
– DC is rejected (both criteria pooled) in 35.06% of the cases for x^L and 37.78% for x^H, which is not significantly different ($\chi^2 = 0.306$ p-value=0.580). DC is more frequently rejected for r^L (40.40%) than for r^H (34.86%), but the difference is not statistically significant ($\chi^2 = 1.188$ p-value=0.276).
– RCL is rejected in 39.86% of the cases for r^L and 41.22% for r^H , a non-significant difference ($\chi^2 = 0.117$ p-value=0.733). The difference of rejection frequency between x^L and x^H (i.e. when we aggregate over the ratios) is also non-significant (39.19% for x^L and 41.89% for x^H, $\chi^2 = 0.565$ p-value=0.452).

The fact that we found no particular effect in this result might appear unfortunate but is mainly due to aggregation of both axioms violation directions which masks possible asymmetry in the violations directions and therefore possible effects of the parameters. This more refined study is presented in the next section and is the one comparable with the existing literature because most of the empirical data available only focuss on CRE violations of axioms.

4.2 Relation between the parameter set and the type of violation

In this section we focus on the two types of violations for each of the dynamic axioms. Recall that the patterns $[D_1/U_2]$, $[D_2/U_3]$ and $[D_3/U_4]$ correspond to dynamic versions of the CRE and will be denoted, for each axiom, as CRE violations. Our approach is systematic and studies the influence of each parameter level (ratio and outcome) on the rate of the two rejection types (CRE versus RCRE). For each result we present a contingency table for the parameter levels and all the tests are presented in table 14 in appendix A.

Result 3 *The CRE violation of CON (D_1/U_2):*

(i) is more frequently observed than RCRE with high outcome level whereas with low outcome level rates of CRE and RCRE violations are even.

(ii) is not affected by the ratio level

		r^L	r^H
$x_1 = 20$	U_1/D_2	11	27
	D_1/U_2	4	9
$x_1 = 24$	U_1/D_2	2	11
	D_1/U_2	7	28
$x_1 = 80$	U_1/D_2	2	6
	D_1/U_2	9	28
$x_1 = 95$	U_1/D_2	3	8
	D_1/U_2	19	31
x^L	U_1/D_2	13	38
	D_1/U_2	11	37
x^H	U_1/D_2	5	14
	D_1/U_2	28	59
Total	U_1/D_2	18	52
	D_1/U_2	39	96

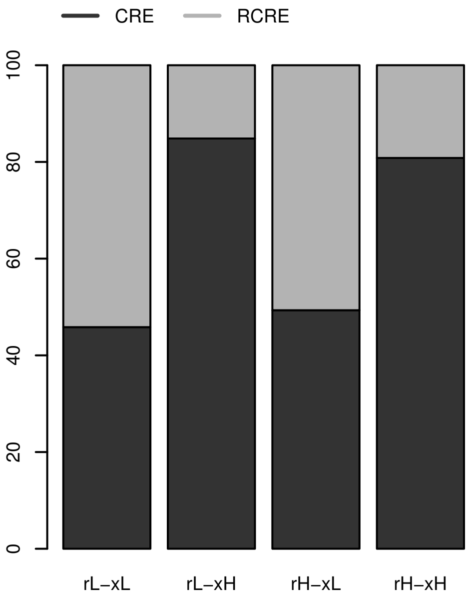

Table 5: Contingency table for CON rejection variable / Frequencies of CRE and R-CRE types of rejection for CON

For i), when we aggregate over the ratio, the distribution of rejections is inverted between the two outcome levels: in table 5, we observe 51.52% of U_1/D_2 and 48.48% of D_1/U_2 for low values of x_1 and 17.92% of U_1/D_2 and 82.08% of D_1/U_2 for high values of x_1. This difference is significant ($\chi^2 = 24.214$ p-value< 0.001). If we test for differences at the ratio level we also find significant differences (for r^L $\chi^2 = 8.066$ p-value=0.005 and for r^H $\chi^2 = 14.743$ p-value< 0.001). For this result, the aggregation process between low outcomes values has an important influence given that, for $x_1 = 20$, we observe much more RCRE than CRE.

Proving ii), the distribution of the rejections between CRE and RCRE is very similar for both ratios at an aggregate level (U_1/D_2: 31.58% and 35.14%, D_1/U_2: 68.42% and 64.86% for respectively r^L and r^H, $\chi^2 = 0.100$, p-value=0.752) and for each aggregated outcome level[18] (for x^L, $\chi^2 = 0.004$, p-value=0.949 and for x^H, $\chi^2 = 0.052$, p-value=0.820). To sum up, the ratio level (r^L or r^H) does not affect the frequency of CRE versus RCRE whether it be at an aggregate level or for each outcome level (table 14).

[18] It is also true for each outcome level, for x_1=20 $\chi^2 = 0.052$ p-value=0.820, for x_1=24 $\chi^2 = 0.003$ p-value=0.959, for x_1=80 χ^2=0.171 p-value=0.679 and for $x_1 = 95$ $\chi^2 = 0.105$ p-value=0.746

These two results reinforce the idea that the counterfactual reasoning involved in the prior lottery problem after the resolution of the prior risk focusses more on the final gains that could have been lost rather than on the probability of having lost these possible gains. Consequently we observe that the outcomes instead of the probability dimension has a non neutral influence on the type of violation of CON.

Result 4 *The CRE violation of DC (D_2/U_3):*

(i) is more frequently observed than RCRE with the small ratio value.

(ii) is not affected by the outcome level

		r^L	r^H
$x_1 = 20$	U_2/D_3	2	16
	D_2/U_3	9	15
$x_1 = 24$	U_2/D_3	2	18
	D_2/U_3	10	16
$x_1 = 80$	U_2/D_3	3	16
	D_2/U_3	16	25
$x_1 = 95$	U_2/D_3	10	10
	D_2/U_3	9	13
x^L	U_2/D_3	4	34
	D_2/U_3	19	31
x^H	U_2/D_3	13	26
	D_2/U_3	25	38
Total	U_2/D_3	17	60
	D_2/U_3	44	69

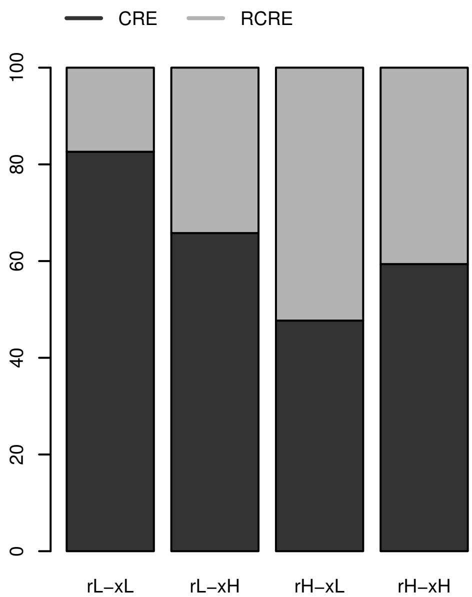

Table 6: Contingency table for DC rejection variable / Frequencies of CRE and R-CRE types of rejection for DC

As shown in result 2, the *DC* axiom is more frequently rejected for r^L (40.40%) than for r^H (34.86%), but the difference is not statistically significant ($\chi^2 = 1.188$ p-value=0.276). However 72.13% of the rejection cases for r^L are due to the D_2/U_3 type against 53.49% for r^H, a significant difference ($\chi^2 = 5.224$ p-value=0.022). More precisely we observe in table 6 that the ratio value affects the rejection type when the x_1 values are low ($\chi^2 = 7.079$ p-value=0.008) but not when the

x_1 values are high ($\chi^2 = 0.188$ p-value=0.664). Moreover the distribution of the rejections between the two types is very similar for both outcomes levels at an aggregate level (D_2/U_3: 56.82% and 61.76%, U_2/D_3: 43.18% and 38.24% for respectively x^L and x^H, $\chi^2 = 0.296$, p-value=0.586) or for both ratio levels (for r^L, $\chi^2 = 1.266$, p-value=0.260 and for r^H, $\chi^2 = 1.331$, p-value=0.249). So, the outcome level (x^L or x^H) does not affect the frequency of $[D_2/U_3]$ whether it be at an aggregate level or for each ratio level (table 14).

We also performed a within-subject test for those participants who answered the prior lottery problem, for both $r^L = 0.3$ and $r^H = 0.7$. Whatever the outcome level ($x_1 = 20$, 24, 80 or 95) we do not observe any significant difference between the numbers of acceptances and rejections for r^L and r^H (Mc Nemar change test, $x_1 = 20$: $\chi^2 = 0.750$ p-value=0.387, $x_1 = 24$: $\chi^2 = 0$ p-value=1, $x_1 = 80$: $\chi^2 = 0.842$ p-value=0.359, $x_1 = 95$: $\chi^2 = 1.389$ p-value=0.239). There is also no significant difference between CRE choices for r^L and r^H except for $x_1 = 20$ (Mc Nemar change test, $x_1 = 20$: $\chi^2 = 3.125$ p-value=0.077, $x_1 = 24$: $\chi^2 = 1.777$ p-value=0.182, $x_1 = 80$: $\chi^2 = 1.388$ p-value=0.239 and $x_1 = 95$: $\chi^2 = 0.100$ p-value=0.752). This emphasizes the fact that a dynamically inconsistent participant (in the CRE direction) for r^H is also dynamically inconsistent (in the CRE direction) for r^L.
These results show that violations of DC are driven by the ratio level. This may be explained by the fact that the only difference between the two-stage and the prior lottery problems is the timing of resolution of the first stage lottery. It seems therefore not too surprising that the key variable in terms of behavioral impact is its probability.

Result 5 *The RCRE violation of RCL (D_3/U_4):*

(i) is more frequently observed for high ratio values than CRE whereas with for low ratio values the rates of CRE and RCRE violations are even.
(ii) is not affected by the outcome level

At the aggregate level the ratio does not affect the frequency of rejection of the RCL axiom (table 4 and 13), since the rejection frequency is around 40% for both samples ($\chi^2 = 0.117$, p-value $= 0.773$). However, the distribution of CRE versus RCRE is very different depending on the ratio. For r^L, CRE (D_3/U_4 pattern) represents 50.28% of the rejections (table 7) while it only represents 21.86% for r^H. This difference is significant at an aggregate level ($\chi^2 = 30.392$, p-value < 0.001). At the aggregated outcome level this difference is also significant (for x^L, $\chi^2 = 8.013$ p-value $= 0.005$ and for x^H, $\chi^2 = 22.919$ p-value < 0.001). Finally this result is also obtained

		r^L	r^H
$x_1 = 20$	U_3/D_4	22	26
	D_3/U_4	24	15
$x_1 = 24$	U_3/D_4	22	36
	D_3/U_4	20	9
$x_1 = 80$	U_3/D_4	17	43
	D_3/U_4	30	10
$x_1 = 95$	U_3/D_4	27	38
	D_3/U_4	15	6
x^L	U_3/D_4	44	62
	D_3/U_4	44	24
x^H	U_3/D_4	44	81
	D_3/U_4	45	16
Total	U_3/D_4	88	143
	D_3/U_4	89	40

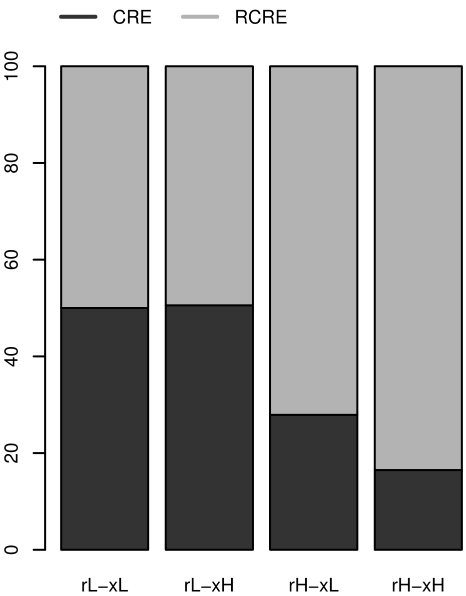

Table 7: Contingency table for RCL rejection variable / Frequencies of CRE and R-CRE types of rejection for RCL

for all outcome levels except for x_1=20, (for $x_1 = 20$: $\chi^2 = 1.546$ p-value $= 0.214$, for $x_1 = 24$: $\chi^2 = 6.266$ p-value $= 0.012$, for $x_1 = 80$: $\chi^2 = 19.151$ p-value< 0.001 and for $x_1 = 95$: $\chi^2 = 4.5432$ p-value=0.033). Finally, the outcome level (x^L or x^H) does not affect the frequency of $[D_3/U_4]$ whether it be at an aggregate level ($\chi^2 = 1.283$ p-value $= 0.157$) or for each ratio level (for r^L, $\chi^2 = 0.006$ p-value $= 0.940$ and for r^H, $\chi^2 = 2.840$ p-value $= 0.092$).

4.3 Within subject analysis and robustness of the results

In the previous section we displayed aggregated results depending on the parameter dimension we aimed to study. If a within-subject protocol was necessary in order to obtain each axiom variable, this analysis was run in a between-subject perspective. This technic allows us to maintain at a reasonable level the number of observations required to draw conclusions about the influence of each parameter dimension on the rate of CRE and RCRE violations for each axiom. However, it is possible to further exploit the within-subject characteristic of our protocol by evaluating for each set of parameter the number of violated dynamic axioms depending on the violation or not of the independence axiom (1 or 3 if independence is violated, 0 or 2 when independence is verified). This allows us to define individual type depending on the number of switches between U and D from a decision task to another: EU subjects verifying IND and all the three dynamic axioms (O switch-type), coherent Non-EU subjects violating IND and only one dynamic axiom (1 switch-type), static EU subjects verifying IND but violating two dynamic axioms in opposite directions (2 switches-type) and random Non-EU subjects who violate IND and all three dynamic axioms for the same parameter set (3 switches-type)[19]. In addition, we can evaluate the robustness of the results presented in the previous section by excluding anomalous subjects from our sample.

4.3.1 Multiple switches statistics

In Table 8, we present the number of switches observed for each parameter set on the sample of subjects that answered all four decision tasks. Over the 16 possible patterns of choices in the four decision tasks, 2 correspond to 0 switch (U or D for all four problems), 2 correspond to 3 switches, 6 to 1 switch and 6 to 2 switches. Thus a proper comparison of frequencies should be made only between 0 and 3-switches types and 1 and 2-switches types.

# switches	r^L 20	24	80	95	Total	r^H 20	24	80	95	Total	Total
0	5	13	6	13	37	24	34	25	26	109	146
	17.86	*37.14*	*15.79*	*26*	*24.50*	*28.24*	*33.01*	*27.17*	*28.89*	*29.46*	*28.02*
1	13	15	22	18	68	30	30	18	38	116	184
	46.43	*42.86*	*57.89*	*36*	*45.03*	*35.29*	*29.13*	*19.57*	*42.22*	*31.35*	*35.32*
2	7	6	9	15	37	24	34	44	22	124	161
	25	*17.14*	*23.68*	*30*	*24.50*	*28.24*	*33.01*	*47.83*	*24.44*	*33.51*	*30.90*
3	3	1	1	4	9	7	5	5	4	21	30
	10.71	*2.86*	*2.63*	*8*	*5.96*	*8.24*	*4.85*	*5.43*	*4.44*	*5.68*	*5.76*
NA	83	76	73	61	293	26	8	19	21	74	367

Table 8: Effectives and frequencies of switches

Result 6 *About two third of the subjects violate one or no dynamic axiom while one quarter of the subjects verify IND and violate two dynamic axioms in opposite directions.*

First, the proportion of subjects that systematically switch from U to D from a decision problem to another is very low (around 6%) in comparison to the 0-switch type. This 3-switches type is hard to explain from a theoretical perspective and most likely reveals pure randomness in the subjects' answers. Between 25% and 35% of our subjects behave accordingly with the independence axiom and its dynamic extensions. They therefore always choose the same option (U or D) in each of the 4 decision tasks (0-switch type). They could be thought as expected utility maximizer both in a static and a dynamic framework. This proportion is consistent with other experimental classification results between EU and Non-EU subjects (Bruhin et al. 2010). The most observed type

[19] We thank an anonymous referee for suggesting us to explore this dimension of our data and to run this fruitful analysis.

in our sample is the one we are interested in, i.e. subjects who are not verifying the independence axiom and that consequently do not verify one and only one dynamic axiom. These subjects fit in the framework of the theorems of Karni & Schmeidler (1991) and Volij (1994). This type is observed more frequently for small than for high ratio. This is consistent with the fact that we observe more violations of independence for a small ratio. Finally, there is a last type that has never been investigated neither in the theoretical nor in the experimental literature, i.e. subjects who satisfy the independence axiom but violate two dynamic axioms. This case is possible on a theoretical point of view and would suggest that preferences revealed on single stage prospects could be totally independent of the one revealed on multiple stage prospects. Nevertheless, we observe that between 25% and 30% of our subjects are of this 2-switches type. This is a significant proportion of our sample. Therefore it is important to determine if these two switches are random which would suggest that this type should be threaten as noise like the 3-switches type or if these two switches are more systematic which would suggest that this type is behaviorally grounded. Next section investigates this question.

4.3.2 2-switches subjects

In this section, we isolated the 2-switches subjects for each parameter set. The 6 possible profiles are presented in table 9. CRE violations correspond to profiles 3 and 4 for CON, profiles 2 and 5 for DC and profiles 1 and 6 for RCL. In table 15, we present the descriptive statistics of these 6 profiles for each parameter set.

Profiles	CON	DC	RCL	r^L	r^H	Total
$RCRE_{con}/CRE_{rcl}$	U_1/D_2	D_2/D_3	D_3/U_4	2 *5.41*	10 *8.06*	12 *7.45*
$RCRE_{con}/CRE_{dc}$	U_1/D_2	D_2/U_3	U_3/U_4	6 *16.22*	6 *4.84*	12 *7.45*
$CRE_{con}/RCRE_{rcl}$	D_1/U_2	U_2/U_3	U_3/D_4	8 *21.62*	37 *29.84*	45 *27.95*
$CRE_{con}/RCRE_{dc}$	D_1/U_2	U_2/D_3	D_3/D_4	4 *10.81*	25 *20.16*	29 *18.01*
$CRE_{dc}/RCRE_{rcl}$	D_1/D_2	D_2/U_3	U_3/D_4	13 *35.14*	43 *34.68*	56 *34.78*
$RCRE_{dc}/CRE_{rcl}$	U_1/U_2	U_2/D_3	D_3/U_4	4 *10.81*	3 *2.42*	7 *4.35*

Table 9: Profiles of 2-switches subjects

Result 7 *For the 2-switches types, CRE violations of CON and RCRE violations of RCL represent more than 75% of the subsample.*

We observe that for all our parameter sets, the profiles 3 and 5 represent more than 50% of the 2-switches types. These two profiles correspond to RCRE behavior in RCL (i.e. U_3/D_4). In particular, profile 5 correspond to CRE behavior in DC. Table 15 in appendix A shows that the profiles distribution within 2-switches subjects is not random as profiles 3, 4 and 5 contains more than 75% of the effectives for each parameter set.

In addition, an interesting feature of these within subject analysis is that it sheds light on one of the between subject results of Cubitt et al. (1998). Indeed, they detect a significant difference between the frequencies of choices of U in S_2 and S_3 (28.9% versus 66.7%) suggesting a CRE violation of DC, but also between the frequencies of choices of U in S_3 and S_4 (66.7% versus 48.1%) suggesting, on the contrary, a RCRE violation of RCL. These two results seems paradoxical with the hypothesis of a representative agent either verifying independence, either exhibiting CRE behavior and violating one and only one dynamic axiom. In fact, under this assumption, the frequencies of choices of U should be increasing from S_1 to S_4. Our study of 2-switches reconcile these two apparently contradictory results of Cubitt et al. (1998) because our within subject protocol allows identification of subject verifying independence but not some dynamic axioms whereas it is not possible with a between-subject protocol.

This section supports the idea that preferences towards dynamic prospects are not only a subset of preferences towards single stage prospects because they characterize more complex behavioral traits. This is consistent with the finding of subjects that verify the independence axiom in a static context but that can be influenced in opposite directions by the different characteristics of the timing of resolution of uncertainty (ex-post, ex ante or simultaneous).

However, we cannot exclude the possibility of these 2-switches type subjects just be due to tremble or noise. Therefore it is necessary to check that the results we presented in section 4.2 are robust to their exclusion of our analysis.

4.3.3 Robustness

In this section, we exclude the 2 and 3-switches types from our analysis and present in Table 10, the contingency tables of the rejection types for each dynamic axiom.

Result 8 *All the results presented in section 4.2 are preserved on this subsample and we detect stronger effect than on the whole sample.*

- Result 3 holds : For CON, CRE is observed more frequently for high outcomes than for low outcomes. More precisely, 72.22% of U_2/D_3 and 27.78% of D_3/U_2 are observed for low outcomes, while the frequencies are respectively 14.63% and 85.37% for high outcomes, the difference is statistically significant ($\chi^2(1)$=23.857 p-value<0.001). The difference is also significant for

		CON		DC		RCL	
		r_L	r_H	r_L	r_H	r_L	r_H
x_L	U/D	6	20	2	15	12	17
	D/U	6	4	9	5	23	9
x_H	U/D	1	5	1	7	13	19
	D/U	15	20	13	4	32	8
Total	U/D	7	25	3	22	25	36
	D/U	21	24	22	9	55	17

Table 10: Effectives for each axioms, without 2 and 3 switchs subjects

each ratio level (r_L: $\chi^2(1) = 4.861$ p-value=0.027, r_H : $\chi^2(1) = 17.202$ p-value<0.001). If we aggregate the outcome levels and test for the effects of the ratio, the frequencies of observation of (U_2/D_3, D_3/U_2) for r_L and r_H are respectively (25%, 75%) and (51.02%, 48.98%), a difference significant ($\chi^2(1) = 3.954$ p-value=0.047).

– Result 4 holds : For DC, CRE is observed more frequently than RCRE for small ratio whereas it is the contrary for high ratio, thus the ratio has a significant impact on the rejection criterion ($\chi^2(1) = 17.159$ p-value<0.001). There is no outcomes effect ($\chi^2(1) = 2.070$ p-value=0.150).

– Result 5 holds : For RCL, CRE is observed more frequently than RCRE for small ratio whereas it is the contrary for high ratio, thus the ratio has a significant impact on the rejection criterion ($\chi^2(1) = 15.824$ p-value<0.001). There is no outcomes effect ($\chi^2(1) = 0.033$ p-value=0.855).

4.4 Associations

Result 9 *Whatever level is considered (global, aggregated over ratios and aggregated over outcomes) there is an association between the acceptance/rejection of IND and CON. For the other axioms, we find no association.*

		$IND * RCL$	$IND * CON$	$IND * DC$
	Total	1.496^{ns}	16.519^{***}	1.904^{ns}
ratios aggregated	x^L	0.689^{ns}	7.550^{***}	7.266^{***}
	x^H	1.514^{ns}	8.236^{***}	0.276^{ns}
outcomes aggregated	r^L	0.215^{ns}	6.232^{**}	0.631^{ns}
	r^H	1.597^{ns}	10.436^{***}	0.712^{ns}

^{ns} not significant *** 1%, ** 5%

Table 11: Chi-square values for association between axiom's rejection variables

Table 11 reports the Chi-square values of the two by two tests of association between the two modality variables (Accept/Reject) for IND and each dynamic axiom. For CON, we find a systematic significant association between the two variables. For the other axioms, there is no significant association (except for DC for small outcomes values). Given the analysis presented in section 4.3, this result reinforces the idea that dynamic preferences are not necessarily connected to preferences over single stage prospects. It is therefore not surprising to find that CON is the axiom that relates the closest to IND as the prior lottery problem also involves choices between single stage prospects (although a prior uncertainty has been resolved). This result gives credit to the argument of Machina (1989) saying that CON is a dynamic version of IND. It also suggests that choices involving multiple stage lotteries require other reasoning mechanisms than the one used in standard static choices.

5 Conclusion

This study provides new empirical evidence concerning individual dynamic preferences. Taking McCrimmon & Larsson (1979) and Cubitt et al. (1998) as a starting point, we go further than these studies insofar our experimental design takes account of individuals' heterogeneity[20] in allowing multiple tests of behavioral axioms at the individual level. This design allows us to test for the acceptance/rejection of all three dynamic axioms (RCL, CON, and DC) and of the independence axiom at an individual level. On the one hand, it brings out the influence of the ratio value and of the outcome level on the rate of violation of these axioms and more specifically on the rate of violation corresponding to the Common Ratio Effect versus the Reverse Common Ratio Effect. On the other hand, it provides information at an individual level about the link between violations of the Independence axiom and its dynamic extensions. In fact, we test the implicit theoretical assumption stating that the violation of a dynamic axiom necessarily implies the violation of independence and find that it is not always verified. Finally, we test the association between independence and each of the dynamic axioms.

Experimental investigation of individual attitudes toward dynamic prospects faces several methodological difficulties : complexity of the decision task, loss of data induced by the prior lottery problem and correct incentivization of the experiment. We construct our experimental design under these constraints and on this last issue, we prefer to use hypothetical incentives[21] ; nevertheless our data is in line with the aforementioned benchmark studies on CRE and dynamic preferences. Our study reveals that none of the dynamic axioms are more rejected than others and that their rejection rates are not affected by the ratio or outcome levels. However, for each dynamic axiom, the rate of CRE violations versus RCRE violations depends on the ratio and outcome values as follows : (i) for Consequentialism, the rate of CRE violations is higher than RCRE for large

[20] For a discussion of the differences between within- and between-subjects experiments, see for example Ballinger & Wilcox (1997)

[21] Nebout & Willinger (2012) use real incentives (RIS) and collected data that, for DC and CON , are consistent with the one presented in this paper.

outcome levels but does not depend on the ratio level, (ii) for Dynamic Consistency, the frequency of CRE is higher than RCRE for large ratio levels but does not depend on the outcomes level and (iii) for the Reduction of Compound Lotteries the frequency of RCRE is higher than CRE for high ratio levels but does not depend on the outcomes level. For CON, this result could be explained by the fact that the counterfactual reasoning involved in the evaluation of the prior lottery problem by a Non-Consequentialist decision maker is probably less focused on the probability of occurrence of a forgone event than on the level of the outcome that could have been lost. This could plead in favor of an interpretation of Non-Consequentialist behavior in terms of changing reference point as proposed by Barkan & Busemeyer (2003)[22]. For DC, as the main difference between the prior and the two stage problems resides in the timing of resolution of the first stage lottery, it seems appropriate that its probability is the relevant variable to consider when looking at choice differences between the two problems.

In addition, our within-subject analysis allows us to distinguish between EU subject verifying IND and all three dynamic axioms, coherent Non-EU subjects violating IND and only one dynamic axiom, static EU subjects verifying IND but violating two dynamic axioms in opposite directions and finally random Non-EU subjects who violate IND and all three dynamic axioms for the same parameter set. We find that about two thirds of the subjects violate one or no dynamic axioms (EU and coherent Non-EU) while one quarter of the subjects verify IND and violate two dynamic axioms in opposite directions. For this last subsample, we find that the two violations are not random as more than 75% of these subjects exhibit CRE violations of CON and RCRE violations of RCL. This suggested that static and dynamic preferences are not as intimately connected as maintained in the theoretical literature. This idea is reinforced by the fact that we only found an association between IND and CON when we crossed the acceptance/rejection variables between independence and each of the dynamic axioms. This result is consistent with Machina (1989)'s claim saying that: "consequentialism is essentially a dynamic version of the separability that non-expected utility maximizers reject", p1642.

This study on the violation of the Independence axiom in the CRE fashion could also be carried out with the common consequence version of the Allais paradoxes. Our study of independence under risk may also be extended to the case where the probabilities in the lotteries are unknown as in Maher & Kashima (1997) who build an experiment on the three colour Ellsberg paradox and also test the influence of the resolution of uncertainty on individual preferences in the case of uncertainty.

[22] In the case of what these authors call dynamic inconsistency which a more general definition than ours and could also be due to Non-Consequentialism using our terminologies.

In conclusion, this experimental study is compatible with the revealed preference paradigm because each decision problem consists of a single binary choice between well-defined prospects. However the set of prospects over which these dynamic preferences are defined is more complicated than the set of single stage lotteries used in the standard models of decision under risk. This set contains lotteries that could have multiple stages and different timing of resolution of uncertainty. The experimental results presented deepen our understanding of the independence axiom and of the probability mixture operation in a dynamic framework. Our findings may be relevant to the study of sequential decision making (i.e. where more than one decision are involved). Indeed, an interesting topic for future research in this direction would be to use, as a primitive, a preference relation that remains observable (unlike plans or strategies) and incorporates the dynamic characteristics that are relevant in sequential decision problems. For example, Nebout (2012) and Nebout & Willinger (2012) use this approach in order to propose a categorization and a way to reveal strategies in sequential decision problems given the properties of the dynamic preferences (i.e. acceptance or rejection of DC, CON and RCL).

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Appendices

A Additional statistics

		*RCL * CON*	*RCL * DC*	*CON * DC*
	Global	0.148^{ns}	2.120^{ns}	0.799^{ns}
ratios aggregated	x^L	0.600^{ns}	0.995^{ns}	0.852^{ns}
	x^H	0.378^{ns}	1.016^{ns}	0.070^{ns}
outcomes aggregated	r^L	0.132^{ns}	0.000^{ns}	0.125^{ns}
	r^H	0.779^{ns}	3.181^{ns}	1.870^{ns}

^{ns} not significant *** 1%, ** 5%

Table 12: Chi-square values of association between Accept/Reject variables

		IND	RCL	CON	DC
r^L vs. r^H	Total	12.447^{***}	0.117^{ns}	0.143^{ns}	1.188^{ns}
	x^L	0.388^{ns}	0.010^{ns}	0.011^{ns}	0.016^{ns}
	x^H	16.251^{***}	0.453^{ns}	0.078^{ns}	1.299^{ns}
x^L vs. x^H	Total	0.000^{ns}	0.565^{ns}	0.002^{ns}	0.306^{ns}
	r^L	2.029^{ns}	0.000^{ns}	0.009^{ns}	0.430^{ns}
	r^H	2.482^{ns}	0.930^{ns}	0.004^{ns}	0.000^{ns}

^{ns} not significant *** 1%, ** 5%

Table 13: Chi-square values for Accept/Reject variables depending of the parameter levels.

		IND	RCL	CON	DC
r^L vs. r^H	Total	35.415^{***}	30.392^{***}	0.100	5.224^{**}
	x^L	15.319^{***}	8.013^{**}	0.004	7.079^{**}
	x^H	16.251^{***}	22.919^{***}	0.052	0.188
x^L vs. x^H	Total	28.628^{***}	1.283	24.214^{***}	0.296
	r^L	14.793^{***}	0.006	8.066^{**}	0.260
	r^H	10.068^{**}	2.840	14.743^{***}	1 .331

*** 1%, ** 5%

Table 14: Chi-square values of the independence tests between CRE and RCRE for different parameter levels

	r=0.3					r=0.7					
Profile	20	24	80	95	Total	20	24	80	95	Total	Total
1	1	1	0	0	2	6	2	2	0	10	12
	14.29	*16.67*	*0*	*0*	*5.41*	*25*	*5.88*	*4.55*	*0*	*8.06*	*7.45*
2	2	1	1	2	6	1	1	1	3	6	12
	28.57	*16.67*	*11.11*	*13.33*	*16.22*	*4.17*	*2.94*	*2.27*	*13.64*	*4.84*	*7.45*
3	1	2	1	4	8	4	13	11	9	37	45
	14.29	*33.33*	*11.11*	*26.67*	*21.62*	*16.67*	*38.24*	*25*	*40.91*	*29.84*	*27.95*
4	0	0	1	3	4	4	8	8	5	25	29
	0	*0*	*11.11*	*20*	*10.81*	*16.67*	*23.53*	*18.18*	*22.73*	*20.16*	*18.01*
5	3	2	5	3	13	7	9	22	5	43	56
	42.86	*33.33*	*55.56*	*20*	*35.14*	*29.17*	*26.47*	*50*	*22.73*	*34.68*	*34.78*
6	0	0	1	3	4	2	1	0	0	3	7
	0	*0*	*11.11*	*20*	*10.81*	*8.33*	*2.94*	*0*	*0*	*2.42*	*4.35*

Table 15: Effectives and frequencies of each profile for 2-switches subjects

B Screenshots

Fig. 3: Scaled up problem (S1)

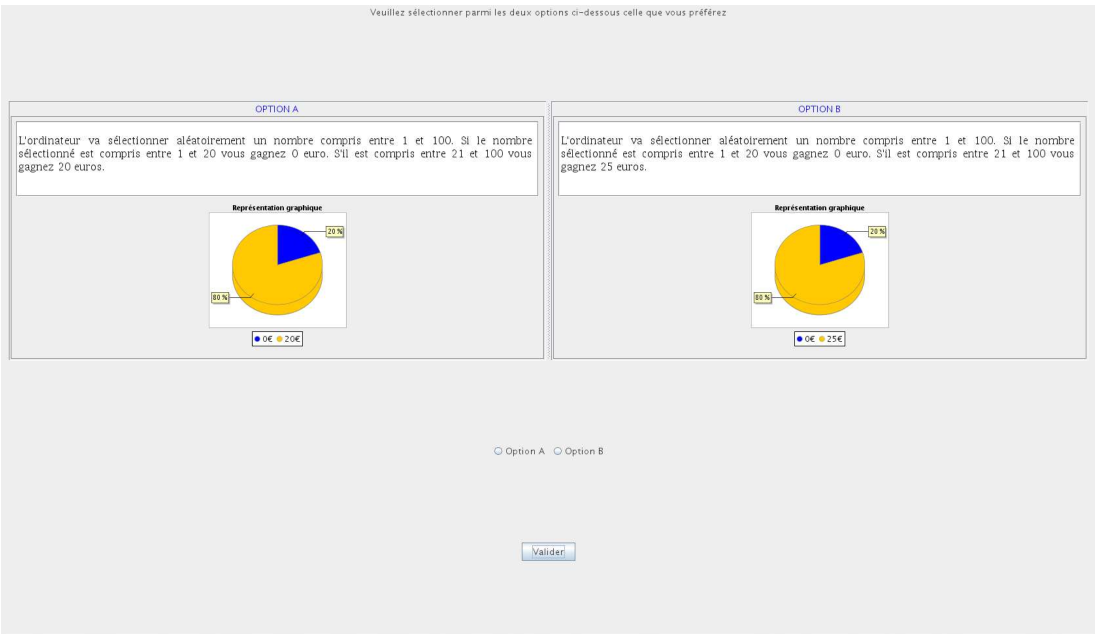

Fig. 4: Scaled down problem (S4)

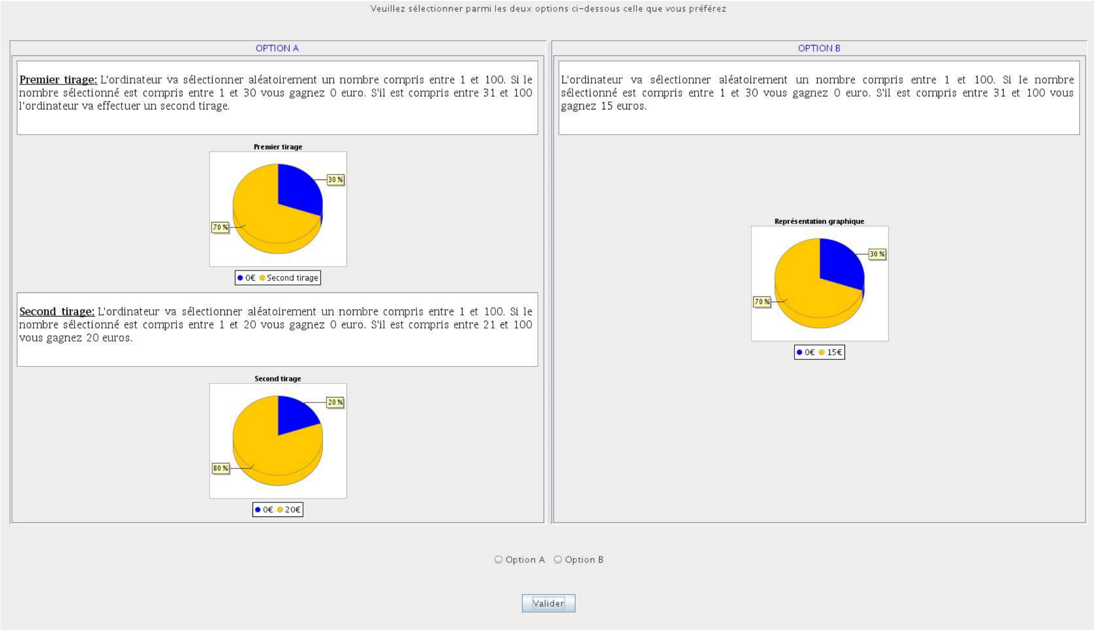

Fig. 5: Two stages problem (S3)

Fig. 6: Prior lottery problem (S2)

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Contact :

Stéphane MUSSARD : mussard@lameta.univ-montp1.fr