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► **To cite this version:**

François Pannequin, Anne Corcos, Claude Montmarquette. Are insurance and self-insurance substitutes? An experimental approach. *Journal of Economic Behavior and Organization*, 2020, 180, pp.797 - 811. 10.1016/j.jebo.2019.05.018 . hal-03492812

**HAL Id: hal-03492812**

**<https://hal.science/hal-03492812v1>**

Submitted on 15 Dec 2022

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## Are insurance and self-insurance substitutes? An experimental approach

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### Abstract:

Our theory-driven laboratory experiment tests a broadened Ehrlich and Becker substitutability property between insurance and self-insurance. The data show that an increase in insurance prices does lead to a substitution effect between insurance and self-insurance. Disentangling the two components of the coverage (whether and how much to invest) suggests that the substitution effect is multilayered: a rise in the unit price is likely to crowd the subjects out of the insurance market while fostering the likelihood of investing in self-insurance. Also, the demand for insurance of those who remain in the market decreases, whereas their demand for self-insurance increases. However, the substitutability effect is mitigated by insufficient sensitivity of the subjects to the price. Therefore, a price subsidy policy is far from being as damaging to self-insurance as theory suggests. Conversely, a high-priced insurance policy does not encourage investment in loss reduction activities as much as it should. Policy issues notably for public health as well as for insurers' policy are discussed as this research suggests possible ways of steering the pricing policy for insurance.

**Keywords:** insurance, self-insurance, substitutability, marginal equalization rule, lab experiment, risk aversion

**JEL Classification:** C91, D81

### Acknowledgments

We are grateful to Nicolas Treich and Louis Eeckhoudt for their valuable comments and suggestions. Referees' comments and suggestions helped to improve this paper substantially. Remaining errors or omissions are ours. This work is partially supported by a grant overseen by the French National Research Agency (ANR) in the context of the "Investissement d'Avenir" program, through the "iCODE Institute project" funded by the IDEX Paris-Saclay, ANR-11-IDEX-0003-02.

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## I. Introduction

The association of policies subsidizing health insurance prices with policies that promote prevention behaviors (sporting practice, healthy diet, limitation of alcohol and soda consumption, smoking cessation...) suggests that governments disregard the potential substitution effect between insurance and self-insurance (loss-reduction prevention), as well as its adverse effects (lack of prevention, increase in social risks, deficits of public insurance systems). The exact opposite assumption seems to be embraced by insurers. A substitutability interplay between insurance and self-insurance is assumed when providing policyholders with devices that track their physical activity or black boxes in their car in return for discounts on the premiums.

Based on conflicting implicit assumptions, these policies raise the question of the evidence of the substitutability property between insurance and loss reduction activities.<sup>1</sup> This property, which has been theoretically established by Ehrlich and Becker (1972), suggests that a rise in the insurance premium enhances the use of self-insurance mechanisms and reduces the size of the insurance market. Symmetrically, a decrease in the insurance price is likely to undermine loss-reduction investments. In their seminal paper, Ehrlich and Becker (1972) also find that considering a decreasing marginal return of the self-insurance technology and a constant marginal return of insurance, optimizing policyholders equalize the marginal returns of insurance and self-insurance.<sup>2</sup>

Many theoretical and empirical results support the idea of substitutability. Using the dual theory of choice, Courbage (2001) has shown the robustness of the substitutability between insurance and self-insurance. Kelly and Kleffner (2003) consider the substitutability property in the context of a monopolistic insurance market and study the impact of loss-reduction activities on optimal insurance rates charged by the monopolist. More recently, Carson et al. (2013) found empirical evidence for this substitution in the case of homeowner insurance and catastrophic risks. Using a unique panel dataset from Florida, Kousky et al. (2014) found a significant crowding out effect of Federal disaster assistance on private insurance demand. Although the consequences of insurance pricing on consumer demand have been documented extensively (see Einav and Finkelstein (2018) in the case of health insurance), their behavioral implications on ex-ante prevention investments remain rather under-investigated.

While these empirical studies shed light on the debate on demand for insurance, they do not validate - or invalidate - the theoretical model, for three main reasons. First, actual data do not allow to properly assess risk aversion, a key variable in the demand model for insurance. Also,

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<sup>1</sup> Since the seminal contribution of Ehrlich and Becker (1972), two types of prevention activities have been identified: self-protection and self-insurance. Self-protection investments are intended to reduce the probability of an accident, while self-insurance expenditures are explicitly devoted to the reduction in the size of the loss, for example, protecting the house against the damages of fire or flooding, public and private investments made in preparing for climate change thru mitigation or adaptation (see Hasson et al., 2010). Self-insurance also includes all the health screening tests designed to diagnose diseases in their infancy (see Barigozzi (2004)), and the capital requirements imposed on banks and insurers can also be interpreted, to some extent, as self-insurance investments.

<sup>2</sup> The reason why self-insurance has decreasing marginal returns seems pretty intuitive (Ehrlich and Becker (1972)): any extra effort of loss-reduction needs a more expensive device (for example, in Health, an earlier detection of diseases would require a more expensive screening). While in the insurance case, for a given risk, insurance costs are mainly conditioned by the cost of capital provision whose marginal cost can be considered as constant.

insofar as the law makes insurance compulsory in many areas (motor insurance, health insurance, etc.), empirical data do not make it possible to measure the propensity of individuals to enter or leave the insurance market. Finally, as Ehrlich and Becker (1972) have shown, insurance is only one of several management tools, with prevention activities - self-insurance and self-protection - complementing the system. In a context with so many prevention opportunities, it is no longer possible to associate a change in insurance coverage with a change in price or income.

An experimental approach is particularly suitable to ascertain cause-effect relationships. Our experimental analysis addresses specifically the issue of the substitutability property between insurance and self-insurance. Implications of this research are significant. Had it been confirmed, the substitutability property would raise the question of the insurance tariff subsidization and its possible deterrent effect on the self-insurance behavior. Today, public healthcare policies overcome this issue by using partial insurance schemes with deductibles or copayments for patients. However, in the current context of the exponential growth of chronic diseases and catastrophic risks, assessing properly the substitution effect would determine whether additional measures, such as the promotion of self-insurance activities, are needed to reduce risk exposure.

Regardless of public deficits and the extent of chronic diseases, a clear substitution between insurance and self-insurance could also provide public authorities with leverage against the market power in insurance. Indeed, such substitution would result in a competition between the two coverage tools. This would mean for the insurers a decrease in their market power and therefore a loss of their ability to increase insurance price. Subsidizing self-insurance activities could become for the public policies a relevant and convenient tool to address the issue of non-competitive insurance markets.

Insurers could nevertheless benefit from the substitution between insurance and self-insurance. Under competition, once the price of insurance is actuarially adjusted, the substitutability property between insurance and self-insurance provides additional leverage for competition between insurers. Indeed, in order to attract policyholders, insurers may be prone to provide premium reductions based on a reduction in the quantity of insurance in return for an investment in prevention measures. Black boxes in cars, activity trackers offered by insurers find here their justification.

The validity of the substitution property addresses, therefore, essential issues that could contribute to public policy debates and provide guidelines for insurers' tariff policies. So far, this behavioral prediction has not been examined more closely in a laboratory experiment. Due to moral hazard considerations, the economics of prevention has emphasized the interactions between insurance and self-protection. Several theoretical papers (Ellis and Manning (2007), Jaspersen and Richter (2015)) stress that premium subsidies in insurance markets enhance moral hazard effects. By contrast, our paper focuses on prevention efforts intended to reduce the size of losses (self-insurance), and our theoretical analysis corroborates that premium subsidies may crowd out self-insurance efforts. However, an important feature of the tuning between insurance and self-insurance is that the optimal level of self-insurance is not expected to depend on the insurer observing it (Brunette et al. (2019)).<sup>3</sup>

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<sup>3</sup> Therefore, economic policy recommendations do not depend on the observability of self-insurance schemes.

With subjects facing both insurance and self-insurance opportunities to cover their risk of loss, our experimental study investigates the very core of the substitutability property in an extended theoretical analysis of Ehrlich and Becker's model. The observed demands for insurance and self-insurance, elicited with different insurance tariffs make it possible to test the substitutability property and the marginal returns equalization prediction alike. As predicted by the theory, our experimental results show that insurance and self-insurance are substitutes: when the unit price of insurance rises, the demand for insurance decreases while the demand for self-insurance increases. Moreover, disentangling the two components of the coverage (whether and how much to invest) shows that the substitution effect operates at all levels: a rise in the unit price is likely to crowd the subjects out of the insurance market and foster the likelihood of investing in self-insurance. In the same way, the demand for insurance of those who remain in the market decreases, whereas their demand for self-insurance increases.

However, due to a lack of adjustment to variations in insurance contractual parameters, individuals do not choose the levels of coverage (insurance and self-insurance) that equalize the marginal benefits of both devices. Therefore, a price subsidy policy is far from being as damaging to self-insurance as theory suggests with individuals overinvesting in self-insurance when the unit price of insurance is subsidized. Symmetrically, an actuarially unfair unit price of insurance does not induce prevention as much as the theory predicts. It would, therefore, be irrelevant to implement a high insurance pricing policy in order to stimulate self-insurance.

In Section II, we present, in an expected utility framework, the theoretical trade-off between insurance and self-insurance and the resulting propositions to be tested. In Section III, we develop the two-step procedure of our experimental design: the measure of risk aversion and the experimental trade-off between insurance and self-insurance. We report in section IV the experimental and econometrical results of the substitutability issues. Finally, in section V, we discuss the economic and policy implications of our behavioral results and conclude the paper.

## **II. The substitutability between the demand for insurance and the demand for self-insurance**

We present the main theoretical results related to the insurance (I) and self-insurance (SI) substitutability property by modeling the joint decision to insure and self-insure.

As risk-hedging choices are voluntary in our experiment, we characterize the four plausible patterns of consumption: interior solutions ( $SI > 0$  and  $I > 0$ ) and corner solutions: single hedging schemes ( $SI > 0$  &  $I = 0$  or  $SI = 0$  &  $I > 0$ ) and full risk retention ( $SI = I = 0$ ).

### **1. The standard model**

We consider an individual endowed with an initial wealth  $W_0$  and facing a risk  $q$  of losing a part  $x(e)$  of this wealth whose size depends on  $e$ , the self-insurance expenditure (or effort). To cope with this risk, she can use insurance and self-insurance opportunities.

*The two-part insurance tariff*

In exchange for the payment of an insurance premium  $Pm = pI + C$ , the individual receives an indemnity  $I$  in the case of an accident where  $p$  and  $C$  stand for the unit price of insurance and the fixed cost respectively. Insurance is determined by a large variety of fixed administrative costs

that need to be paid regardless of the level of coverage; on the other hand, the level of coverage is associated with a unit price that varies with the amount purchased. In many countries, health insurance involves a mandatory contribution that is complemented by a user fee. For the insured, this design amounts to paying a fixed cost that is then adjusted to reflect the number of medical services consumed. This premium-setting innovation makes it possible to test, in a same experimental session, the impact of both a change in the unit price and a change in wealth, over the effect of the fixed component of the cost. The latter acts as a tax on individuals' wealth when they buy a positive amount of insurance.

*The self-insurance technology*

The loss  $x(e)$  is a decreasing function of  $e$  with a decreasing return to scale technology:  $x'(e) < 0, x''(e) > 0$ .<sup>4</sup>

Risk-averse preferences are characterized by a strictly concave utility function  $U(W)$ , and the decision maker maximizes her expected utility (EU). Moreover, a positive fixed cost may deter the individual from buying insurance and requires; therefore, the use of a participation constraint (PC) to the insurance market. According to (PC), the optimal choices for  $I$  and  $e$ , must involve a higher EU than  $EU(\hat{e})$ , the optimal self-insurance effort when insurance hedging is not used:

$$\begin{aligned} EU(I, e) &= (1 - q)U(W_0 - pI - C - e) + qU(W_0 - pI - C - e - x(e) + I) \\ &\geq EU(0, \hat{e}) = \max_e (1 - q)U(W_0 - e) + qU(W_0 - e - x(e)) \quad (PC) \end{aligned}$$

In this context, the optimization problem of a decision maker combining the two risk-hedging tools can be written as follows:

$$\begin{cases} \max_{I, e} EU = (1 - q)U(W_0 - pI - C - e) + qU(W_0 - pI - C - e - x(e) + I) \\ \text{s. t. } EU(I, e) \geq EU(0, \hat{e}); \\ \quad I \geq 0; \\ \quad e \geq 0 \end{cases}$$

Appendices A and B provide a detailed examination of interior and corner solutions. While interior solutions focus on the demand of those who invest in hedging schemes (the conditional demands of insurance and self-insurance), corner solutions allow understanding how each parameter specifically affects the willingness of people to use the hedging instruments (the propensity to insure and to self-insure). To a lesser extent, corner solutions may provide additional information about conditional demands.

For this purpose, the demand for insurance  $I$  (resp. self-insurance  $SI$ ) is broken down into  $PI$  (resp.  $PSI$ ) the propensity to insure (resp. to self-insure) and  $CI$  (resp.  $CSI$ ) the demand for coverage for those who participate in the insurance (resp. self-insurance) market. Each hedging demand ( $D = I$  or  $SI$ ) can be written as:  $D = P * CD$ , where  $P = PI$  or  $PSI$  and  $CD = CI$  or  $CSI$ . At the decision-making level,  $P$  is 1 or 0. At a sample level,  $P$  refers therefore to the propensity to cover and is between 1 and 0. Emphasis will be put on implications at the individual level.<sup>5</sup>

<sup>4</sup> The link between  $e$ , the effort in self-insurance, and  $SI$ , the demand for self-insurance, is straightforward. The loss function may be rewritten as:  $x(e) = x_0 - SI(e)$ , with  $x_0 = x(0)$  and  $SI'(e) > 0, SI''(e) < 0$ .

<sup>5</sup> The demand for risk hedging ( $D = I$  or  $SI$  with  $I, SI \in [0; x]$ ) represents the genuine demand for each type of hedging. At individual level  $i$ ,  $D_i = P_i * CD_i$ , where  $P_i$  stands for the decision of individual  $i$  to buy insurance or self-insurance (1 or 0) and  $CD_i$  for the conditional demand for hedging (the amount of insurance or self-insurance bought if the decision is positive ( $P_i=1$ )). At an individual level,  $CD_i$  does not exist if  $P_i = 0$ , and  $CD_i = D_i$  otherwise.

## 2. Theoretical predictions

Predictions related to the substitutability property (P1 and P2) and issues related to risk aversion and fixed cost (P3 and P4) are summarized below.

### The substitutability issues

*The marginal returns' (MRs) equalization (Ehrlich and Becker (1972))*

**P1: The MRs' equalization: A rational optimizing EU risk-avertter invests in hedging tools until the MRs of conditional demands (CI and CSI) are equal:  $\frac{1}{p} = -x'(e)$ .**

*The substitutability property*

The overall result of an increase in the unit price of insurance is a decrease in the demand for insurance, along with an increase in the self-insurance effort  $e$  (and then in SI the demand for self-insurance). The comparative statics effect on the demand for insurance may require the CARA assumption, as stated in Appendix A. Due to the financial stakes involved in experimental economics, we retained this assumption.

The substitutability involves each component of the hedging demands (PI, PSI CI, and CSI) and implies that an increase in the insurance price is likely to crowd some individuals out of the insurance market (PI $\searrow$ ) and reduce the demand of those who continue to participate (CI $\searrow$ ). Along with these insurance market effects, some individuals should enter the self-insurance market (PSI $\nearrow$ ) while those who keep investing in the SI activity are expected to increase their demand (CSI $\nearrow$ ).

**P2: The substitutability property: a rise in the unit insurance price fuels all components of the demand for self-insurance (PSI, CSI, SI) to the detriment of those of the insurance demand (PI, CI, I).**

### Additional results

*The fixed cost effect and the between-tools substitutability*

In addition to the substitution effect induced by an increase in the insurance price, an increase in the fixed cost generates substitutability between tools. Indeed, a change in  $C$  has a positive effect on SI through PSI, while CSI is independent of  $C$  whenever the insurance coverage is positive.<sup>6</sup>

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At the aggregate mean level,  $D = \frac{1}{n} \sum_{i=1}^n D_i$ . If we denote  $k$  the number of times  $P_i=0$ ,  $D$  can be rewritten as the product of the propensity to buy insurance or self-insurance (proportion of individuals buying a strictly positive amount of hedging) by the mean conditional demand (the mean demand of those buying a strictly positive amount of hedging).

<sup>6</sup> If  $C$  reaches a prohibitive level, CSI rises with the insurance coverage vanishing; but we did not retain this effect as we expect its incidence to be marginal. This effect of  $C$  can be easily inferred from the discussions in Appendices A and B. But as a majority of subjects is expected to combine both risk hedging schemes, we found it reasonable to discard this specific prediction.

The propensity to insure diminishes with  $C$ . The behavior of the demand for insurance  $I$  is therefore driven by  $CI$ : Under CARA assumption  $CI$  is constant, and  $I$  is decreasing with  $C$ . As a result,  $C$  should influence only  $PSI$  and  $PI$ .

**P3: The between-tools substitutability effect of the fixed cost. Assuming a CARA utility function, an increase in the fixed cost  $C$  induces a between-tools substitution effect: Participants are expected to leave the insurance market ( $PI \downarrow$ ) and to enter the self-insurance one ( $PSI \uparrow$ ).**

*The risk aversion (RA) influence*

The demand for insurance is expected to increase with  $RA$ , accounting for the rise of both  $PI$  and  $CI$ . The demand for self-insurance is not expected to vary with  $RA$ .<sup>7</sup>

**P4: RA weighs positively on coverage: the higher the RA, the higher the demand for insurance. The demand for self-insurance is independent of RA.**

Table 1 details the expected effects of the  $p$ ,  $RA$  and  $C$  parameters on the demands and their components, assuming the utility is CARA.

**Table 1: The theoretical predictions for  $p$ ,  $RA$ , and  $C$**

Hedging activity	I			SI		
	PI	CI	$I=PI*CI$	PSI	CSI	$SI=PSI*CSI$
(P2) $p \uparrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\uparrow$	$\uparrow$	$\uparrow$
(P3) Fixed cost $\uparrow$	$\downarrow$	Indep	$\downarrow$	$\uparrow$	Indep	$\uparrow$
(P4) $RA \uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	Indep	Indep	Indep

<sup>7</sup> As mentioned in Appendices A and B, conflicting effects characterize the comparative statics of  $CSI$  and  $PSI$ . However, as discussed in Appendix B for  $CSI$ , it seems reasonable to retain the prediction resulting from equation (A.1):  $CSI$  is independent from  $RA$ . Regarding  $PSI$ , Appendix B shows that, according to the most likely corner solution (“insurance only”, see inequality (B.1)),  $PSI$  is not affected by  $RA$ ; this prediction is invalidated by the study of the less likely corner solution (“no insurance – no self-insurance”). Again, we retained the independence.



### III. Experimental design: Insurance and self-insurance

Our experimental protocol is an extension to self-insurance of the experimental design used in Corcos et al. (2017) to study the demand for insurance. It has been developed to test the optimality condition of the demands for insurance and self-insurance and the two-level substitutability property. It also allows to address risk aversion and fixed cost issues.

The experiment is a two-step procedure. We first measure the subjects' risk aversion coefficient. Then, in a six-round step, subjects have to decide whether and how much to hedge their risk of loss. They could use either insurance (I) or self-insurance (SI) opportunities or both.

#### 1. Step 1: Measuring risk aversion in an insurance context

Insurance decisions boil down to a trade-off between a significant random loss and a smaller one. Therefore, Kahneman and Tversky's findings (1979), which showed that risk attitudes depend on whether losses or gains are involved, require the elicitation procedure to carry a risk of loss. Thus, in each of the 10 rows of the adapted-Holt-and-Laury table below (Table 2), the subjects had to choose their preferred option between A and B, both options involving losses (see Chakravarty and Roy (2009)).

**Table 2: Measurement of risk aversion**

Decision	Option A			Option B			Expected Payoff Difference E(A)-E(B)		
	% Probability	Loss (in \$)	% Probability	Loss (in \$)	% Probability	Loss (in \$)			
1	10	-4	90	-6	10	0	90	-10	3.2
2	20	-4	80	-6	20	0	80	-10	2.4
3	30	-4	70	-6	30	0	70	-10	1.6
4	40	-4	60	-6	40	0	60	-10	0.8
5	50	-4	50	-6	50	0	50	-10	0
6	60	-4	40	-6	60	0	40	-10	-0.8
7	70	-4	30	-6	70	0	30	-10	-1.6
8	80	-4	20	-6	80	0	20	-10	-2.4
9	90	-4	10	-6	90	0	10	-10	-3.2
10	100	-4	0	-6	100	0	0	-10	-4

Moreover, to provide a measure of risk aversion as close as possible to an insurance choice, each decision in Table 2 was designed to mimic a hedging trade-off. The subjects had to choose between facing the risk of losing \$ 10 (option B) and purchasing a positive amount of insurance coverage (option A).<sup>8</sup>

Subjects' degree of risk aversion is revealed by their switching point from option A to option B. The last column of Table 2 shows, for each row, intervals for relative risk aversion compatible with a switch from option A to option B. In row 5, a risk-neutral individual would be indifferent

<sup>8</sup> Option A offers a partial insurance coverage: a \$ 4 insurance premium guarantees an indemnity of \$ 8 if the loss (\$ 10) occurs, which results in two loss levels, \$ 4 and \$ 6.

between option A and option B. Therefore, as in Corcos et al. (2017), subjects switching to option B before row 5 were risk lovers while the others were classified as risk averters.

For ethical reasons, the subjects were initially endowed with \$10 to cover their risk of loss. However, as mentioned by Thaler and Johnson (1990), subjects could, therefore, exhibit a riskier behavior due to a “house money” hypothetical bias. Considering the endowment as manna from heaven, the subjects might take more risk than with their own money. However, comparing several performance-based reward schemes, Etchart-Vincent and L’Haridon (2011) investigated the role of monetary incentives in the loss domain. They argued that “the choice of a payment scheme may not be a very critical issue in the loss domain” and found that a “losses-from-an-initial-endowment” procedure is not significantly affected by psychological biases.

## 2. Step 2: Investigating the trade-off between insurance and self-insurance

The second step consisted of six rounds where only insurance tariff differs. In each round, the subjects were first endowed with a wealth of 1000 EMU (experimental monetary units) facing a 10% chance of losing it all. Subjects were given the opportunity to buy insurance coverage and to invest in a self-insurance activity. They could use both schemes, only one of them, or none of them. Before they could combine both risk hedging schemes, each of them – insurance and self-insurance – were explained in detail to the subjects.

Providing that a subject decide to turn to the insurance device, then, in exchange for an insurance premium  $P_m$ , she would receive an indemnity  $I$  in the event of damage. The premium was an increasing function of the indemnity’s chosen level, according to the following equation:  $P_m = pI + C$ , where  $P_m$  stands for the insurance premium,  $p$  for the unit price of insurance, and  $I$  for the indemnity (namely the demand for insurance  $I$ ).

Table 3 provides an example of the offered premiums and their indemnities for an actuarially fair unit price and a zero fixed cost. For example, the premium payment  $P_m = 70$  EMU at the beginning of the round entitles to an indemnity  $I = 700$  EMU in case of loss during the round. The last column of Table 3 also gives the marginal return on insurance, i.e., the additional indemnity for an extra EMU invested in  $I$ .

**Table 3: Insurance premium schedule**

(1) Premium $P_m$	0	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150
(2) Indemnity $I$	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
(3) Add. indemnity	-	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

(1) Total cost of insurance with  $p = 0.1$   $C=0$

(2) Demand for Insurance: Reimbursement in the event of damage

(3) Additional indemnity from an additional EMU of premium

Simultaneously, as shown in Table 4, the subject also had the opportunity to self-insure: in return for an investment  $A$  in SI, she would secure a part of her wealth in the event of damage.

Table 4 gives the possible values for  $A$ ; Column (2) gives the corresponding SI. For example, if she decided to secure an amount  $SI = 630$  EMU, the subject would have to invest the proper

amount in SI, i.e.,  $A = 60$  EMU. Then, when facing damage, she would lose 370 EMU instead of 1000 EMU.

The column (3) in Table 4 provides the marginal return on additional investment in SI.

**Table 4: Self-insurance investment**

(1) Investment in SI	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
(2) $SI$	0	90	170	240	305	365	415	460	500	535	570	600	630	655	680	700	715	725	730	730	730
(3) Add. SI/EMU	-	18	16	14	13	12	10	9	8	7	7	6	6	5	5	4	3	2	1	0	0

(1) Investment SI in the activity A

(2) Demand for Self-Insurance (SI): the secured amount of wealth due to investment in prevention activity

(3) Additional secured amount of wealth per additional EMU spent in self-insurance activity SI

Table 3 and 4 were simultaneously displayed on the subject's computer screen. A device allowed the subjects to test as many combinations of  $Pm$  and  $A$  as they wished, to better adjust their desired final wealth where  $W_1$  stands for the no loss state and  $W_2$  for the loss state:

$$\begin{cases} W_1 = 1000 - Pm - A \\ W_2 = 1000 - Pm - A - 1000 + I + SI \end{cases}$$

With no hedging, the final wealth was respectively equal to  $W_1 = 1000$  EMU in the no loss state and to  $W_2 = 0$  in the loss state. In all cases, the total amount of compensation ( $I + SI$ ) paid in the event of an accident could not exceed the initial wealth (1000 EMU).

Once made, choices were confirmed by the subjects by clicking the button provided for this purpose. At the end of the round and after the subjects had made their decisions, a random draw determined whether damage occurred during the round. The computer calculated their final wealth, which was displayed on their screens.

Using different levels of the insurance contract parameters, the same round was played five more times. The six insurance grids were obtained by crossing three levels of unit price (subsidized ( $p = 0.05$ ), actuarially fair ( $p = 0.1$ ) and actuarially unfair ( $p = 0.15$ )) with two levels of fixed cost ( $C = 0$  and  $C = 50$ ).<sup>9</sup> The grids were randomly displayed to control for a possible order effect.

To ensure the between-round independency, the initial wealth was reset at the beginning of each round. Also, subjects were made aware that wealth and losses from previous rounds were not reported in the consecutive rounds.

### 3. Monetary incentives

Subjects were given a show-up fee endowment of \$10 to cover for their possible losses (about \$5) from the step devoted to the measurement of risk aversion. Additionally, both steps of the experimentation were incentivized. By computer, a first draw involving a number between 1 and

<sup>9</sup> This fixed cost level amounts to 50%, 33% and 25% of the full insurance premium for the 3 considered unit prices (0.05, 0.1 and 0.15 respectively).

10 identified a specific row in Table 2. Given the chosen option by the subjects for that row, a second random draw determined the size of the personal loss. In step 2, one of the six hedging choices rounds was drawn at random. The final wealth obtained during this step was converted from EMU into dollars (1 EMU = 1 cent).

To avoid a wealth effect, none of the step-1-or-2 gains (or losses) was disclosed until the end of the experiment. On average, the total amount earned represented \$15 on an hourly basis.

#### IV. Results

The experiment took place in Montreal and included 76 risk-averse individuals. This sample consisted of students (65%) and workers, men (40%), and women. The average age was 30 with a high concentration of subjects between 20 and 30 years old.

In line with the theoretical model of substitutability between insurance and self-insurance, our analysis focused on risk averters. Following Levy-Garboua et al. (2012), Charness et al. (2013) or Corcos et al. (2017), regardless of the number of switches, we used a count of the number of safe choices made as a measure of risk aversion. Therefore, 76 subjects, with at least five safe choices, were identified as risk averters (including risk neutral behavior).<sup>10</sup> However, of the 76 subjects, 4 subjects never insured nor self-insured and therefore were not concerned with the substitutability issue. They were discarded from our empirical analysis.<sup>11</sup>

Across all insurance contracts, the average global coverage demand in case of damage is 714 EMU encompassing the 414 EMU invested in the insurance activity and the 300 EMU in the self-insurance activity. On average, subjects spent 86 EMU for a coverage split between insurance (60 EMU) and self-insurance (26 EMU). 32 subjects (42%) chose to always invest in both insurance and self-insurance.

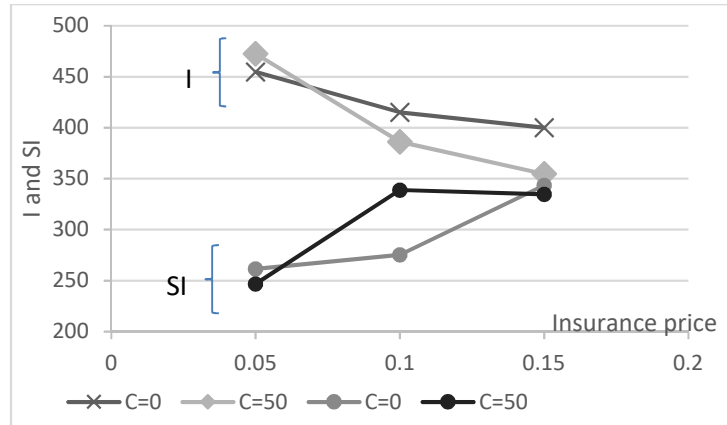
In Figure 1, the demands for I and SI are plotted according to unit price (x-axis) distinguishing the two levels of fixed cost ( $C=0$  and  $C=50$ ). Figure 1 highlights several salient points: the increase in the price of insurance makes apparent the substitution interplay between insurance and self-insurance demands. On the other hand, the fixed cost has no clear effect on any of the insurance and self-insurance demands.

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<sup>10</sup> The other 41 subjects, classified as risk lovers, have been discarded from our study.

<sup>11</sup> What distinguishes those four individuals from the others are not the contractual insurance or self-insurance parameters but specific characteristics.

**Figure 1: Demands for insurance and self-insurance**



In the following paragraphs, we first consider the marginal returns equalization and some of the substitutability property issues before reviewing additional results related to fixed cost and risk aversion.

### 1. The substitutability issue

#### *The marginal returns equalization*

The theory states that individuals are expected to equalize the marginal returns of insurance and self-insurance. To what extent are those predictions supported by the experimental data? Do subjects trade-off insurance and self-insurance in a way that differs from what is expected?

For each insurance contract with actuarially fair or unfair unit price ( $p = 0.1$  and  $p = 0.15$  respectively), we test whether the observed demands for insurance and self-insurance MRs are equal. When  $p = 0.1$ , the MR of insurance is equal to 10 (see Table 3) and two values of self-insurance are consistent with the MRs' equalization rule: 365 and 415.<sup>12</sup> When  $p = 0.15$ , the MR of insurance is 6.66 and the corresponding optimal amount for SI\* is equal to 570. When the unit price of insurance is subsidized,  $p = 0.05$ , the first units of SI's returns are smaller than insurance's, making SI not attractive. The optimal behavior is, therefore, a corner solution with individuals choosing only to insure (if C is not perceived as prohibitive). The corner solution leads to an MRs' equalization-like rule such that the optimal self-insurance level is zero.

We used one-sample Student tests to compare the theoretical and observed mean of the demand for self-insurance. When  $p = 0.1$ , the Student test has been carried out with  $SI^* = 390$  (the average of 365 and 415).

For each unit price, Table 5 provides the average value of observed SI (col. (1)), the theoretical  $SI^*$  level (col. (2)), the proportion of observed SI compliant with  $SI^*$  (col. (3)), and the Student

<sup>12</sup> A rational policyholder should be indifferent between 365 and 415: if the policyholder equalizes the marginal returns in the strict sense, she should invest in self-insurance until 415 (see Table 3) and complement her hedging with an insurance coverage. But, she could also implement the same hedging degree at the same cost by investing in self-insurance until 365.

statistics and p-values (col. (4)). As the theoretical levels depend only on unit price, the demands related to the different levels of fixed cost have been pooled.

**Table 5: Observed vs. theoretical self-insurance matching**

Unit Price of insurance	(1) Observed self-insurance: SI	(2) Theoretical self-insurance: SI*	(3) Nb of observed decisions in compliance with the theory (%)	(4) Student statistic (p-value)
0.05	268	0	50 (34.72%)	12.65* (0.000)
0.1	324	390 (365 or 415)	12 (8.34%)	3.24* (0.001)
0.15	357	570	8 (5.56%)	-10.39* (0.000)

The number of observations N is 144, given that the 0 and 50 EMU fixed costs rounds are pooled.

\*Significant at 0.001.

Column (4) in Table 5 shows that when the unit price is actuarially fair or unfair, the MRs' equalization rule is firmly rejected by most of the subjects due to a lack of adjustment of SI relative to prices (see column (1) and (3)). Neither is the corner solution for the subsidized unit price -no investment in SI – empirically validated (1<sup>st</sup> row, column 4).

**Result 1: Regardless the unit price of insurance, the marginal returns equalization behavior (P1) is rejected: Compared to the optimum, subjects overinvest in self-insurance when the insurance price is subsidized ( $p=0.05$ ) while underinvesting when it is actuarially fair or unfair ( $p>0.05$ ).**

*The substitutability property*

Table 6 provides the one-tailed Spearman's rank correlation tests between each component of the hedging activities and the unit price p.

**Table 6: Spearman's rank correlation coefficients between the unit price and the demands for hedging**

Hedging activity	I			SI		
	Correlation coefficient (p-value)			Correlation coefficient (p-value)		
Components	(1) PI (N=432)	(2) CI (N=363)	(3) I=PI*CI (N=432)	(4) PSI (N=432)	(5) CSI (N=321)	(6) SI=PSI*CSI (N=432)
Unit price p	-0.070* (0.074)	-0.072* (0.084)	-0.095** (0.024)	0.136** (0.002)	0.076* (0.087)	0.145** (0.001)

(N=number of observations); \* 10% significant; \*\*5% significant

Our data Both Figure 1 and Spearman's tests show evidence of the substitutability property (P2). The demands for self-insurance and insurance follow their expected path: when the price rises, the demand for insurance decreases (column (3)) while the self-insurance one increases (column (6)), making apparent their expected substitutability.

Columns (1) to (3) in Table 6 point out that a higher unit insurance price has a deterrent effect on the demand for insurance, through both a market exit (PI) and a demand contraction (CI). Table 6 also suggests that a higher unit price of insurance enhances the demand for self-insurance, with a rise in both the likelihood to invest in self-insurance (PSI, col. (4)) and, to a lesser degree, the conditional demand (CSI, col. (5)). This behavioral evidence supports the substitutability effect proposition (P2). However, the fact that subjects fail to equalize marginal returns, overinvesting in self-insurance activity when the price of insurance is subsidized, underinvesting when it is not, shows that this substitutability is weaker than it should be.

The econometric models developed below will allow going further in the validation of proposition P2.

#### *The econometric model of substitutability*

Based on statistical tests, the previous paragraphs presented and discussed results on the marginal equalization rule and the substitution issues. Although we rejected the marginal equalization rule, the Spearman rank correlation coefficients suggested the presence of substitution between insurance and self-insurance. In this section, controlling for contractual parameters and risk aversion, the substitutability property is estimated with econometric models using the panel structure of our experimental data (each participant made six choices).

Consider the following econometric specifications. Equation (1) is for self-insurance with a specification directly associated with the theoretical considerations summarized in Table 1, showing the effects of insurance parameters on self-insurance choices (SI).<sup>13</sup> Equation (2) relates to an insurance choice whose specifications is aimed to test the proposition P2 of our theoretical model related to the substitutability issue. In particular, the proposition P2 states clearly that insurance and self-insurance vary symmetrically as the unit price of insurance increases ( $\gamma_1 < 0$ ).

$$SI = \alpha_0 + \alpha_1 DCOST50 + \alpha_2 p + \alpha_3 RA + \mu_1 \quad (1)$$

$$I = \gamma_0 + \gamma_1 SI + \gamma_2 RA + \gamma_3 DCOST50 + \mu_2 \quad (2)$$

Specification of equations (1) and (2) assumes a sequential decision process with participants choosing first the level of self-insurance (equation (1)) when facing different insurance contract parameters (fixed cost and unit price of insurance, p) and following their level of risk aversion, RA. Next, the level of insurance (equation (2)) results from their risk aversion, the fixed cost, and

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<sup>13</sup> Ehrlich and Becker refer to a substitutability that considers only interior solutions (CI and CSI). In this paragraph, we test the hypothesis of substitutability between insurance and self-insurance by extending it to corner solutions. However, estimates based on interior solutions support their hypothesis and lead to results conform with those of equations (1) and (2). Corner solution substitutability (between PI and PSI) is also statistically significant. All econometrics results are available upon request.

the extent of the self-insurance. This sequential process from self-insurance to insurance find its justification in the theoretical model: the unit price of insurance induces the decision maker to set her level of self-insurance and to complement it by buying some insurance coverage for the residual risk (see Appendix A).

$DCOST50 = 1$  for a fixed cost equal to 50. The unit price of the insurance  $p$  is a three-value variable (0.05; 0.1; 0.15) and is treated as a continuous one. To avoid assuming a linear relationship between  $RA$  and the hedging behavior and to clearly disentangle risk neutrals and risk averters, risk aversion coefficient is dichotomized: the 65% weak risk averters and risk neutral ( $RA=5$ ) have been distinguished from the 34% higher risk-averse subjects ( $RA>5$ ):  $RA = 1$ , and  $RA = 0$  otherwise for neutral and weak risk-averse participants.<sup>14</sup> The  $\mu$ s are the error terms.

To test Proposition P2 on substitutability,  $\gamma_1$ , is the parameter of interest. From Table 1, we also expect that a more risk-averse participant should increase her level of insurance ( $\gamma_2 > 0$ ). We expect ( $\gamma_3 < 0$ ) that is a global negative effect of the fixed cost on  $I$ , through the decision to buy insurance.

For both equations, the parameter estimates are obtained with random-effect Tobit regressions on panel data. We refer to a two-stage procedure (instrumental variables) with predictive values for self-insurance being substituted in the insurance equation to complete the estimation of the model.

In Table 7, we report the estimation results for equations (1) and (2). P-values are provided in parentheses.

**Table 7: Testing the substitutability hypothesis between insurance and self-insurance**

	(1)	(2)
	$SI$	$I$
$p$	1206.04*** (0.000)	
$DCOST50$	25.61 (0.144)	-2.96 (0.913)
$RA$	10.15 (0.434)	210.64*** (0.002)
$\widehat{SI}$		-1.14*** (0.001)
<i>Constant</i>	129.18 (0.004)	680.10 (0.000)
<i>Observations</i>	432	432
<i>Participants</i>	(111 left-censored obs)	(69 left-censored obs)
	72	72

\*\*\*1%

With  $\widehat{\gamma}_1 < 0$  and significant, Table 7 shows that the substitution between the demands for insurance and self-insurance is supported by the data: A rise in the demand for self-insurance decreases the level of insurance.

<sup>14</sup> This segmentation overlaps Holt and Laury's (2002).



In equation (1), only  $p$  is significant to explain SI, though we were expecting a positive and significant coefficient estimates for DCOST50. Therefore, the substitutability observed between insurance and self-insurance is indisputably the effect of the unit price of insurance.

**Result 2: Experimental data endorses the fundamental property of substitution (P2): a rise in the insurance price significantly increases the demand for self-insurance while reducing the demand for insurance. The substitution effect is achieved by adjustment of each of the components of the demand for coverage (corner and conditional decisions)**

## 2. Further results: the impact of the fixed cost and RA on hedging demands

The question also arises as to how fixed cost and risk aversion influence hedging behavior. Non-parametric tests and econometric models are used to address this issue.

### *The fixed cost exit effect*

The one-tailed Spearman's rank correlation tests with the contractual parameter of the fixed cost  $C$  are given in row (1) of Table 8. The levels of significance are given in parentheses.<sup>15</sup>

**Table 8: Spearman's rank correlation coefficients between RA or C and the demand for hedging**

Hedging activity	I			SI		
	Correlation coefficient (p-value)			Correlation coefficient (p-value)		
Components	(1) PI (N=432)	(2) CI (N=363)	(3) I=PI*CI (N=432)	(4) PSI (N=432)	(5) CSI (N=321)	(6) SI=PSI*CSI (N=432)
(1) Fixed cost C	-0.044 (0.179)	0.004 <sup>a</sup> (0.936)	-0.025 (0.300)	0.058 (0.113)	-0.029 <sup>a</sup> (0.609)	0.029 (0.276)
(2) RA <sup>b</sup>	0.212** (0.000)	0.152** (0.002)	0.245** (0.000)	0.073 <sup>a</sup> (0.130)	-0.078 <sup>a</sup> (0.165)	0.012 (0.402)

(N=Number of observations); \* 10% significant; \*\*5% significant.

a: In compliance with the prediction of independence, a two-tailed test has been implemented.

b: To homogenize with the econometric models, risk aversion is dichotomized.

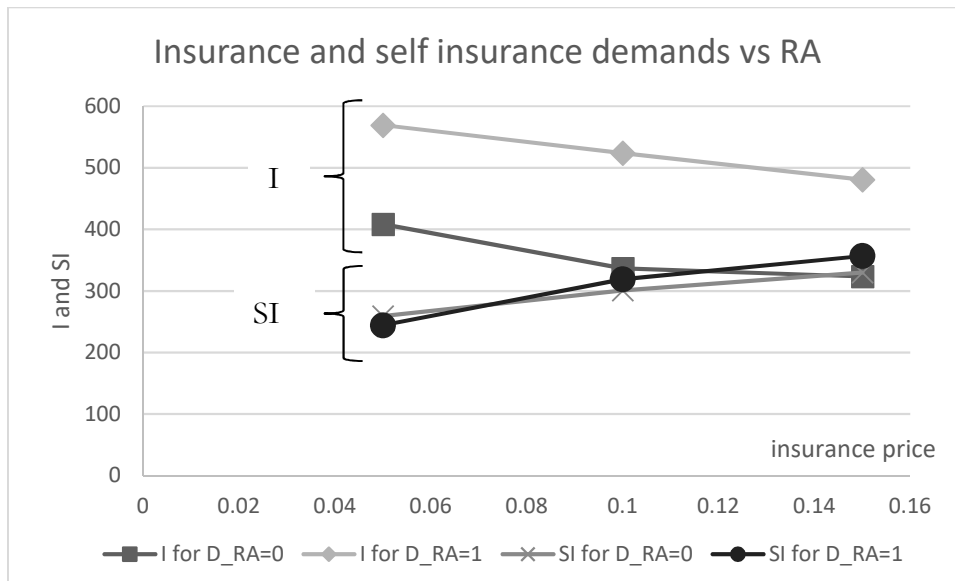
Spearman rank correlation tests (Table 8, row (1)) indicate that the fixed cost increase has no significant effect on any of the hedging demands' components. These results are consistent with the econometrics model (see models (1) and (2) above related to SI and I) where DCOST50 is never significant.

**Result 3: The fixed cost between-tools effect (P3) is not supported by our experimental data: an increase in the insurance price has no significant effect on any of the components of the demand.**

<sup>15</sup> The 0 and 50 EMU fixed costs rounds are pooled since considering them separately does not significantly modify the results.

Figure 2 shows the demands for insurance and self-insurance for each level (weak and strong) of risk aversion. Table 8, row (2) examines the relationship between RA coefficient and the demands for coverage, providing one-tailed Spearman’s rank correlation tests between the RA coefficient and each component of the related hedging activity.

**Figure 2: The demands for coverage vs risk aversion intensity**



Controlling for the effects of unit price and fixed cost, the econometric model (equations (1) and (2)) above makes it possible to assess the impact of RA. Only the demand for insurance (equation (2)) is higher for a more risk-averse participant, the self-insurance demand being unaffected (equation (1)).

Both Figure 2 and the statistical results lead to consistent findings: the influence of RA is only driven by insurance demand, which supports the theoretical predictions P4 relative to RA in Table 1.

**Result 4: As the risk aversion rises, the demand for insurance and its breakdown decreases which validates the theoretical proposition (P4).**

Implications of those results for public policies and insurers are further examined in the next section.

## V. Discussion and conclusion

Our analysis provides new insights into the behavior of insurance and self-insurance demands. We extend the theoretical Ehrlich-Becker’s substitutability model by unraveling the two decisions of whether and how much to cover. Our paper investigated with an experimental protocol the

marginal returns equalization prediction and carried out statistical tests on the extended substitutability property between insurance and self-insurance.

The experimental data support the substitutability effect. An increase in the unit price of insurance results in the dual effect of the ousting from the insurance market of some individuals and the contraction in the conditional demand for insurance. The exact opposite effect is observed regarding the self-insurance activity: both the propensity and the conditional demand of self-insurance increase. However, because of a lack of adjustment to changes in insurance unit prices, the subjects fail to equalize the marginal returns of hedging coverage.

We also studied the role of the fixed cost and the level of intensity of the risk aversion of participants. As expected, an increase in the risk aversion influences only the demand for insurance and its breakdown PI and CI which fully supports the theoretical predictions. However, we did not find evidence of the fixed cost between-tools substitutability effect: Our data suggest that the fixed cost has no significant effect on any components of the demands for insurance and self-insurance.

#### *Substitutability issues, the private sector, and public policy*

Given the evidence of the substitution effect between insurance and self-insurance, a policy intended to promote insurance through subsidized prices could be doomed to fail as it expands the risk to crowd out self-insurance. However, our behavioral results show that this substitutability effect is not as strong as it should be: when the unit price is subsidized, the observed level of self-insurance is far from the theoretical zero level. With an eviction effect from the self-insurance market not as significant as expected, governments are entitled to subsidize the insurance rates.

For the very same reason of lack of adjustment to insurance price, a policy that would promote high insurance prices in order to stimulate investment in self-insurance activities would not be as effective as expected, with subjects significantly underinvesting in self-insurance when the unit price of insurance is actuarially unfair.

Incidentally, this study provides a post hoc justification for the existence of self-insurance clauses in insurance contracts. Under competition on the insurance market, insurers are induced to maximize the well-being of the policyholders. According to the standard theory, investment in self-insurance is determined by the unit price of insurance through the equalization of marginal returns of insurance and self-insurance. However, as seen before, for actuarially fair and unfair unit prices of insurance, the amounts of self-insurance are significantly lower than they should be. Given the behavioral reluctance to adjust self-insurance hedging to insurance pricing, such self-insurance clauses in private insurance contracts could make it possible to align theoretical and observed values of self-insurance.

Our study therefore provides an explanation of the paradox of the existence of self-insurance clauses in insurance contracts, given the substitutability between insurance and self-insurance. Until now, from a theoretical perspective, mandatory self-insurance clauses in insurance contracts (e.g., the requirement for a burglar alarm or a security gate in the case of household insurance)

observed in the real world appeared to be a puzzle: To the extent that self-insurance behaviors are not dependent on being observable (Brunette et al. (2019)), individuals are not likely to deviate from their optimum. Therefore, the main effect of compulsory self-insurance clauses would be to crowd out insurance as a result of the substitutability property between insurance and self-insurance. As far as enforcing self-insurance levels results in more efficient premiums, this paper suggests a way to overcome the puzzle of compulsory self-insurance clauses.

### *Nudging higher coverage*

Our results reveal quite different insurance coverage behaviors from those obtained in Corcos et al. (2017), using the same experimental design with insurance opportunities only. The present analysis suggests that, compared to the situation with insurance alone, self-insurance opportunities modify the nature of the trade-off made by the subjects. In that earlier paper, the authors found that an increase in the insurance unit price leads the subjects to exit the market rather than reducing their coverage. Combined with insurance, self-insurance opportunities mitigate this exit effect since most subjects prefer to reduce their insurance coverage rather than exiting the insurance market.

Also, Brunette et al. (2019) theoretically determine that self-insurance opportunities lead to an increase in total coverage despite a reduction in insurance demand. A comparison of the present study with that of Corcos et al. (2017) confirms this prediction. First, in Corcos et al. (2017), the risk-aversers' average demand for insurance is 594 while it is only 414 in the present paper. Second, the average total amount of coverage with insurance and self-insurance opportunities is  $714 > 594$ .

Increasing the number of tools for opportunities to cover a disaster could encourage the subjects to use them all. This “nudge” proposition calls for further investigation.

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## Appendices

### 1. Appendix A: Interior solutions (CI>0 and CSI>0)

The decision maker maximizes expected utility with respect to  $I$  and  $e$ , facing three constraints, the participation constraint ( $EU(I, e) \geq EU(0, \hat{e})$ , where  $\hat{e} = \operatorname{argmax}_e (1 - q)U(W_0 - e) + qU(W_0 - e - x(e))$ ) and the two non-negativity constraints ( $I \geq 0$ ,  $e \geq 0$ ). The resulting optimization problem is the following:

$$\left\{ \begin{array}{l} \max_{I, e} EU = (1 - q)U(W_0 - pI - C - e) + qU(W_0 - pI - C - e - x(e) + I) \\ \text{s. t. } (1 - q)U(W_0 - pI - C - e) + qU(W_0 - pI - C - e - x(e) + I) \geq \\ \quad (1 - q)U(W_0 - \hat{e}) + qU(W_0 - x(\hat{e}) - \hat{e}); \quad (PC) \\ I \geq 0; \quad (NI) \\ e \geq 0; \quad (NSI) \end{array} \right.$$

#### Characterization of the solution:

When the condition (PC) and non-negativity constraints ((NI) and (NSI)) are not binding, the optimal choice for CI and CSI is described by the first order conditions (FOC):

$$\begin{aligned} \frac{\partial EU}{\partial e} &= -(1 - q)U'(W_1) - [1 + x'(e)]qU'(W_2) = 0 \\ \frac{\partial EU}{\partial I} &= -p(1 - q)U'(W_1) + (1 - p)qU'(W_2) = 0 \end{aligned}$$

Second order conditions are checked below:

$$\frac{\partial^2 EU}{\partial e^2} = (1 - q)U''(W_1) + [1 + x'(e)]^2 qU''(W_2) < 0$$

$$\frac{\partial^2 EU}{\partial I^2} = p^2(1 - q)U''(W_1) + (1 - p)^2 qU''(W_2) < 0$$

$$\left| \begin{array}{cc} \frac{\partial^2 EU}{\partial I^2} & \frac{\partial^2 EU}{\partial I \partial e} \\ \frac{\partial^2 EU}{\partial I \partial e} & \frac{\partial^2 EU}{\partial e^2} \end{array} \right| = q(1 - q)[1 + x'(e)]^2 U''(W_1) U''(W_2) > 0$$

Thus, the FOC are necessary and sufficient for an optimum. We rewrite both conditions to compare, for each coverage tool, the marginal cost (MC) to the marginal benefit (MB):

$$\frac{\partial EU}{\partial e} = -(1 - q)U'(W_1) - qU'(W_2) - x'(e)qU'(W_2) = 0$$

$$\frac{\partial EU}{\partial I} = -p[(1 - q)U'(W_1) + qU'(W_2)] + qU'(W_2) = 0$$

The ratio of these conditions leads to a fundamental result: a rational EU agent invests in self-insurance to equalize marginal returns (MRs) of insurance and self-insurance:

$$\frac{1}{p} = -x'(e) \quad (\text{A.1})$$

From equation (1), the unit price of I indirectly settles the CSI investment chosen. The decision maker sets the level of CSI at the point that equalizes the MRs and complements it by buying some insurance coverage (CI) for the residual risk.

### Comparative statics:

From FOC, we infer the impacts on optimal choices ( $I^*$  and  $e^*$ ) of changes in  $p$ ,  $C$  and risk aversion (RA).

#### a) *The influence of $p$ on the conditional demands CI & CSI*

From equation (1), we readily infer that an increase in the unit price of I results in an increase in CSI (since  $-x'(e)$  is decreasing with  $p$ ,  $e$  and CSI increase with  $p$ ).

In this case, it is straightforward that when  $e$  increases, CI decreases. Indeed, the derivative of EU with respect to  $e$  can be written as follows:

$$\frac{\partial EU}{\partial e} = -(1 - q)U'(W_0 - pI - C - e) - [1 + x'(e)]qU'(W_0 - pI - C - e - x(e) + I)$$

Following an increase in  $e$ , assuming a CARA utility function, the 1<sup>st</sup> negative term increases (in absolute value) while the 2<sup>nd</sup> positive term decreases (at least relatively).<sup>16</sup> So, as to avoid this condition being negative, it is necessary to decrease I, which has exactly the opposite effect to an increase in  $e$ .<sup>17</sup>

Therefore, as shown by Ehrlich and Becker (1972), CI and CSI are substitutes.

#### b) *The influence of RA on the conditional demands CI & CSI*

The level of CSI is independent of the degree of risk aversion since it is driven by the equalization of MRs. Self-insurance alone would be increasing with risk aversion (see Dionne and Eeckhoudt (1985)), but when combined with insurance opportunities, the marginal return equalization rule makes self-insurance independent of risk aversion intensity.

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<sup>16</sup> CARA: constant absolute risk aversion; DARA: decreasing absolute risk aversion; IARA: increasing absolute risk aversion.

<sup>17</sup> Under DARA assumption, an increase in  $p$  produces a wealth effect which blurs the comparative statics.



On the insurance side, whether self-insurance is available or not, the behavior of insurance demand is characterized by the same FOC, so the insurance coverage (CI) increases with risk aversion.

*c) The influence of C on the conditional demands CI & CSI*

The other results of comparative statics are also straightforward. A rise in C has no impact on the CSI demand since the equality of I and  $e$  MRS,  $\frac{1}{p} = -x'(e)$ , results in the same amount for  $e$ .

The behavior of the conditional demand for insurance CI is described by the FOC ( $\frac{\partial EU}{\partial I} = 0$ ), rewritten as:

$$\frac{p(1-q)}{(1-p)q} = \frac{U'(W_2)}{U'(W_1)} = \frac{U'(W_0 - pI - C - x(e) + I - e)}{U'(W_0 - pI - C - e)}$$

Deriving the right-hand side with respect to C leads to:  $\frac{U'(W_2)}{U'(W_1)} [A(W_2) - A(W_1)]$ , where  $A(W)$  is the Arrow-Pratt coefficient. Thus, following an increase in C, and excluding over-insurance (so,  $W_1 \geq W_2$ ), the right-hand side ratio increases (resp. decreases) if the utility is DARA (resp. IARA). Therefore, to comply with optimality, the decision maker will have to compensate for that change in the ratio and will demand more (resp. less) insurance under the DARA (resp. IARA) assumption. CI will remain stable in the case of a CARA utility function.

Note also that a sufficient increase in C could lead to the 2<sup>nd</sup> case of Appendix B (“self-insurance only”); in this particular case, CSI would increase as a reaction to the exit of the insurance market. Unless the fixed cost is very high, the likelihood of such an effect seems rather low and was discarded in our predictions.

## 2. Appendix B: Corner Solutions and the behavior of PI and PSI

When risk hedging is voluntary, three types of corner solutions may occur: insurance only, self-insurance only, none of them. The study of these corner solutions brings information about the determinants of the propensities to insure and self-insure (PI and PSI).

The 1<sup>st</sup> case – insurance only – happens when (PC) and (NI) are not binding while (NSI) is binding and the first monetary unit invested in self-insurance is not profitable. To characterize this situation, we evaluate the 1<sup>st</sup> order derivative of EU with respect to  $e$ , for a zero investment in  $e$  and optimal insurance  $\hat{I}$ :

$$\left. \frac{\partial EU}{\partial e} \right|_{e=0} = -(1-q)U'(W_0 - \hat{P}) - q[1 + x'(0)]U'(W_0 - \hat{P} - x(0) + \hat{I}) \leq 0$$

If this expression is negative, it is optimal to neglect this hedging scheme. Combining this inequality with the 1<sup>st</sup> order condition for a strictly positive insurance demand, we obtain the following inequality:

$$-x'(0) \leq \frac{1}{p} \quad (\text{B.1})$$

Therefore, as the marginal return of self-insurance is decreasing and the marginal return of insurance is constant, it is sufficient to compare their levels for the 1<sup>st</sup> unit of self-insurance to decide to engage or not in this hedging scheme.

The occurrence of this situation does not depend on the risk aversion intensity, but it could be overruled in the presence of a prohibitive fixed cost: a positive investment in self-insurance may occur even if the previous inequality is true, when (PC) is violated.

Therefore, at a sample level, when the individual only buys a positive amount of insurance, the PSI is increasing with  $p$ , with the fixed cost, and is not expected to vary with the risk aversion intensity.

On the other side, the demand for insurance (CI) matches Mossin's model.<sup>18</sup>

The 2<sup>nd</sup> case – self-insurance only – appears whenever (NI) and/or (PC) are saturated, i.e., when the unit price and/or the fixed cost are too high.

To assess the effect a too high unit price may have, we need to calculate the 1<sup>st</sup> order derivative of EU with respect to  $I$  and evaluate it for  $I=0$  and for  $\hat{e}$  the optimal investment:

$$\left. \frac{\partial EU}{\partial I} \right|_{I=0} = -p(1-q)U'(W_0 - \hat{e}) + (1-p)qU'(W_0 - \hat{e} - x(\hat{e})) \leq 0$$

Using this inequality and the optimality condition for self-insurance simultaneously, we get:

$$-x'(\hat{e}) \geq \frac{1}{p} \quad (\text{B.2})$$

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<sup>18</sup> Since Mossin (1968), we know that the demand for insurance increases with RA. Assuming a CARA utility function, CI would decrease with  $p$  and would be invariant to a change in  $C$  (as soon as (PC) is satisfied).

Then, the unit price of insurance is a deterrent, and the decision maker finds it profitable only to invest in self-insurance since the last desired unit of  $e$  is more profitable than insurance. In this case, from Dionne and Eeckhoudt (1985)), we know that the CSI demand is increasing with risk aversion and a less risk-averse decision maker would demand a lower level of CSI; as a result,  $-x'(\hat{e})$  would be greater than  $\frac{1}{p}$ . Therefore, in the context of  $I=0$ , CSI is expected to increase with risk aversion. But at the same time, the likelihood of this corner solution would decrease with RA, which would generate a decrease in CSI resulting from the participation to the insurance market. Finally, this corner solution effect is not clear, so we retained the prediction of invariance resulting from the study of interior solutions.

However, even if the unit price is not that high, the decision maker may leave the insurance market if condition (PC) is not satisfied. By developing this constraint, we see that there always exists, ceteris paribus, a threshold  $\bar{C}$  that leaves the decision maker indifferent between the optimal bundle  $(I^*, e^*)$  and no insurance  $(0, \hat{e})$ :

$$\begin{aligned} (1 - q)U(W_0 - pI^* - \bar{C} - e^*) + qU(W_0 - pI^* - \bar{C} - e^* - x(e^*) + I^*) \\ = (1 - q)U(W_0 - \hat{e}) + qU(W_0 - \hat{e} - x(\hat{e})) \end{aligned}$$

According to the implicit function theorem, it is evident that this threshold is decreasing with the unit price  $p$ . The threshold  $\bar{C}$  is also increasing with risk aversion, a consequence of the fact that the insurance premium is increasing with risk aversion (Pratt (1964)). Thus, ceteris paribus, a more risk-averse individual will be ready to bear a higher level for the fixed cost, without leaving the market.

We infer from these results that PI is increasing with RA and decreasing with  $p$  and  $C$ .

The 3<sup>rd</sup> case – no insurance, no self-insurance – occurs under two circumstances:

- when (NI) and (NSI) are simultaneously binding (then (PC) is also saturated);
- when (NSI) and (PC) are simultaneously binding (but not (NI)).

The 1<sup>st</sup> situation occurs when none of the marginal returns of hedging schemes are attractive enough. More precisely, it arises if the marginal return of  $e$  is too low and if the unit insurance price is high. By evaluating the FOC at  $e=0$  &  $I=0$ , we obtain the following conditions to be met:

$$\begin{aligned} \left. \frac{\partial EU}{\partial e} \right|_{\substack{e=0 \\ I=0}} &= -(1 - q)U'(W_0) - q[1 + x'(0)]U'(W_0 - x(0)) \leq 0 \\ \left. \frac{\partial EU}{\partial I} \right|_{\substack{e=0 \\ I=0}} &= -p(1 - q)U'(W_0) + (1 - p)qU'(W_0 - x(0)) \leq 0 \end{aligned}$$

After rearrangements, full risk retention occurs if the following inequalities are simultaneously satisfied:

$$-x'(0) \leq \frac{(1 - q)U'(W_0)}{qU'(W_0 - x(0))} + 1 \text{ and } \frac{1}{p} \leq \frac{(1 - q)U'(W_0)}{qU'(W_0 - x(0))} + 1 \quad (\text{B.3})$$

Then, marginal returns of both hedging schemes are too small to attract the interest of the decision maker. These inequalities are more likely to be true if risk aversion is low. Indeed, the

ratio on the right of the inequality is decreasing with the intensity of risk aversion. Therefore, all things being equal, the likelihood of full risk retention decreases with risk aversion.

The 2<sup>nd</sup> situation occurs if the participation constraint is violated. Then, the individual does not resort to any insurance coverage, which arises if the fixed cost is sufficiently high while (NSI) is saturated.

Finally, considering the two previous inequalities and the role played by  $C$  (through condition (PC)), this “full risk retention” case underlines the positive effect of RA on both PI and PSI, while  $p$  and  $C$  have negative effects on PI and positive effects on PSI.