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Mickael Beaud, Marc Willinger

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Mickael Beaud, Marc Willinger
Laboratoire Montpelliérain d'Economie Théorique et Appliquée (LAMETA), Université Montpellier 1, 34960 Montpellier, France
{beaud@lameta.univ-montp1.fr, willinger@lameta.univ-montp1.fr}

We report on a within-subject experiment, with substantial monetary incentives, designed to test whether or not people are risk vulnerable. In the experiment, subjects face the standard portfolio choice problem in which the investor has to allocate part of his wealth between one safe asset and one risky asset. We elicit risk vulnerability by observing each subject's portfolio choice in two different contexts that differ only by the presence or absence of an actuarially neutral background risk. Our main result is that most of the subjects are risk vulnerable: 81% chose a less risky portfolio when exposed to background risk. More precisely, 47% invested a strictly smaller amount in the risky asset, whereas 34% were indifferent. Furthermore, contrasting the predictions provided by competing decision-theoretic models, we conclude that expected utility theory best fits our experimental data.

Keywords: background risk; incomplete markets; portfolio choice; risk vulnerability; lab experiment
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1. Introduction

Most individuals are exposed to several risks simultaneously. Although for some risks individuals can choose their preferred level, there are other risks to which individuals are simply exposed without control, i.e., risks that are nondiversifiable or noninsurable. The fundamental implication of this fact is that there is no risk-free situation for individuals. On the one hand, diversification is limited because of systematic risk. Indeed, economic fluctuations caused by natural disasters, nuclear hazards, financial crisis, wars, or popular uprisings cannot be fully insured. On the other hand, because of informational asymmetries, nontransferability, transaction costs, or budget constraints, there exists many idiosyncratic risks for which full insurance is not feasible. In any event, some risks remain inevitably in the background. All such committed but unresolved risks constitute what is usually called the *background risk*.

Depending on the structure of individuals' preferences, the presence of background risk may lead to more or less cautious behavior, thereby affecting the price of risk in the economy. Thus, taking into account the background risk to which individuals are exposed can significantly improve our understanding of risk-taking behavior in many economically relevant contexts. Examples include the demand for insurance (Doherty and Schlesinger 1983, Eeckhoudt and Kimball 1992, Meyer and Meyer 1998), portfolio choices and asset prices (Mehra and Prescott 1985; Weil 1992; Finkelshtain and Chalfant 1993; Heaton and Lucas 1997, 2000; Franke et al. 1998, 2004), and efficient risk sharing (Gollier 1996, Dana and Scarsini 2007).

The fundamental conjecture upon which this literature rests is that risk-averse individuals consider independent risks as substitutes rather than as complements. According to Gollier and Pratt (1996, p. 1109),

> Conventional wisdom suggests that independent risks are substitutes for each other. In particular, adding a mean-zero background risk to wealth should increase risk aversion to other independent risks. However, risk aversion is not sufficient to guarantee this.

Relying on von Neumann and Morgenstern's (1944) expected utility (EU) theory, Gollier and Pratt (1996) identified "risk vulnerability" as the weakest restriction to impose on the Bernoulli utility function of a decreasingly risk-averse individual to guarantee that he or she would behave in a more cautious way if an actuarially neutral background risk is added to his or her initial wealth, be it random or not.[1] Since the seminal contribution of Pratt (1964) and Arrow (1971), it is well known that the absolute risk aversion function governs the risk-taking behavior of individuals with EU preferences. Therefore, the comparative statics properties of risk vulnerability are derived directly from the standard comparative statics properties of comparative risk aversion.[2]

In the framework of EU, risk vulnerability fits nicely to commonly accepted restrictions that have

[1] See Propositions 2 and 4 of Gollier and Pratt (1996).

[2] See Theorem 1 of Pratt (1964).

important and desirable comparative statics properties: risk vulnerability implies decreasing absolute risk aversion (DARA) and is implied by both Pratt and Zeckhauser's (1987) proper risk aversion and Kimball's (1993) standard risk aversion.[3] Because risk vulnerability is necessary to obtain desirable comparative statics properties in many economic contexts, the question of whether or not most individuals' behavior actually exhibits risk vulnerability is of paramount interest for economic analysis under EU. Yet the empirical relevance of the risk vulnerability conjecture is beyond the scope of EU theory because it represents an issue for any decision-theoretic modeling.

In contrast, Quiggin (2003) showed that, for the wide class of risk-averse generalized expected utility preferences that exhibit constant risk aversion in the sense of Safra and Segal (1998) and Quiggin and Chambers (1998), independent risks are actually complementary: an individual who is exposed to background risk would be willing to take more foreground risk. In particular, under Yaari's (1987) dual theory (DT), individuals exhibit constant risk aversion and therefore contradict the risk vulnerability conjecture by behaving in a less cautious way when exposed to background risk.

Because alternative theories have different best-guess predictions about the impact of background risk on risk-taking behavior, there is a need for empirical evidence about risk vulnerability to contrast predictions with data. More broadly, the validity of the risk vulnerability conjecture is a relevant issue for decision-theoretic modeling in the context of multiple risks.

In this paper, we provide experimental evidence about the impact of an actuarially neutral background risk on individuals' risk-taking behavior. We report on a within-subject experiment, with substantial monetary incentives, designed to test whether or not people are risk vulnerable. In the experiment, subjects face a simple portfolio choice problem for which they have to allocate part of their wealth between a safe and a risky asset. We elicit risk vulnerability by observing each subject's portfolio choice in two different contexts that differ only by the presence of an actuarially neutral background risk. Our main result is that most of the subjects are risk vulnerable: 81% chose a less risky portfolio when exposed to background risk. More precisely, 47% invested a strictly smaller amount in the risky asset, whereas 34% were indifferent. Thus, only 19% of the subjects contradict the risk vulnerability conjecture.

In addition, we explore the theoretical predictions about the impact of background risk on the optimal portfolio choice obtained under various preference representations. We separately consider Quiggin's (1982) rank dependent utility (RDU) theory and its two dual special cases: EU and DT. We show that these theories have contrasted predictions about the impact of background risk on the optimal portfolio choice. We also explore the impact of background risk under Tversky and Kahneman's (1992) cumulative prospect theory (CPT). We show that, depending on how the reference point of CPT -investors is affected by the presence of background risk, CPT can predict the presence or absence of risk vulnerability. Finally, we consider the generalization of CPT proposed by Schmidt et al. (2008)—namely, third-generation prospect theory (PT^3), in which the reference point can be a lottery. We show that under PT^3, the exposition to background risk does not affect the optimal portfolio choice. Hence, contrasting the predictions of competing decision-theoretic models, we conclude that the EU theory best fits our experimental data.

The remainder of the paper is organized as follows. Section 2 briefly reviews previous empirical research on risk vulnerability. Section 3 describes our experimental design. Section 4 provides the theoretical foundation for our elicitation procedure of risk vulnerability and presents the predictions for the portfolio choice problem under the above-mentioned alternative decision-theoretic models. Section 5 reports our experimental findings. Section 6 concludes.

2. Evidence of Risk Vulnerability

To the best of our knowledge, few studies have attempted to question whether people are risk vulnerable. Using naturally occurring data, Guiso et al. (1996) found that investment in risky financial assets responds negatively to income risk, and Guiso and Paiella (2008) showed that individuals who are more likely to face income uncertainty or to become liquidity constrained exhibit a higher degree of absolute risk aversion.

Based on a framed field experiment, Harrison et al. (2007) found strong evidence in favor of risk vulnerability for numismatists. They relied on Holt and Laury's (2002) multiple price list methodology to elicit traders' risk aversion under three alternative incentives—monetary prizes, graded coins, and ungraded coins—that entailed background risk. Their estimates show that using ungraded coins in the lotteries sharply increased the level of risk aversion of coin traders compared with the conditions where monetary prizes or graded coins were used.[4] They

[3] In fact, DARA is equivalent to vulnerability to sure losses, whereas properness and standardness are equivalent to vulnerability to background risks that reduce expected utility and increase expected marginal utility, respectively.

[4] A similar field experiment was carried out with students and farmers by Herberich and List (2012).

suggest that it would be worth exploring further the extent of their empirical findings on the basis of a controlled laboratory experiment aimed at isolating the impact of background risk on risk-taking behavior.

Lee (2008) reported experimental findings from a laboratory experiment with the aim of comparing the random round payoff mechanism (RRPM) with a system where all rounds are being paid, the accumulated payoff mechanism (APM). In each round subjects had to perform two tasks. Task 1 was a risk-taking decision for which subjects had to trade off a higher (lower) probability of winning for a lower (higher) prize. Task 2 was identical except that the event of winning was not determined by a chance event but by the choice made by an opponent player. According to the author, the RRPM entails background risk because the subject has to make a decision for task 1 without knowing the outcome of task 2, whereas in the APM treatment the subject knows his accumulated wealth for both tasks 1 and 2. The main finding is that risk-averse subjects tend to behave in a more cautious way under RRPM than under APM. But the data are scarce and the results not clear-cut.

Our study is more closely related to Lusk and Coble (2008), who explicitly designed a laboratory experiment to test the risk vulnerability conjecture. Their experiment involved 130 subjects each endowed with \$10 based on Holt and Laury's (2002) method in a between-subjects design: 50 subjects faced no background risk, 27 subjects faced a zero-mean background risk $(-\$10, 1/2; \$10, 1/2)$, and 53 subjects faced an unfair background risk $(-\$10, 1/2; \$0, 1/2)$. The impact of background risk on risk aversion was measured by comparing the subjects' number of safe choices across treatments. The authors found weak evidence of risk vulnerability: the median number of safe choices is identical in the three treatments (6 safe choices), and a slightly greater mean number of safe choices was observed in the zero-mean background risk treatment (5.89 safe choices) and the unfair background risk treatment (5.68 safe choices) compared with the no background risk treatment (5.40 safe choices).[5]

Finally, a few recent unpublished field experiments (Cameron and Shah 2012, Bchir and Willinger 2013) found empirical evidence in support of the risk vulnerability conjecture.

3. Experimental Design

To identify risk vulnerability, we rely on a within-subject design. The experiment is based on the standard portfolio choice problem in which the investor has to allocate part of his wealth between a safe asset and a risky asset. The portfolio choice task may be thought of as a useful tool to elicit risk attitudes. It was used for the first time in experiments by Gneezy and Potters (1997) and has been successfully applied to various issues (see, e.g., Haigh and List 2005, Gneezy et al. 2009, Charness and Gneezy 2010).

Before performing the portfolio choice task, subjects were first instructed on how their initial cash balance (wealth) would be determined. Because there is striking experimental evidence about the house money effect on risk taking (see, e.g., Thaler and Johnson 1990, Weber and Zuchel 2005, Martinez et al. 2010), our aim was to control for such a possible effect in our experiment. Although the within-subject method is also intended to wipe out such possible windfall effects, it is an unanswered question whether such effects may affect risk-taking behavior under background risk. We therefore take the house-money issue seriously. We discuss how we propose to address it below.

Each subject entered the experiment with a controlled level of wealth w. Half of it was credited on a blocked account, and the other half was available to the subject for the portfolio choice task. The safe asset had a rate of return equal to 1 and, thus, simply secured the amount invested. On the other hand, the expected return of the risky asset was strictly larger than 1 with a binary random rate of return $\tilde{k} = (0, 1/2; 3, 1/2)$, taking either value 0 (losing the amount invested) or value 3 (tripling the amount invested) with equal probability. Letting $\delta \in [0, 1]$ denote the fraction of $w/2$ invested in the risky asset, the endogenous random wealth of the investor is given by

$$\tilde{x} = w + \delta[\tilde{k} - 1]\frac{w}{2}. \tag{1}$$

Each subject faced the portfolio choice task twice in two different situations, labeled A and B, which were presented sequentially. It was made clear that only one of the two situations would apply at the end of the experiment, and the choice of the relevant situation was decided on a random basis. Situation A involved no background risk; in situation B, each subject was exposed to an independent, additive, and actuarially neutral background risk $\tilde{y} = (-y, 1/2; y, 1/2)$ affecting his blocked account. We chose the level of background risk in such a way that subjects could eventually lose their whole wealth in the blocked account; i.e., $y = w/2$. The balance of a subject's blocked account was certain in situation A (equal to $w/2$) and risky in situation B (equal to either 0 or w with equal probability). Thus, because the two situations A and B only differ by the presence or absence of background risk, our experimental design allows us to elicit each subject's risk vulnerability in

[5] Because the unfair background risk they have chosen exhibits nonpositive monetary outcomes only, their results from the unfair background risk treatment allow a test of DARA rather than a test of risk vulnerability.

an unambiguous way by comparing his or her investment in situations A and B. We control for a possible order effect by randomizing the sequence of situations: approximately half of the subjects faced situation A first, whereas the other half faced situation B first. Our main result is unaffected by the ordering of the two situations.

Because we relied on the RRPM procedure for selecting the relevant situation at the end of the experiment, one could actually argue that we implemented a second (uncontrolled) background risk, as in Lee's (2008) experiment. Although this might be the case, it does not affect our conclusion. Indeed, whether or not an uncontrolled background risk was present in our experiment, it is wiped out by our within-subject design because it does not differ between situations A and B. The background risk generated by the RRPM procedure merely cumulates with each subject's own background risk that he or she brings to the lab and for which we are unable to control. With the exception of the order effect, the impact of background risk is therefore fully captured, all other things being equal, by our experimental design.

Our experiments included 279 student-subject participants. The participants were selected randomly from a large pool of more than 3,000 volunteers. Real monetary incentives were offered to all participants. To allow for a robustness check, we report on two experiments, labeled experiment 1 and experiment 2, where we deliberately varied many aspects of the experimental design. Experiment 1 was run as a paper and pencil session involving 91 subjects, and experiment 2 was a computerized experiment involving 188 subjects. In experiment 2, prior to the portfolio choice task, each subject had to "work" to accumulate wealth ($w = \text{E}20$) by performing a tedious task.[6] In contrast, in experiment 1, the subjects' wealth was a windfall endowment ($w = \text{E}100$) provided by the experimenter.[7] The reason for including this first stage in experiment 2 was to control for the house money effect that could have affected the results of experiment 1. Finally, in experiment 1, which involved high stakes, only 10% of the participants were randomly selected to be paid out for real. By contrast, in experiment 2, where stakes were much lower, all participants were paid according to their earnings. As we show in §5, despite these strong design differences, the results of the two experiments almost perfectly match.

[6] The work consisted of reporting the number of times number "1" appeared in a matrix containing strings of 0's and 1's. Ten different matrixes with varying sizes had to be counted this way during a limited period of time. At the end of this preliminary stage, only subjects who had completed the task correctly for all 10 matrixes received the flat reward of E20. Those who failed were instructed that they could stay in the experiment until the end but that they would play with fictitious money (9% of the subjects).

[7] In the experiments, the amount invested in the risky asset was restricted to integer values. Therefore the choice space differed somehow between experiment 1 and experiment 2. With $w/2 = \text{E}50$ in experiment 1 and $w/2 = \text{E}10$ in experiment 2, the corresponding choice set in experiment 1 was $\{0, 0.02, \ldots, 1\}$ and in experiment 2 was $\{0, 0.1, \ldots, 1\}$. That is, subjects could invest fractions of 2% in experiment 1 but only fractions of 10% in experiment 2.

4. Theoretical Predictions

In this section, we derive theoretical predictions about risk vulnerability. The issue of risk vulnerability has been extensively discussed within the framework of EU, but it has received sparse attention otherwise. It is therefore of interest to contrast the predictions of EU with the predictions of alternative theories: DT, RDU, CPT, and PT^3. As one can expect, EU and DT lead to sharp but opposite predictions. On the other hand, more general forms of RDU provide less clean predictions. Predicting the investor's behavior under CPT is more problematic because it depends on the definition of the reference point under background risk. Hence, we consider the predictions of the most recent version of CPT, PT^3, which allows the reference point to be random. Under PT^3, we show that the investor is indifferent with respect to the introduction of the background risk.

4.1. Portfolio Choice and Risk Vulnerability

Let us consider an investor seeking to maximize a general preferences function v defined over random wealth. Without background risk (situation A), the investor's optimal portfolio is given by

$$\delta^A = \arg\max_{\delta\in[0,1]} v(\tilde{x}). \tag{2}$$

Now suppose that the investor is exposed to the actuarially neutral background risk $\tilde{y}$ (situation B). The investor's random wealth is now $\tilde{x} + \tilde{y}$, and his or her optimal portfolio is given by

$$\delta^B = \arg\max_{\delta\in[0,1]} v(\tilde{x} + \tilde{y}). \tag{3}$$

In this framework, risk vulnerability amounts to the comparison of the two optimal levels of investment δ^A and δ^B. We rely on two categorizations: a coarse categorization that distinguishes between risk-vulnerable and non-risk-vulnerable investors and a fine categorization that adds a further distinction within the risk-vulnerable category between investors that are strictly risk-vulnerable and those that are considered indifferent. Definition 1 summarizes the possible types of behavior.

Definition 1. The behavior of the investor is risk vulnerable if $\delta^A \geq \delta^B$, strictly risk vulnerable if $\delta^A > \delta^B$, indifferent if $\delta^A = \delta^B$, and non-risk vulnerable if $\delta^A < \delta^B$.

4.2. Expected Utility Theory

Under EU theory, the preferences function is linear in the probabilities and takes the following form:

$$v(\tilde{x}) = Eu(\tilde{x}), \tag{4}$$

where u is a strictly increasing real-valued Bernoulli utility function defined over final wealth and E is the expectation operator. Following previous literature (Kihlstrom et al. 1981, Nachman 1982, Pratt and Zeckhauser 1987, Pratt 1988, Gollier and Pratt 1996), it is convenient under background risk to define an indirect Bernoulli utility function $U(x) = Eu(x + \tilde{y})$. Thus, when the EU investor is exposed to the background risk, his or her preferences function becomes[8]

$$v(\tilde{x} + \tilde{y}) = EU(\tilde{x}). \tag{5}$$

The Kuhn–Tucker first-order conditions for situation A are

$$\begin{aligned} \frac{u'(x_1)}{u'(x_2)} &\geq 2 \quad \text{if } \delta^A < 1, \\ \frac{u'(x_1)}{u'(x_2)} &\leq 2 \quad \text{if } \delta^A > 0, \end{aligned} \tag{6}$$

where $x_1 = [2 - \delta]w/2$ and $x_2 = [1 + \delta]w$ represent the investor's wealth in the bad state of the world (unsuccessful investment) and in the good state of the world (successful investment), respectively. The optimal portfolio for situation A can then be summarized as follows:[9]

$$\begin{aligned} \delta^A &= 1 \quad \text{if } \frac{u'(x_1)}{u'(x_2)} < 2, \\ \delta^A &\in [0, 1] \quad \text{if } \frac{u'(x_1)}{u'(x_2)} = 2, \\ \delta^A &= 0 \quad \text{if } \frac{u'(x_1)}{u'(x_2)} > 2. \end{aligned} \tag{7}$$

First note that, because the excess rate of return is strictly positive with $E\tilde{k} > 1$, a risk-neutral individual would always choose the maximum possible level of investment. On the other hand, because $\delta = 0 \Leftrightarrow x_1 = x_2$, it is apparent from (7) that, under monotonic preferences, a zero investment cannot be an optimal choice for an EU investor.[10] Observe also that, because $\delta > 0 \Leftrightarrow x_1 < x_2$, the ratio of marginal utilities in (7) is greater than 1 under risk aversion and is increasing with the investor's degree of risk aversion. Hence, recognizing that U is at least as risk averse as u if and only if[11]

$$\frac{u'(x_1)}{u'(x_2)} \leq \frac{U'(x_1)}{U'(x_2)} \quad \forall x_1 \leq x_2, \tag{8}$$

we get that the investor is risk vulnerable if and only if the ratio of marginal utilities is larger in the presence of background risk. According to (7), this suggests that $\delta^A \geq \delta^B$. Gollier and Pratt (1996, Definition 1) equivalently defined risk vulnerability by the following inequality:

$$r(x) = -\frac{u''(x)}{u'(x)} \leq -\frac{U''(x)}{U'(x)} = R(x) \quad \forall x. \tag{9}$$

Thus, the Arrow–Pratt framework of comparative risk aversion fully applies as if u and U corresponded to the preferences of two different investors. In particular, the following well-known result applies.[12]

Proposition 1. *Under EU theory, the following statements are equivalent*:
- U is at least as risk averse as u ($r \leq R$).
- The behavior of the investor is risk vulnerable ($\delta^A \geq \delta^B$).

As mentioned by Gollier and Pratt (1996), all commonly used Bernoulli utility functions that satisfy nonincreasing harmonic absolute risk aversion exhibit risk vulnerability. Assuming constant absolute risk aversion (CARA), the additive background risk $\tilde{y}$ has obviously no impact on absolute risk aversion. Thus, CARA investors would be indifferent to the background risk. On the other hand, DARA investors are risk vulnerable if

$$\frac{r(x) - r(x+y)}{r(x-y) - r(x)} \leq \frac{u'(x-y)}{u'(x+y)} \quad \forall x, y > 0. \tag{10}$$

The right-hand side of inequality (10) corresponds to the investor's marginal rate of substitution between his or her wealth in the case of a bad outcome of the background risk and his or her wealth in the case of a good outcome of the background risk. Under monotonic preferences and risk aversion, this ratio is obviously greater than 1. Therefore, a sufficient condition for a DARA investor to be risk vulnerable is that the ratio of changes in absolute risk aversion in the left-hand side of inequality (10) is smaller than 1. Because the numerator, $r(x) - r(x + y)$, is the increase in absolute risk aversion as a result of the loss $-y$ at wealth level $x + y$ and the denominator, $r(x - y) - r(x)$, is

[8] The rationale for this formulation is that examining the effect of the introduction of background risk is equivalent to examining differences between preferences represented by u and U. An investor exposed to the background risk and having preferences represented by u would act as a nonexposed investor with preferences represented by U.

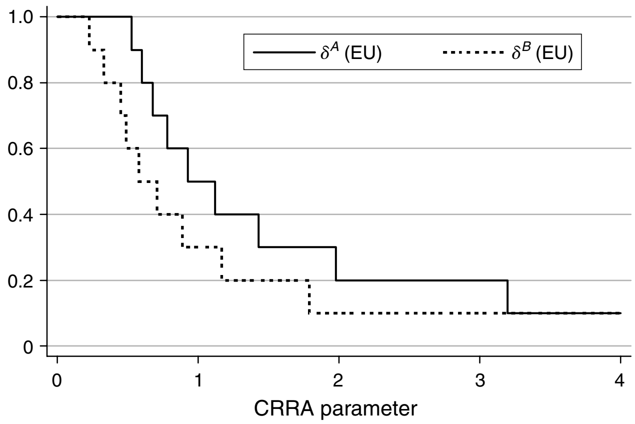
[9] Substituting U for u and δ^B for δ^A in (6) and (7) gives the analogous conditions for situation B.

[10] In our experiments, we observed that 8% (16%) of the subjects chose a zero investment in situation A (B). On the other hand, 17% (11%) chose a maximum investment in situation A (B).

[11] See Equation (2) in Pratt (1988).

[12] See Theorem 1 of Pratt (1964) and Proposition 1 of Gollier and Pratt (1996).

Figure 1 Predicted Portfolio Choice: EU



Note. *A*, without background risk; *B*, with background risk.

the increase in absolute risk aversion as a result of the loss $-y$ at wealth level x, it follows that the convexity of absolute risk aversion is sufficient for (10) to hold. Therefore, as observed by Gollier and Pratt (1996), decreasing and convex absolute risk aversion constitutes a simple and intuitive sufficient condition for risk vulnerability in the EU framework.[13]

Let us illustrate by considering the widely used power utility function exhibiting constant relative risk aversion (CRRA) with parameter γ:

$$u(x) = \begin{cases} \dfrac{1}{1-\gamma} x^{1-\gamma} & \text{if } \gamma > 0, \\ \ln x & \text{if } \gamma = 1, \end{cases} \quad \forall x > 0. \tag{11}$$

The predicted impact of background risk on the portfolio choice is illustrated as a function of the CRRA parameter in Figure 1.[14] As the CRRA parameter increases, the optimal investment curve is first horizontal and then nonincreasing. Because the CRRA Bernoulli utility function exhibits risk vulnerability, the investor behaves in a more cautious way after the introduction of the background risk, and the optimal investment curve shifts down.

4.3. Dual Theory

Assume now that the investor behaves according to DT. As opposed to EU theory, under DT the preferences function is linear in monetary outcomes and nonlinear in probabilities. By convention, but with no loss of generality, outcomes are ordered from the smallest to the largest. Without background risk, only two outcomes are possible, and we have $x_1 = x_2 \Leftrightarrow \delta = 0$ and $x_1 < x_2 \Leftrightarrow \delta > 0$. The probability weight attributed to wealth x_i is then determined as follows:

$$\pi_i = g(\Pr(\tilde{x} \le x_i)) - g(\Pr(\tilde{x} < x_i)) \quad \forall i = 1, 2, \tag{12}$$

where g: $[0, 1] \to [0, 1]$ is a strictly increasing probability weighting function satisfying $g(0) = 0$ and $g(1) = 1$. Thus, we have $\pi_1 = 1 - \pi_2 = g(1/2)$. Recognizing that the probability weights are positive and sum to 1, Yaari (1987) interpreted the preferences function as a "corrected mean" of $\tilde{x}$:

$$v(\tilde{x}) = \sum_{i=1}^{2} \pi_i x_i. \tag{13}$$

If the probability weighting function is concave (convex), the DT investor behaves pessimistically (optimistically), as though an unsuccessful investment is more (less) likely than it really is: $\pi_1 > 1/2 > \pi_2$ ($\pi_1 < 1/2 < \pi_2$).[15] Furthermore, because the preferences function in (13) is linear in the level of investment, DT typically leads to corner solutions, and the optimal portfolio is fully determined by the probability weight of an unsuccessful investment:

$$\begin{aligned} \delta^A &= 1 \quad \text{if } \pi_1 < \tfrac{2}{3}, \\ \delta^A &\in [0, 1] \quad \text{if } \pi_1 = \tfrac{2}{3}, \\ \delta^A &= 0 \quad \text{if } \pi_1 > \tfrac{2}{3}. \end{aligned} \tag{14}$$

In the words of Yaari (1987), DT predicts "plunging," rather than diversification. DT investors stay put until plunging becomes justified.[16] From (14) we see that DT investors who are not too pessimistic with $\pi_1 < 2/3$ would choose the maximum possible level of investment in the risky asset. On the other hand, DT investors who are strongly pessimistic with $\pi_1 > 2/3$ would choose to invest zero in the risky asset. Thus, it is only in the special case where $\pi_1 = 2/3$ that DT investors are indifferent between all possible levels of investment and, hence, would choose a nonextreme level of investment.

In the presence of background risk, there are four (equiprobable) possible outcomes: $x_{11} = x_1 - y$, $x_{12} = x_1 + y$, $x_{21} = x_2 - y$, and $x_{22} = x_2 + y$, where $y = w/2$. The weight attributed to wealth x_{ij} is written as

$$\pi_{ij} = g(\Pr(\tilde{x} + \tilde{y} \le x_{ij})) - g(\Pr(\tilde{x} + \tilde{y} < x_{ij})) \quad \forall i, j = 1, 2, \tag{15}$$

[13] In particular, decreasing and convex risk aversion means that the level of investment in the risky asset is increasing and concave in wealth.

[14] In all our numerical illustrations, we used the parameters of experiment 2, where $w = E20$ and $y = E10$, with $\delta \in \{0, 0.1, \ldots, 1\}$.

[15] As pointed out by Yaari (1987, p. 108), however, "this is *not* a case where probabilities are being distorted in the agent's perception... this essay deals with how perceived risk is processed into choice, and not with how actual risk is processed into perceived risk."

[16] Plunging must not be confused with risk seeking, which means never stay put under EU theory.

where $\sum_{i=1}^{2}\sum_{j=1}^{2}\pi_{ij}=1$. The preferences function is then defined as follows:

$$v(\tilde{x}+\tilde{y})=\sum_{i=1}^{2}\sum_{j=1}^{2}\pi_{ij}x_{ij}. \tag{16}$$

As without background risk, the optimal portfolio is fully determined by the probability weight of an unsuccessful investment:[17]

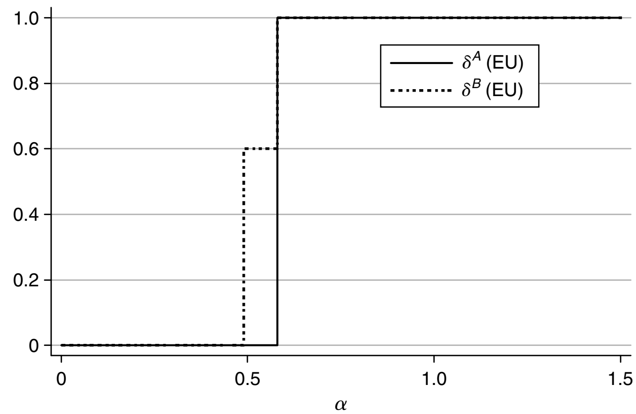
$$\begin{aligned}\delta^B&=1 \quad \text{if } \sum_{j=1}^{2}\pi_{1j}<\tfrac{2}{3},\\ \delta^B&\in[0,1] \quad \text{if } \sum_{j=1}^{2}\pi_{1j}=\tfrac{2}{3},\\ \delta^B&=0 \quad \text{if } \sum_{j=1}^{2}\pi_{1j}>\tfrac{2}{3}.\end{aligned} \tag{17}$$

From the comparison of the optimal portfolio choices in (14) and (17), it appears that DT investors may be risk vulnerable only if the background risk makes them more pessimistic regarding the outcome of their investment—that is, if $\sum_{j=1}^{2}\pi_{1j}\geq\pi_1$. However, as shown by Safra and Segal (2008), in general, individuals who behave according to DT cannot be risk vulnerable.[18] In the present context, it can be shown that the introduction of the background risk cannot make DT investors more pessimistic whenever the probability weighting function is concave.[19] Observe also that the concavity of the probability weighting function is a necessary and sufficient condition for strong risk aversion (see, e.g., Chew et al. 1987). Therefore, under strong risk aversion, DT cannot predict strictly risk-vulnerable behavior. We provide a numerical example to illustrate this result. To generate probability weights, we use Safra and Segal's (2008) single parameter functional form:

$$g(p)=p^{\alpha} \quad \forall p\in[0,1], \tag{18}$$

where $\alpha>0$. This function is concave (convex) for $\alpha<1$ so that relatively more (less) weight is given to probabilities associated with bad outcomes. Thus, if $\alpha<1$ ($\alpha>1$), the individual is pessimistic (optimistic). The predicted impact of background risk on the portfolio choice is illustrated as a function of the parameter α in Figure 2.

Figure 2 **Predicted Portfolio Choice: DT**



Note. *A*, without background risk; *B*, with background risk.

4.4. Rank-Dependent Utility

EU and DT are special cases of RDU. Thus, under RDU, the preferences function is nonlinear in both monetary outcomes (as under EU) and probabilities (as under DT) and takes the following general form:

$$v(\tilde{x})=\sum_{i=1}^{2}\pi_i u(x_i). \tag{19}$$

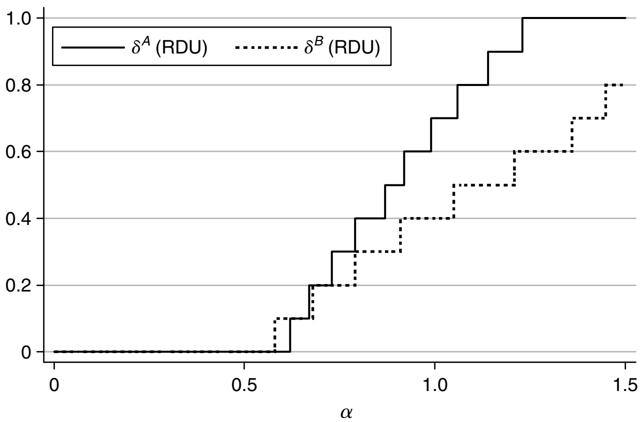
To illustrate, we use the CRRA Bernoulli utility function (11) together with the probability weighting function (18). The RDU investor's preferences are therefore defined by two parameters: the degree of risk aversion captured by the parameter γ (the curvature of the Bernoulli utility function u) and the degree of pessimism captured by the parameter α (the curvature of the probability weighting function g). Keeping constant the CRRA parameter at $\gamma=0.75$, the predicted impact of background risk on the portfolio choice is illustrated as a function of the parameter α in Figure 3. First, note that the EU side of the RDU investor is risk vulnerable because the Bernoulli utility function (11) exhibits decreasing and convex absolute risk aversion. On the other hand, for $\alpha<1$, the probability weighting function (18) is concave and the DT side of the RDU investor cannot be risk vulnerable. Thus, whenever $\alpha<1$, the two sides of the RDU investor act against each other, and the RDU investor may or may not be risk vulnerable. However, as α increases and approaches 1, the DT side becomes less influent. It is indeed apparent from Figure 3 that the RDU investor is first non-risk vulnerable and moves toward risk vulnerability as α increases. For $\alpha>1$, the probability weighting function (18) is convex and

[17] Things are slightly more complicated in the presence of background risk because the ranking of outcomes depends on the level of investment and is therefore endogenous. Whatever the level of investment, x_{11} and x_{22} represent the lowest payment and the highest payment, respectively. Thus, $\pi_{11}=g(1/4)$ and $\pi_{22}=1-g(3/4)$. On the other hand, the ordering of x_{12} and x_{21} depends on δ: $x_{12}<(>)x_{21}\Leftrightarrow\delta>(<)2/3$. Thus, $\pi_{12}=g(1/2)-g(1/4)$ and $\pi_{21}=g(3/4)-g(1/2)$ if $\delta>2/3$, and $\pi_{12}=g(3/4)-g(1/2)$ and $\pi_{21}=g(1/2)-g(1/4)$ if $\delta<2/3$.

[18] See Proposition 2 of Safra and Segal (2008). The result is based on a property called "stochastic B3," which is similar to risk vulnerability.

[19] If $\delta>2/3$, then $\sum_{j=1}^{2}\pi_{1j}=\pi_1=g(1/2)$. On the other hand, if $\delta<2/3$, then $\sum_{j=1}^{2}\pi_{1j}\geq\pi_1$ is equivalent to $[g(1/4)+g(3/4)]/2\geq g(1/2)$. By Jensen's inequality, this cannot be true whenever g is concave.

Figure 3 Predicted Portfolio Choice: RDU



Note. *A*, without background risk; *B*, with background risk.

the DT side of the RDU investor is risk vulnerable. Thus, the two sides of the RDU investor reinforce each other, and the RDU investor becomes unambiguously risk vulnerable.

4.5. Cumulative Prospect Theory

CPT belongs to the class of rank-dependent models. As under RDU, the preferences function is nonlinear in both monetary outcomes and probabilities, but because asset integration does not apply under CPT, the carriers of value are the variations of wealth with respect to a reference point x^*. This is captured by the value function introduced by Kahneman and Tversky (1979) that is defined over gains and losses (above and below the reference point):

$$u(x) = \begin{cases} u^+(x - x^*) & \text{if } x \geq x^*, \\ -u^-(x^* - x) & \text{if } x \leq x^*, \end{cases} \tag{20}$$

where $u(x^*) = u^-(0) = u^+(0) = 0$. The value function is increasing, concave for gains and convex for losses. Without background risk the reference point is clearly the level of initial wealth, i.e., $x^* = w$, which is also the sure level of wealth that can be obtained if the individual stays put by choosing to invest zero in the risky asset. In this context, we have $x_1 = x^* = x_2 \Longleftrightarrow \delta = 0$ and $x_1 < x^* < x_2 \Longleftrightarrow \delta > 0$. Thus, according to the realized state of the rate of return of the risky asset, the investor records, with equal probability, either a loss or a gain:

$$x^* - x_1 = \tfrac{1}{2}\delta w \quad \text{(loss)} \tag{21}$$

or

$$x_2 - x^* = \delta w \quad \text{(gain)}. \tag{22}$$

A second feature of CPT is that the probability weighting function differs for gains and for losses. The probability weighting function is defined over the cumulative distribution function for losses,

$$\pi_1^- = g^-(\Pr(\tilde{x} \leq x_1)) - g^-(\Pr(\tilde{x} < x_1)), \tag{23}$$

and over the decumulative distribution function for gains,

$$\pi_2^+ = g^+(\Pr(\tilde{x} \geq x_2)) - g^+(\Pr(\tilde{x} > x_2)), \tag{24}$$

where g^- and g^+ are strictly increasing functions from the unit interval into itself, satisfying $g^-(0) = g^+(0) = 0$ and $g^-(1) = g^+(1) = 1$. Thus, we have $\pi_1^- = g^-(1/2)$ and $\pi_2^+ = g^+(1/2)$. The preferences function takes therefore the following form:

$$v(\tilde{x}) = g^+(1/2)u^+(x_2 - x^*) - g^-(1/2)u^-(x^* - x_1). \tag{25}$$

When exposed to the background risk, it is unclear what the CPT investor's reference point might be. If we rely on the same benchmark as that without background risk, i.e., the level of wealth that can be reached if the investor chooses to stay put, there are now two possible candidates, denoted $\underline{x}^* = x^* - y$ and $\bar{x}^* = x^* + y$, which are respectively below and above the reference point without background risk: $\underline{x}^* < x^* < \bar{x}^*$. These two possible reference points may be thought as pessimistic and optimistic, respectively. Indeed, if the CPT investor takes into account $\underline{x}^*$ ($\bar{x}^*$) as the reference point, he evaluates the outcomes of his investment decision as if he believed that the bad (good) outcome of the background risk will be realized for sure.

Hence, intuition suggests that a pessimistic (optimistic) CPT investor would be risk vulnerable (nonrisk vulnerable). The reasoning is the following: if the individual is pessimistic (optimistic) about the outcome of the background risk, most outcomes will be above (below) his or her reference point $\underline{x}^*$ ($\bar{x}^*$). Because the value function is concave (convex) in the domain of gains (losses), pessimistic (optimistic) CPT investors will be more (less) reluctant to invest in the risky asset when exposed to the background risk. However, one needs to also take into account the property that the probability weighting function differs in the loss and gain domains. Table 1 provides numerical illustrations for which this intuition is verified. Probability weights have been generated using Prelec's (1998) single parameter function:

$$g(p) = \exp\{-[-\ln(p)]^\theta\} \quad \forall p \in [0, 1], \tag{26}$$

with $\theta^+ = 0.5$ for gains and $\theta^- = 0.65$ for losses. Moreover, we used power value functions $u^+(x) = x^\alpha$ for gains and $u^-(x) = \lambda x^\beta$ for losses, with three standard cases for parameters α, β, and λ. Without background risk, CPT predicts a positive but small investment in the risky asset for the three sets of parameter values. In the presence of background risk, with the pessimistic reference point $\underline{x}^*$, the optimal investment is even lower, and the investor's behavior exhibits risk vulnerability. On the contrary, with the optimistic reference point $\bar{x}^*$, the maximum investment becomes

Table 1 Predicted Portfolio Choice: CPT

	δ^A	δ^B	
Reference point =	Stay put (x^*)	Stay put and pessimistic ($\underline{x}^*$)	Stay put and optimistic ($\bar{x}^*$)
Type of behavior =		Strictly RV ($\delta^A > \delta^B$)	Non-RV ($\delta^A < \delta^B$)
$\alpha = 0.2$; $\beta = 0.4$; $\lambda = 1$	0.005	0.000	1.000
$\alpha = 0.6$; $\beta = 0.9$; $\lambda = 2$	0.009	0.001	1.000
$\alpha = 0.8$; $\beta = 0.88$; $\lambda = 2.25$	0.001	0.000	1.000

Note. RV, risk vulnerable; *A*, without background risk; *B*, with background risk.

optimal. Thus, depending on the reference point chosen in the presence of background risk, CPT predicts either strictly risk-vulnerable or non-risk-vulnerable behavior.

An alternative way of choosing the reference point in the presence of background risk is to rely on the Schmidt et al. (2008) PT^3, the third generation of Kahneman and Tversky's (1979) prospect theory, which allows the reference point to be random. Recalling that there are four equiprobable outcomes in the presence of background risk, the random reference point can be represented by the following lottery: $\tilde{x}^* = (x^*_{11}, 1/4; x^*_{12}, 1/4; x^*_{21}, 1/4; x^*_{22}, 1/4)$. To determine the reference point in each state of the world, one needs to define a "reference act." As without background risk, the natural reference act in our setting is to stay put—that is, to choose a zero investment. Thus, if $\delta = 0$, then $x^*_{11} = x^*_{21} = \underline{x}^*$ in the case of a bad outcome of the background risk and $x^*_{12} = x^*_{22} = \bar{x}^*$ in the case of a good outcome of the background risk. Therefore, the reference act leads to the same two equiprobable outcomes, as without background risk:

$$x^*_{11} - x_{11} = x^*_{12} - x_{12} = x^* - x_1 \quad \text{(loss)} \qquad (27)$$

or

$$x_{21} - x^*_{21} = x_{22} - x^*_{22} = x_2 - x^* \quad \text{(gain)}. \qquad (28)$$

Thus, the impact of the background risk is fully absorbed by the randomness of the reference point, and the preferences function takes exactly the same form as that without background risk: $v(\tilde{x} + \tilde{y}) = v(\tilde{x})$. As a result, PT^3 investors are indifferent to the presence of background risk.

5. Experimental Results

According to Definition 1, we rely on two levels of categorization of our subjects: a *coarse categorization* and a *fine categorization*. The coarse categorization adopts Gollier and Pratt's (1996) original definition by separating risk-vulnerable subjects for whom independent risks are substitutes (or independent), i.e., $\delta^A \geq \delta^B$, from non-risk-vulnerable subjects for whom they are complements, i.e., $\delta^A < \delta^B$. The fine categorization divides the risk-vulnerable category further into strictly risk-vulnerable subjects for whom independent risks are substitutes, i.e., $\delta^A > \delta^B$, and indifferent subjects for whom they are independent, i.e., $\delta^A = \delta^B$.

Table 2 Observed Portfolio Choices (Pooled Data)

Type of behavior =	**RV** ($\delta^A \geq \delta^B$)	Strictly RV ($\delta^A > \delta^B$)	Ind ($\delta^A = \delta^B$)	**Non-RV** ($\delta^A < \delta^B$)	**All**
Frequencies (%)	**81**	47	34	**19**	**100**
Mean δ^A	**0.568**	0.608	0.513	**0.326**	**0.522**
Mean δ^B	**0.376**	0.278	0.513	**0.608**	**0.421**
No. of obs.	**225**	131	94	**54**	**279**

Note. RV, risk vulnerable; Ind, indifferent; *A*, without background risk; *B*, with background risk.

Among the 279 subjects who participated in our experiments, 11% chose the same limit investment in both situations *A* and *B*. More precisely, 4% chose $\delta^A = \delta^B = 0$ and 7% chose $\delta^A = \delta^B = 1$. Because the range of possible investments was bounded in the experiment, these subjects may be categorized as indifferent, strictly risk vulnerable, or non-risk vulnerable. Because these subjects are likely to be of any of these types, we decided to categorize them as indifferent.[20]

Result 1. A large majority of subjects are risk vulnerable, i.e., behave as if independent risks were substitutes (or independent). Risk vulnerability is robust both to treatment effects and to experimental manipulations.

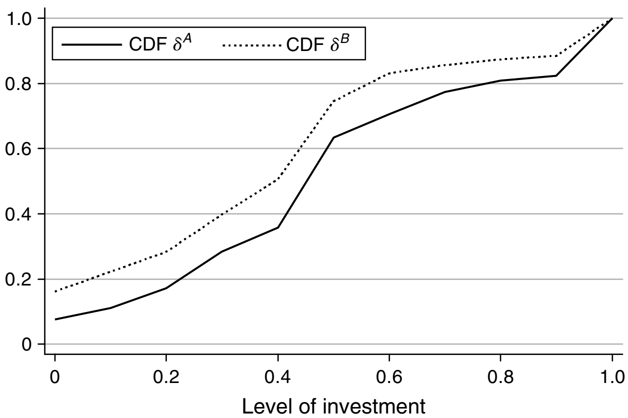
5.1. Support for Result 1

Table 2 summarizes the results for the pooled data of the two experiments and treatments. We find that a nontrivial portion of the subjects invested an equal or lower amount in the risky asset when exposed to background risk. According to the coarse categorization (in bold characters), 81% of the subjects are risk vulnerable, whereas 19% are non-risk vulnerable. According to the fine categorization, 47% are strictly risk vulnerable, and 34% are indifferent. Our main result is that the relative frequency of risk-vulnerable subjects is significantly larger than 50% in both experiments and for both treatments (binomial test, $p = 0.000$).

Figure 4 provides further evidence in support for Result 1. The cumulative distribution function (CDF) of investment without background (CDF of δ^A) first-order stochastically dominates the CDF of δ^B. Because

[20] If we exclude the 30 subjects who have chosen the same limit investment in the two situations, 78% of the remaining 249 subjects are risk vulnerable, 53% are strictly risk vulnerable, 26% are indifferent, and 22% are non-risk vulnerable.

Figure 4 **CDF of Observed Portfolio Choices (Pooled Data)**



Note. *A*, without background risk; *B*, with background risk.

$\Pr(\delta^A \le \delta) < \Pr(\delta^B \le \delta)$ for any $\delta < 1$, the dominance relation is strong. In other words, for each possible level of investment δ, the probability that a randomly selected subject chose to invest less than δ is always larger with background risk than without.

Table 3 presents the data separately for each treatment. We observe that whether subjects are first exposed to situation *A* (without background risk, treatment *AB*) or first exposed to situation *B* (with background risk, treatment *BA*) is irrelevant. Because there is no order effect with respect to the frequency of risk-vulnerable subjects (Fisher's exact test, 5%), we can pool the data of the two treatments.

To highlight the impact of our experimental manipulations, Table 4 summarizes the data from experiments 1 and 2 separately. Despite the many differences in design features, the two experiments produce an equal frequency of risk-vulnerable subjects (Fisher's exact test, 5%). The null hypothesis of equal distributions of percentages invested in experiments 1 and 2 cannot be rejected neither for situation *A* nor for situation *B* (Kolmogorov–Smirnov (KS) test, two-sided, 5%). Furthermore, the null hypothesis of equal distributions for $\delta^A - \delta^B$ in experiments 1 and 2 cannot be rejected either (KS test, two-sided, 5%). We therefore conclude that experiments 1 and 2 produce almost exactly the same results.[21]

Result 2. When background risk is either introduced or removed, there is a significantly large level of adjustment of the investment in the risky asset both for strictly risk-vulnerable and for non-risk-vulnerable subjects.

5.2. Support for Result 2

We compare the distributions of the absolute value of adjustments only for strictly risk-vulnerable and non-risk-vulnerable subjects. (We exclude indifferent subjects for which the adjustment equals zero.) It is apparent from Table 2 that the mean adjustment is 0.330 for strictly risk-vulnerable subjects and 0.282 for non-risk-vulnerable subjects, an insignificant difference (t-test, two-sided, $p = 0.187$; KS, $p = 0.787$). Furthermore, there is no significant difference in adjustment when background risk is introduced (treatment *AB*) or removed (treatment *BA*), neither for strictly risk-vulnerable nor for non-risk-vulnerable subjects (KS test, two-sided, 5%).

Table 3 **Observed Portfolio Choices Across Treatments**

Type of behavior =	**RV** $\delta^A \ge \delta^B$	Strictly RV $\delta^A > \delta^B$	Ind $\delta^A = \delta^B$	**Non-RV** $\delta^A < \delta^B$	**All**
Treatment *AB*					
Frequencies (%)	**80**	44	36	**20**	**100**
Mean δ^A	**0.492**	0.522	0.455	**0.350**	**0.464**
Mean δ^B	**0.327**	0.223	0.455	**0.601**	**0.381**
No. of obs.	**107**	59	48	**26**	**133**
Treatment *BA*					
Frequencies (%)	**81**	49	32	**19**	**100**
Mean δ^A	**0.637**	0.679	0.573	**0.304**	**0.574**
Mean δ^B	**0.420**	0.322	0.573	**0.614**	**0.457**
No. of obs.	**118**	72	46	**28**	**146**

Note. RV, risk vulnerable; Ind, indifferent; *A*, without background risk; *B*, with background risk.

Table 4 **Observed Portfolio Choices Across Experiments**

Type of behavior =	**RV** $\delta^A \ge \delta^B$	Strictly RV $\delta^A > \delta^B$	Ind $\delta^A = \delta^B$	**Non-RV** $\delta^A < \delta^B$	**All**
Experiment 1					
Frequencies (%)	**80**	52	29	**20**	**100**
Mean δ^A	**0.626**	0.715	0.465	**0.307**	**0.563**
Mean δ^B	**0.398**	0.361	0.465	**0.612**	**0.440**
No. of obs.	**73**	47	26	**18**	**91**
Experiment 2					
Frequencies (%)	**81**	45	36	**19**	**100**
Mean δ^A	**0.541**	0.549	0.531	**0.336**	**0.502**
Mean δ^B	**0.365**	0.231	0.531	**0.606**	**0.411**
No. of obs.	**152**	84	68	**36**	**188**

Note. RV, risk vulnerable; Ind, indifferent; *A*, without background risk; *B*, with background risk.

[21] Note, however, that the finer categorization of risk-vulnerable subjects into strictly risk-vulnerable and indifferent types reveals a slight difference between experiment 1 and experiment 2. As can be seen from Table 4, the percentage of strictly risk-vulnerable subjects drops from 52% in experiment 1 to 45% in experiment 2, while at the same time the percentage of indifferent subjects increases from 29% in experiment 1 to 36% in experiment 2. A plausible reason for such a difference might be the finer scale of the choice space in experiment 1, where $\delta \in \{0, 0.02, \dots, 1\}$, compared with experiment 2, where $\delta \in \{0, 0.1, \dots, 1\}$. The minimum reduction possibility was 0.02 in experiment 1, whereas it was 0.10 in experiment 2. Thus, in experiment 2, some subjects might have felt a sharper constraint for adjusting their level of investment in the risky asset. For instance, in experiment 2, subjects who might have been willing to reduce their investment by 0.05 in situation *B* were unable to do it and therefore might have kept their investment at the same level as in situation *A*. On the other hand, the frequency of non-risk-vulnerable subjects is the same in both experiments (Fisher's exact test, 5%).

It is important to observe that these adjustments are large compared with previous experimental findings. For instance, Lusk and Coble (2008, p. 334) found that "background risk has small to no affect on risk-taking behavior." They observed a slight increase in the mean number of safe choices (from 5.40 to 5.89) when subjects had to face a zero-mean background risk while the median number of safe choices was unaffected (equal to 6 both with and without background risk). Similarly, in the investment task analyzed by Lee (2008), the average absolute adjustment over 10 rounds was 0.364 on a scale from 0 to 10. We believe that the key reason for such a strong difference between our results and the former ones is that we relied on a within-subject design, which allows us to capture separately the impact of background risk on the level of investment of strictly risk-vulnerable and non-risk-vulnerable subjects. The results summarized in Table 2 highlight the strong impact of the background risk on the portfolio choice for both types of nonindifferent subjects. When exposed to background risk, strictly risk-vulnerable subjects roughly halve their level of investment (from 0.608 to 0.278), whereas non-risk-vulnerable subjects roughly double their investment (from 0.326 to 0.608). By contrast, if we had relied on a between-subjects design, with half of the subjects exposed to background risk (and the other half not exposed), we would have found only a small difference of 0.101 between the average level of investment of the nonexposed (0.522) and the exposed (0.421) subjects, an approximate decrease of about 20% as shown by the last column of Table 2.

Result 3. The level of adjustment to background risk of the investment in the risky asset is affected neither by sociodemographic variables nor by treatment effects.

5.3. Support for Result 3

To identify the variables that may affect the level of adjustment to background risk, we rely on subjects' sociodemographic data: gender (1 if women), age, number of siblings, and religion (measured by the number of days of worship per month). Because the choice space is not the same in experiments 1 and 2, we run a separate regression for each data set. Moreover, to provide a meaningful estimate for the difference $\delta^A - \delta^B$, we need to run censored regressions that capture the fact that subjects were constrained both for their choice of δ^A and for their choice of δ^B. Consider, for instance, a subject who invests $\delta^A = 0.8$ without background risk. After background risk is introduced, his adjustment is constrained by his initial investment level, both downward ($\delta^A - \delta^B \leq 0.8$) and upward ($\delta^A - \delta^B \geq -0.2$). More generally, the following two inequalities hold: (i) $\delta^A - 1 \leq \delta^A - \delta^B \leq \delta^A - 0$ and (ii) $0 - \delta^B \leq \delta^A - \delta^B \leq 1 - \delta^B$.[22] Based on these constraints, we define the censoring variable cv as follows:

$$cv = \begin{cases} -1 & \text{if } \delta^A = 0 \text{ or } \delta^B = 1 \text{ or both (left censored)}, \\ 0 & \text{if } 0 < \delta^A < 1 \text{ and } 0 < \delta^B < 1 \text{ (uncensored)}, \\ 1 & \text{if } \delta^A = 1 \text{ or } \delta^B = 0 \text{ or both (right censored)}. \end{cases}$$

Table 5 **Determinants of the Level of Adjustment to Background Risk**

Variable	Experiment 1	Experiment 2
Model		
Treatment	0.0415	0.1316
Age	0.0055	−0.0248
Gender	−0.0706	−0.2506*
No. of siblings	0.0004	−0.0027
Religion	−0.0044	−0.0015
Constant	0.0447	0.8465
Sigma		
Constant	0.3886***	0.5009***
Statistics		
N	167	81
N_lc	14	8
N_unc	119	52
N_rc	34	21

Note. N, number of observations; *lc*, left censored; *unc*, uncensored; *rc*, right censored.
*$p < 0.1$; ***$p < 0.01$.

The results of the censored regressions with robust standard errors are reported in Table 5.[23] For experiment 1, neither the variable treatment (*AB* or *BA*) nor the sociodemographic variables affected the adjustment of the portfolio choice. However, we observe an insignificant gender effect in experiment 2 ($p = 0.062$), which is mainly due to a larger adjustment by males: on average, $\delta^A - \delta^B = 0.193$ (0.122) for men versus 0.065 (0.082) for women in experiment 2 (experiment 1). Because of the many differences between experiment 1 and experiment 2, several reasons are likely to explain such an effect, such as the larger stakes or the windfall nature of endowments in experiment 2. However, the likelihood of being risk vulnerable is not affected by gender.[24]

[22] To compute these boundaries, notice that $\delta^A - \delta^B$ is minimal if $\delta^A = 0$ and $\delta^B = 1$ (left bound) and $\delta^A - \delta^B$ is maximal if $\delta^A = 1$ and $\delta^B = 0$ (right bound).

[23] The regressions do not take into account the data of the 30 subjects for whom either $\delta^A = \delta^B = 0$ or $\delta^A = \delta^B = 1$ because for those subjects, the censuring variable cv cannot be defined. Indeed, letting $\hat{\delta}^A$ and $\hat{\delta}^B$ stand for the unconstrained portfolios, subjects who expressed such choices could have chosen unconstrained portfolios such that $\hat{\delta}^A > \hat{\delta}^B$, $\hat{\delta}^A < \hat{\delta}^B$, or $\hat{\delta}^A = \hat{\delta}^B$.

[24] For each experiment, we ran a separate logit regression with the sign of $\delta^A - \delta^B$ as the dependent variable (equals 1 if $\delta^A - \delta^B \geq 0$ and equals 0 otherwise). The explanatory variables are treatment, age, gender, religion, and number of siblings. None of these variables affected the likelihood of being risk vulnerable.

6. Discussion and Conclusions

Based on the results of our two different lab experiments, we found that over 80% of our subjects are risk vulnerable in the following sense: they do not increase their investment in the risky asset in favor of the safe asset when exposed to an actuarially neutral and independent additive background risk that affects their initial wealth. Although our data add to the already existing experimental evidence about risk vulnerability, it does so in a nonambiguous way. First, in contrast to some previous experiments related to risk vulnerability, our experiment was designed on purpose for eliciting subjects' risk vulnerability. Second, in contrast to previous experiments designed on purpose, our experiment relied on a within-subject comparison that seems more appropriate for the issue of risk vulnerability. Finally, as opposed to some previous experiments, our results are nonambiguous and clear-cut. Although the lab has the advantage of offering high control over the background risk that the experimenter can manipulate, stake sizes are necessarily limited, and the background risk is bounded by the frame of the lab. Therefore, it would be useful to contrast our findings obtained with standard student subjects to data from field experiments for which the researcher would be able to compare individuals that are exposed (versus unexposed) to some well-identified background risk (e.g., earthquake, tsunami, flood) or, more generally, individuals with variable and measurable exposure to some background risk.

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