The Geneva Risk and Insurance Review (2024) 49:6–35
https://doi.org/10.1057/s10713-023-00094-1

ORIGINAL ARTICLE

The economics of self-protection

A tribute to EGRIE

Richard Peter[1]

Published online: 25 February 2024

Abstract
Self-protection is a costly activity that reduces the probability of an unfavorable outcome. Even the simplest model with a binary risk of loss and expected utility of final wealth produces interesting comparative statics that are by no means trivial. This article provides a selective survey of the economics of self-protection. It puts particular emphasis on the contributions made by members of the European Group of Risk and Insurance Economists and research published in the Geneva Risk and Insurance Review. The article provides a conceptual framework to catalog existing models of self-protection, discusses the tension between risk aversion and downside risk aversion, reveals the role of probability thresholds, surveys extensions to non-expected utility, and highlights the recent surge in two-period models. Ideas for future research directions are also developed.

Keywords Self-protection · Prevention · Comparative statics · Risk preferences

JEL Classification D61 · D81

I would like to thank Michael Hoy and Wanda Mimra for inviting me to write this survey about the economics of self-protection and for offering excellent comments. I owe gratitude to Christophe Courbage, Liqun Liu and an anonymous reviewer for their valuable feedback and encouragement. I would also like to thank Louis Eeckhoudt for sparking my interest in the economic analysis of self-protection during one of his visits to Munich when I was a second-year Ph.D. student. I dedicate this paper to the memory of Anny Theunynck.

✉ Richard Peter
richard-peter@uiowa.edu

[1] Department of Finance, University of Iowa, Iowa City, IA 52240, USA

1 Introduction

The year 2023 marked the 50th anniversary of the European Group of Risk and Insurance Economists (EGRIE). As part of the celebration, the EGRIE board proposed the publication of a special issue in EGRIE's journal, the Geneva Risk and Insurance Review (GRIR), on topics that fit the aims and scope of the journal.[1] The economic analysis of self-protection is one such topic. Self-protection is a costly activity to reduce the probability of an unfavorable outcome. Over the past 50 years, much has been learned about the economics of self-protection but there is still plenty of opportunity for further inquiry. This article reviews some of the literature on self-protection to summarize the existing body of knowledge and identify directions for future research.

Coincidentally, EGRIE's golden jubilee is just one year later than the 50-year anniversary of Ehrlich and Becker (1972)'s seminal article on self-insurance and self-protection. The first evidence that these topics were of interest to the EGRIE group is found ten years later, when Gougeon (1983) writes: "Plus précisément deux effets sont escomptés: (i) une réduction de la probabilité de survenance du risque; (ii) une moindre gravité du sinistre si celui-ci, malgré tout, survient." It takes little knowledge of French to recognize self-protection in (i) and self-insurance in (ii). To put it in Henri Loubergé (2013)'s words, the work by Ehrlich and Becker "may be seen as the first theoretical article on risk management." Orio Giarini, first Secretary General of the Geneva Association and founding president of EGRIE, emphasized that insurance is just one pillar in addressing the risks households, firms, and society face. He insisted that other pillars should be studied too. A true visionary, Orio Giarini recognized already back in the 1970s the importance of non-insurance mechanisms to deal with a firm's risks (Courbage and Loubergé 2021; Doherty 2021). Fifty years later the concepts of prevention, loss control, and self-protection in particular could not be more relevant.

Self-protection activities matter at the household, corporate, and societal level. Individuals may invest in burglar alarm systems for their homes to prevent robbery (Vollaard and Van Ours 2011). In regions prone to natural disasters, home fortification efforts can reduce the probability of property damages in case a disaster strikes (e.g., Awondo et al. 2023). Safety features in vehicles like lane assist, blind spot monitors, backup cameras, traffic-sign recognition, and collision avoidance systems reduce the likelihood of traffic accidents. In the health domain, examples of primary prevention include vaccination, postexposure prophylaxis, information provision on behavioral and medical health risks, inclusion of prevention programs at primary and specialized health care levels, nutritional and food supplementation, as well as dental hygiene (see the World Health Organization, https://www.who.int). Firms engage in loss control to make the workplace safer for customers, employees, and third parties on the premises. Many of these activities are subject to regulatory oversight, for example, by the Occupational Safety and Health Administration (OSHA) in the USA. At the societal level, one encounters self-protection activities

[1] As I understand it, much of the credit for proposing this idea in the first place goes to Wanda Mimra, who served as the EGRIE president at the time.

in the context of risk regulation in environmental policy, public health, and transportation (see Jones-Lee et al. 1985). The self-protection problem is embedded in the standard principal-agent model of incentive contracting (Holmström 1979) and also constitutes a building block in the contest literature (Lazear and Rosen 1981). Some, including the author of this survey, would go so far as to claim that self-protection is an archetypal problem in the theory of choice under risk and uncertainty, which makes it a canonical subject for economists to understand.

This paper is not the first attempt to survey the literature on self-protection. Courbage et al. (2013) provide a review of prevention and precaution for the 2nd edition of George Dionne's Handbook of Insurance, and Courbage et al. (2024) give some updates for the 3rd edition. Now there is also a chapter about the technical aspects of the self-protection problem in the Handbook (Peter 2024). Newhouse (2021) provides a recent perspective on the economic value of prevention in the health domain. In his Geneva Risk Economics Lecture, Han Bleichrodt (2022) speaks of the "prevention puzzle" for the difficulty that economic theory has in guiding prevention decisions.[2] It is inevitable that there will be some overlap between this survey and the other surveys on prevention. However, my emphasis is to carve out the important roles played by the annual EGRIE Seminar and the GRIR for the progress that has been made in the analysis of self-protection over the years. I conclude that we would not be where we are today in our understanding of the economics of self-protection if it was not for EGRIE and the valuable contributions by many of its members. I hope that readers will join me in viewing this conclusion as a truly remarkable reason for celebration and an accolade to the important work carried out by the association and its members.

Section 2 outlines a general model of self-protection that encompasses many variations of Ehrlich and Becker (1972)'s model as special cases. Section 3 focuses on classical puzzles in the economic analysis of self-protection. Section 4 discusses the behavioral economics of self-protection, which is typically carried out in non-expected utility theories. Section 5 presents two-period models of self-protection, which have gained increasing attention in recent years. Section 6 reviews a selection of other topics related to self-protection. Section 7 discusses avenues for further research and a final section concludes.

2 A conceptual framework

Self-protection is a costly investment that reduces the odds of unfavorable outcomes and raises the chances of favorable outcomes. In this section, I formulate a general model of self-protection that contains many variants of the problem from the literature as special cases. Let $(\Omega, \mathcal{F}, \mathbb{P})$ be a probability space. There are N states of the world so the state space is $\Omega = \{\omega_1, \ldots, \omega_N\}$. Assume that outcomes are M-dimensional, that is, $\mathbf{x} = (x^1, \ldots, x^M)$. I refer to x^m as the mth attribute of outcome

[2] He gave his lecture on the occasion of the 48th EGRIE Seminar, which was held virtually due to the ongoing Covid-19 pandemic. It is needless to say that the recent experience with Covid-19 has sparked renewed interest in issues of self-protection and prevention more generally (see, e.g., Dobson et al. 2020).

$\mathbf{x}$ for $m \in \{1, \dots, M\}$. Outcomes are random, and I denote by $\mathbf{x}_1, \dots, \mathbf{x}_N$ the different possible outcome vectors. The decision-maker (DM) has an initial endowment of $\mathbf{w}_0 = (w_0^1, \dots, w_0^M)$. Let $\preceq$ denote the DM's preference over outcomes and let $\prec$ denote the asymmetric part of $\preceq$. Suppose the possible outcomes are ordered from worst to best by the state of the world, that is, $\mathbf{w}_0 + \mathbf{x}_1 \prec \cdots \prec \mathbf{w}_0 + \mathbf{x}_N$. For ease of exposition, I assume that no state is redundant (i.e., if $\mathbf{w}_0 + \mathbf{x}_i \sim \mathbf{w}_0 + \mathbf{x}_j$ held for states $\omega_i \neq \omega_j$, collapse ω_i and ω_j into a single state).

The cumulative distribution function (CDF) over states is given by $F(n) = \mathbb{P}(\{\omega_1, \dots, \omega_n\})$ for $n \in \{1, \dots, N\}$ with the convention that $F(0) = \mathbb{P}(\emptyset) = 0$. The probability of state ω_n is then given by $p_n = F(n) - F(n-1)$. Suppose now that the DM has access to a self-protection technology that allows her to manipulate the probabilities of states of the world. In particular, let $\mathbf{e} = (e^1, \dots, e^K)$ represent the DM's behavior in the model with associated cost vector $\mathbf{c}_n(\mathbf{e}) = (c_n^1(\mathbf{e}), \dots, c_n^M(\mathbf{e}))$ in state ω_n.[3] I assume that higher levels of self-protection are more costly, that is, $\mathbf{e}' \geq \mathbf{e}$ implies that $\mathbf{c}_n(\mathbf{e}') \geq \mathbf{c}_n(\mathbf{e})$ in all states ω_n. Inequalities between vectors are to be understood component-wise. The terminal consumption bundle in state ω_n is then given by $\mathbf{w}_n(\mathbf{e}) = \mathbf{w}_0 + \mathbf{x}_n - \mathbf{c}_n(\mathbf{e})$. Let E denote the set of feasible levels of self-protection.[4] I assume that the cost does not alter the ordering assumption from the previous paragraph, that is, $\mathbf{w}_1(\mathbf{e}) \prec \cdots \prec \mathbf{w}_n(\mathbf{e})$ for all $\mathbf{e} \in E$. Self-protection improves the CDF over outcomes in the sense of first-order stochastic dominance (FSD), so for $\mathbf{e}' \geq \mathbf{e}$ we have $F(n, \mathbf{e}') \leq F(n, \mathbf{e})$ for all $n = 1, \dots, N$, with a strict inequality for some n. Outcomes are unaffected because only the probability of outcome $\mathbf{x}_n$ depends on $\mathbf{e}$, that is, $p_n(\mathbf{e})$.

Assuming that preferences over terminal consumption bundles have an expected-utility representation, the DM's choice problem is given by

$$\max_{\mathbf{e} \in E} U(\mathbf{e}) = \sum_{n=1}^{N} p_n(\mathbf{e}) u(\mathbf{w}_0 + \mathbf{x}_n - \mathbf{c}_n(\mathbf{e})), \tag{1}$$

where u is an N-variate real-valued utility function, $u : \mathbb{R}^N \to \mathbb{R}$. Despite its generality, the conceptual framework captures the main trade-off inherent in the self-protection decision. Consider two levels of self-protection, $\mathbf{e}', \mathbf{e} \in E$ with $\mathbf{e}' \geq \mathbf{e}$. The following decomposition holds by basic algebra:[5]

[3] Models that allow effort to be multivariate are standard in the principal-agent literature (e.g., Holmström and Milgrom 1991) but scarce in the self-protection literature. I believe there is room for further research.

[4] For example, E might be defined via a nonnegativity constraint on the attributes, that is, $E = \{\mathbf{e} \geq 0 : \mathbf{w}_n(\mathbf{e}) \geq 0 \text{ for all } n = 1, \dots, N\}$.

[5] Recognize that $U(\mathbf{e} :) = u(\mathbf{w}_N(\mathbf{e})) - \sum_{n=1}^{N-1} F(n, \mathbf{e}) \cdot \left[u(\mathbf{w}_{n+1}(\mathbf{e})) - u(\mathbf{w}_n(\mathbf{e}))\right]$.

$$U(\mathbf{e}') - U(\mathbf{e}) = \sum_{n=1}^{N-1} \Big[\underbrace{F(n,\mathbf{e}) - F(n,\mathbf{e}')}_{\geq 0}\Big] \cdot \Big[\underbrace{u(\mathbf{w}_{n+1}(\mathbf{e}')) - u(\mathbf{w}_n(\mathbf{e}'))}_{>0}\Big]$$
$$- \sum_{n=1}^{N} \underbrace{p_n(\mathbf{e})}_{\geq 0} \cdot \Big[\underbrace{u(\mathbf{w}_n(\mathbf{e})) - u(\mathbf{w}_n(\mathbf{e}'))}_{\geq 0}\Big].$$

The first sum represents the marginal benefit of self-protection. The first square bracket is nonnegative for all n and positive for some n because of the FSD improvement. The second square bracket is positive because states order the outcomes from worst to best. The second sum is the marginal cost of self-protection. Probabilities are nonnegative and the square bracket is nonnegative because the increase in the level of self-protection from $\mathbf{e}$ to $\mathbf{e}'$ is costly. To decide whether the higher level of self-protection is worth it, the DM needs to compare the marginal benefit of improved odds of favorable outcomes against the marginal cost of the state-dependent reduction in terminal consumption. Starting from the general objective function (1), I obtain most of the existing self-protection models as special cases.

The standard model. Ehrlich and Becker (1972)'s classical model of self-protection has two states of the world ($N = 2$), a single monetary attribute ($M = 1$), univariate behavior ($K = 1$), and a state-independent cost, $c_1(e) = c_2(e) = e$. In this setting, assuming that e measures the cost of self-protection directly is without loss of generality, see Peter (2024). The DM's objective function is as follows:

$$\max_{e \in E} U(e) = p(e)u(w_0 - e - \ell) + (1 - p(e))u(w_0 - e), \tag{2}$$

where I set $x_1 = -\ell$ and $x_2 = 0$ for the outcome variable. I suppress superscripts because the attribute and behavior are assumed univariate. To ensure nonnegative consumption and rule out dominated final wealth prospects, set $E = [0, \min\{\ell, w_0 - \ell\}]$ and focus on self-protection technologies defined on E that are decreasing, $p' < 0$. Oftentimes, convexity of the self-protection technology is also assumed, $p'' > 0$, which is a typical diminishing marginal return property. Convexity of the technology and risk aversion of the utility function are not strong enough to ensure global concavity of the objective function, see Footnote 8.

The conditional payment model. Liu et al. (2009) consider a variation of (2) in which the cost is only incurred conditional on success. They argue that individuals often hire professionals such as a lawyer to increase the chance of getting compensation in a civil case or to reduce the chance of imprisonment in a criminal case. Compensation arrangements can be made so that the lawyer is paid a fee only if the case is settled favorably for the individual (contingency fee system). In terms of the model, the cost function is then given by $c_1(e) = 0$ in the bad state and by $c_2(e) = e$ in the good state resulting in the following objective:

$$\max_{e \in E} U(e) = p(e)u(w_0 - \ell) + (1 - p(e))u(w_0 - e).$$

On the occasion of the 35th EGRIE Seminar in Toulouse in 2008, a version of this article was presented and discussed by Bruno Jullien.

Disutility cost. The principal-agent literature often assumes a separable disutility of effort for the cost (see, e.g., Holmström 1979). The typical approach puts no restriction on the number of states ($N \geq 2$), focuses on a monetary attribute along with an effort attribute ($M = 2$), and has effort univariate ($K = 1$) with a state-independent cost in the effort dimension, $c_1(e) = c_2(e) = (0, e)$. These settings so far yield

$$\max_{e \in E} U(e) = \sum_{n=1}^{N} p_n(e) u(w_0^1 + x_n^1, w_0^2 + x_n^2 - e).$$

For separability, focus on two states of the world ($N = 2$), use a separable utility function, $u(w^1, w^2) = u_1(w^1) + u_2(w^2)$, let x^2 be deterministic (i.e., $x_1^2 = x_2^2 = x^2$), and set $\phi(e) = -u_2(w^2 + x^2 - e)$. The objective function then simplifies to

$$\max_{e \geq 0} U(e) = p(e) u_1(w_0^1 - \ell) + (1 - p(e)) u_1(w_0^1) - \phi(e),$$

with $x_1^1 = -\ell < 0 = x_2^1$. Objective function U is concave in e if p and ϕ are convex in e. The point is that one can think of a disutility cost of effort in terms of a bivariate utility function that is assumed separable across attributes, see also Liu and Wang (2017).

Primary prevention in health. Courbage and Rey (2006) and Peter (2021a) consider self-protection against a health risk, which is often referred to as primary prevention in health economics. They focus on two states of the world ($N = 2$), a bivariate utility function ($M = 2$), univariate behavior ($K = 1$), and a state-independent cost function with a purely monetary cost, $c_1(e) = c_2(e) = (e, 0)$. The objective function then takes the following form:

$$\max_{e \in E} U(e) = p(e) u(w_0 - e - \ell, h_1) + (1 - p(e)) u(w_0 - e, h_2),$$

where I write $x_1 = (-\ell, h_1)$ for the outcome in the bad state and $x_2 = (0, h_2)$ for the outcome in the good state with $h_1 < h_2$ for the health attribute. On the occasion of the 32nd EGRIE Seminar, which was held as part of the inaugural World Risk and Insurance Economics Congress (WRIEC) in Salt Lake City in 2005, an earlier version of Courbage and Rey (2006)'s work was presented and discussed by Emilio Venezian.

Two-period self-protection. Menegatti (2009) argues that self-protection often takes the form of an upfront investment to mitigate a future risk. To capture this intertemporal aspect, one needs at least two periods. In terms of my conceptual framework, he focuses on two states of the world ($N = 2$), a bivariate utility function with consumption today and consumption tomorrow ($M = 2$), univariate behavior ($K = 1$), and a state-independent cost function with the cost of prevention incurred today, $c_1(e) = c_2(e) = (e, 0)$. The objective function is

$$\max_{e \in [0, w_0^1]} U(e) = p(e) u(w_0^1 - e, w_0^2 - \ell) + (1 - p(e)) u(w_0^1 - e, w_0^2).$$

I set $x_1^1 = x_2^1 = 0$ because risk only affects the second period with $x_1^2 = -\ell < 0 = x_2^2$. Parameters w_0^1 and w_0^2 can be interpreted as the certain amount of income in the first and second period, respectively. Menegatti (2009) works with a time-separable utility function so that $u(w^1, w^2) = u_1(w^1) + u_2(w^2)$. Section 5 provides further details.

Bivariate self-protection. In Hofmann and Peter (2015)'s model, the DM's behavior in both periods affects the probability of loss, see also Menegatti (2018). They have two states of the world ($N = 2$), bivariate utility ($M = 2$), bivariate behavior ($K = 2$), and a state-independent cost function, $c_1(e^1, e^2) = c_2(e^1, e^2) = (e^1, e^2)$. The DM's objective function is then given by

$$\max_{(e^1,e^2)\in E} U(\mathbf{e}) = p(e^1, e^2)u(w_0^1 - e^1, w_0^2 - e^2 - \ell) + (1 - p(e^1, e^2))u(w_0^1 - e^1, w_0^2 - e^2).$$

As in Menegatti (2009), w_0^1 and w_0^2 can be interpreted as certain income in the first and second period and risk affects only the second period (i.e., $x_1^1 = x_2^1 = 0$ and $x_1^2 = -\ell < 0 = x_2^2$). Feasible prevention levels are given by $E = \{(e^1, e^2) : e^1 \in [0, w_0^1], e^2 \in [0, \min\{w_0^2, \ell\}]\}$. Both Hofmann and Peter (2015) and Menegatti (2018) consider time-separable utility. Menegatti (2018) introduces the following simplifying assumption on the self-protection technology: $p(e^1, e^2) = \tilde{p}(e^1 + e^2)$. If $\tilde{p}$ is convex, this assumption introduces a substitution effect because an increase in first-period effort reduces the marginal benefit of effort in the second period. In general, different types of self-protection activities may substitute or complement one another, that is, $\partial^2 p/\partial e^1 \partial e^2$ may be positive or negative.

More than two states. Lee (2019) studies self-protection in a model with more than two states. He considers two periods. I focus on the standard model with three states ($N = 3$), a single monetary attribute ($M = 1$), univariate behavior ($K = 1$), and a state-independent cost, $c_1(e) = c_2(e) = c_3(e) = e$. The objective function is as follows:

$$\max_{e\in E} U(e) = p_l(e)u(w_0 - e - \ell_l) + p_s(e)u(w_0 - e - \ell_s) + (1 - p_l(e) - p_s(e))u(w_0 - e),$$

with $x_1 = -\ell_l$, $x_2 = -\ell_s$, and $x_3 = 0$. Subscripts l and s are shorthand for large and small loss, respectively, $\ell_l > \ell_s > 0$. Cumulative probabilities are $p_l(e)$, $p_l(e) + p_s(e)$, and 1. Consistency with FSD requires $p_l' \leq 0$ and $p_l' + p_s' \leq 0$ with at least one inequality strict. It is thus possible that $p_s' \geq 0$. For example, if self-protection only reduces the probability of large losses but has no effect on the probability of small losses, the marginal benefit of the activity is still positive for all DMs with positive marginal utility. If, however, $p_l' + p_s' > 0$ was the case, one can find a utility function with $u' > 0$ for which the marginal benefit of the activity is no longer positive, which makes it difficult to even think of it as an investment that raises the chances of better outcomes. I argue that the FSD effect on the outcome distribution is an integral part of the definition of self-protection. It rules out activities that increase the probability of small losses to an extent that overcompensates the reduction of the probability of large losses (i.e., $p_s' > -p_l'$). It is conceivable that such activities exist, but I would argue that they should not be classified as self-protection. Lee (2019) also finds that the FSD assumption is critical to preserve results about precautionary effort.

The cataloging exercise in this section shows that Ehrlich and Becker (1972)'s standard model of self-protection has been extended in many different directions. My approach takes stock of the number of states of the world (N), the dimensionality of the attribute (M), the dimensionality of behavior (K), and the state-dependence of the cost function. Section 4 discusses extensions to non-expected utility models. Even within expected utility, the list of extensions is by no means exhaustive. For example, Hong and Kim (2024) look at two states ($N = 2$), four attributes ($M = 4$), univariate behavior ($K = 1$), and a state-independent cost function, $c_1(e) = c_2(e) = (e, 0, 0, 0)$. The objective function takes the following form:

$$\max_{e \in E} U(e) = p(e)u(w_0^1 - e + x_1^1, w_0^2 + x_1^2, w_0^3 + x_1^3, w_0^4 + x_1^4) + (1 - p(e))u(w_0^1 - e + x_2^1, w_0^2 + x_2^2, w_0^3 + x_2^3, w_0^4 + x_2^4).$$

Set $(x_1^1, x_1^2, x_1^3, x_1^4) = (0, 0, -\ell, -d)$ and $(x_2^1, x_2^2, x_2^3, x_2^4) = (0, 0, 0, 0)$, interpret w_0^1 and w_0^2 as baseline income and baseline health in the first period, w_0^3 and w_0^4 as baseline income and baseline health in the second period, $\ell > 0$ and $d > 0$ as the potential losses in income and health, and assume intertemporal separability with bivariate utility functions u_1 and u_2 for the first and second periods, respectively. The objective function then simplifies to

$$\max_{e \in E} U(e) = u_1(w_0^1 - e, w_0^2) + p(e)u_2(w_0^3 - \ell, w_0^4 - d) + (1 - p(e))u_2(w_0^3, w_0^4).$$

An earlier version of Hong and Kim (2024)'s paper was presented at the 49th EGRIE Seminar in 2022 in Vienna and discussed by Art Snow.

It is certainly possible to come up with new variations of the self-protection problem along the lines of the taxonomy developed in this section or along other dimensions. For example, at the 50th EGRIE Seminar in Málaga in 2023, Christoph Heinzel presented about self-protection and self-insurance for multiplicative risks, see Heinzel (2023). Niklas Haeusle discussed. It is my hope that researchers will keep first principles in mind as they advance the self-protection literature. In my view, the focus should be on model extensions whose predictions are qualitatively different from the existing body of knowledge in economically meaningful ways.

3 Some classical puzzles

3.1 Risk aversion

Self-protection lowers the likelihood of an unfavorable outcome. One might thus conjecture that more risk-averse people should have a higher demand for self-protection than less risk-averse people. After all, self-protection appears to reduce risk, and it is well known that greater risk aversion leads to less risk-taking, for example, in the standard portfolio problem (Pratt 1964) or the coinsurance problem.[6] Dionne and Eeckhoudt (1985) show that this intuition is flawed and that greater risk aversion may well lead to *less*, not more, self-protection. Their short note is the second-most cited paper on self-protection, see Table 1 in Appendix A.[7]

In the standard model presented in Eq. (2), suppose the DM chooses a positive level of self-protection, $e^* > 0$, which is then characterized by the following first-order condition:

$$\begin{aligned} &-p'(e^*)\left[u(w_0 - e^*) - u(w_0 - e^* - \ell)\right] \\ &\quad = p(e^*)u'(w_0 - e^* - \ell) + (1 - p(e^*))u'(w_0 - e^*). \end{aligned} \tag{3}$$

Now consider another DM with utility function v, who is more risk-averse than the first DM in the Arrow–Pratt sense, that is, $v(w) = k(u(w))$ for an increasing and concave transformation function k. Use the shorthand notation $p^* = p(e^*)$ for the loss probability at DM u's optimal choice, and write $w_N^* = w_0 - e^*$ and $w_L^* = w_0 - e^* - \ell$ for final wealth in the no-loss state and the loss state at the optimal level of self-protection e^*. Evaluating DM v's first-order expression at DM u's optimal choice yields

$$-p'(e^*)\left[k(u(w_N^*)) - k(u(w_L^*))\right] - \left[p^* k'(u(w_L^*))u'(w_L^*) + (1 - p^*)k'(u(w_N^*))u'(w_N^*)\right].$$

The sign of this expression predicts whether the increase in risk aversion leads to an increase or a decrease in self-protection, assuming the objective function is inverse U-shaped in e.[8] I assume without loss of generality that $v(w_N^*) = u(w_N^*)$ and $v(w_L^*) = u(w_L^*)$.[9] Solving the first-order condition for $-p'(e^*)$ and substituting then yields

$$p^* \cdot u'(w_L^*) \cdot \left[1 - k'(u(w_L^*))\right] + (1 - p^*) \cdot u'(w_N^*) \cdot \left[1 - k'(u(w_N^*))\right]. \tag{4}$$

Utility v is more risk-averse than u; therefore, $v(w_N^*) = u(w_N^*)$ and $v(w_L^*) = u(w_L^*)$ imply $k'(u(w_L^*)) > 1$ and $k'(u(w_N^*)) < 1$. The first square bracket in (4) is then

[6] The result that an increase in risk aversion raises insurance demand is often attributed to Mossin (1968). His main result is that full insurance is optimal under (second-order) risk aversion if and only if the premium is actuarially fair. He also shows four results for decreasing absolute risk aversion (DARA): (i) the maximum premium for full coverage decreases in wealth; (ii) the optimal coverage level decreases in wealth; (iii) a firm's optimal reinsurance quota decreases in the amount of funds; and (iv) the optimal deductible increases in wealth. All these results hold for a given utility function; no change in risk preferences is ever considered.

[7] According to personal conversations with the authors, their paper was never presented at an EGRIE Seminar because it only took three days to write it when Louis Eeckhoudt visited Georges Dionne in Montréal.

[8] Jullien et al. (1999) provide a condition on the self-protection technology under which objective function (2) is inverse U-shaped in e for all risk-averse DMs. Peter (2024) discusses their condition and shows that it rules out some self-protection technologies that are convex and even some that are log-convex. Fagart and Fluet (2013) show that objective function (2) is globally concave in e if the self-protection technology is log-convex and the DM has nonincreasing absolute risk aversion.

[9] In the model with a binary risk, one can always apply a positive affine transformation to utility function v to accomplish this normalization. Take $t(v) = s \cdot v + i$ with slope $s = (v(w_N^*) - v(w_L^*))/(u(w_N^*) - u(w_L^*))$ and intercept $i = (u(w_L^*)v(w_N^*) - u(w_N^*)v(w_L^*))/(u(w_N^*) - u(w_L^*))$. Then, utility functions $t(v)$ and v represent the same risk preferences and $t(v)$ satisfies the normalizing assumption.

negative, the second one positive, and the overall sign is indeterminate. This observation constitutes Dionne and Eeckhoudt (1985)'s famous puzzle that risk aversion has no clear effect on self-protection.

Briys et al. (1991) introduce a nonreliability risk on self-protection, which is the idea that the technology may not work as intended. In the model, the authors introduce uncertainty over the effectiveness of self-protection. They find that the link between risk aversion and self-protection is then indeterminate a fortiori. An earlier version of their paper was presented at the 16th EGRIE Seminar held in Jouy-en-Josas in 1989. The program notes two discussants, Louis Eeckhoudt and Henri Loubergé.[10]

Fifteen years after Dionne and Eeckhoudt (1985) posed their puzzle, Jullien et al. (1999) present a solution (see also Lee 1998). The loss probability p^* in (4) can be interpreted as the weight on the negative term and the no-loss probability $(1-p^*)$ as the weight on the positive term. Hence, risk aversion raises the demand for self-protection if and only if the loss probability of the less risk-averse DM is small enough in a precise technical sense. Probability threshold results like the one discovered by Jullien et al. (1999) are common in the economic analysis of self-protection. An important caveat is the question how to determine the magnitude of the threshold (see Dachraoui et al. 2004). The loss probability p^* is endogenous because it depends on the risk preferences of reference DM u. The probability threshold itself is also an endogenous quantity because it depends on the risk preference of DM u *and* the risk preferences of DM v. How to test the result empirically is by no means obvious.

The paper by Jullien et al. (1999) is the second-most cited paper ever published in the GRIR. It was reprinted for the 40-year anniversary collection of the journal. It represents beyond doubt a milestone in the economic analysis of self-protection and ranks among the most influential papers on self-protection to date, see Table 1 in Appendix A.

3.2 Intuition

It is not obvious from objective function (2) why the comparative statics of risk aversion are indeterminate in the self-protection problem. Already Ehrlich and Becker (1972) provide the main clue. They notice the following: "Unlike insurance, self-protection does not redistribute income, because the amount spent reducing the probability of loss decreases income in all states equally, leaving unchanged the absolute size of the loss." A simple example helps demonstrate the importance of this feature of self-protection.

Suppose a DM has initial wealth of $w_0 = 200$ and faces a chance of $p_0 = 65\%$ of suffering a loss of $\ell = 100$. The DM has the opportunity to invest 30 upfront in

[10] The issue of a nonreliability risk on self-insurance and self-protection was recently revisited by Li and Peter (2021) through the lens of technological uncertainty and precaution. An earlier version of their paper was presented at the 45th EGRIE Seminar in Nuremberg in 2018. Richard Watt served as the discussant.

self-protection, which reduces the loss probability to $p_1 = 35\%$ without affecting the loss severity. Should the DM take up this self-protection opportunity?

To answer this question, let $F(w)$ and $G(w)$ be the CDFs of final wealth without and with self-protection, respectively, see Fig. 1. Self-protection has two effects. It lowers the CDF uniformly because the loss becomes less likely (downward shift). Second, it shifts the CDF to the left because of the self-protection investment. As a result, the two CDFs cross twice, which rules out FSD as a ranking criterion. As noted by Jullien et al. (1999), this double-crossing property is characteristic of self-protection and impedes the use of Jewitt (1989)'s minimal comparative static result for risk aversion.

To gain more intuition, I integrate over the difference between the two CDFs, see Fig. 2. Panels (a) and (b) show $\int_0^w [G(t) - F(t)]\,\mathrm{d}t$ and $\int_0^w \int_0^t [G(s) - F(s)]\,\mathrm{d}s\,\mathrm{d}t$ as functions of w. I make several observations. First, $\int_0^w [G(t) - F(t)]\,\mathrm{d}t = 0$ for $w \geq 200$ in Panel (a) because self-protection is mean-preserving in the example. Indeed, the cost of 30 coincides with the expected benefit, which is a reduction of the expected loss by 30 from 65 to 35. One can observe this property directly in Fig. 1. The areas enclosed between the two CDFs exactly offset each other, $A + C = B$. Panel (a) also shows that $\int_0^w [G(t) - F(t)]\,\mathrm{d}t$ does not have a uniform sign. Some risk averters will take up the self-protection opportunity, others will refuse it. The same dichotomy holds for risk lovers.[11] Self-protection induces a mean-preserving spread at low final wealth levels and a mean-preserving contraction at high final wealth levels. This effect was first observed in a well-cited paper by Briys and Schlesinger (1990), two regulars at EGRIE Seminars. Their paper is the third-most cited paper on self-protection to date.

Panel (b) reveals that $\int_0^w \int_0^t [G(s) - F(s)]\,\mathrm{d}s\,\mathrm{d}t = 0$ for $w \geq 200$ because self-protection is variance-preserving in the example. Indeed, $0.65 \cdot (1 - 0.65) \cdot 100^2 = 0.35 \cdot (1 - 0.35) \cdot 100^2$ because p_0 and p_1 sum up to 1. This property is represented in Fig. 1 because A and C are identical. Unlike the single integral, the double integral does have a uniform sign. In the example, self-protection increases the downside risk of the final wealth distribution in the sense of Menezes et al. (1980). As a result, all DMs with $u''' < 0$ will take up the self-protection opportunity while those with $u''' > 0$ will decline it. DMs with quadratic utility are indifferent because their attitude towards downside risk is neutral. In the example, self-protection flips the skewness of the final wealth distribution from +0.63 to −0.63 without affecting mean or variance.

Denuit et al. (2016) extend this argument to show that *any* increase in self-protection can be decomposed into an increase in downside risk and a residual stochastic change. This residual stochastic change takes into account that self-protection is not mean-variance-preserving in practice. DMs will then have to trade-off both changes and will only raise their investment in self-protection if the effect of the residual stochastic change on expected utility is beneficial and outweighs the effect of the

[11] Along those lines, Jindapon (2013) derives conditions under which risk lovers invest in self-protection. Already Ehrlich and Becker (1972) conjecture that "the incentive to self-protect (...) is not so dependent on attitudes toward risk, and could be as strong for risk preferrers as for risk avoiders."

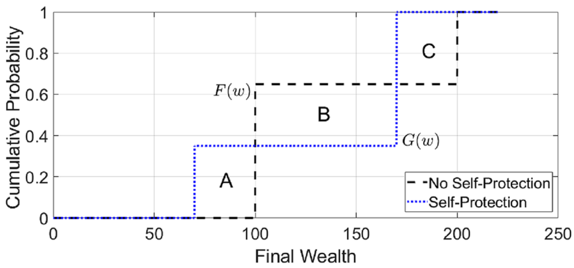
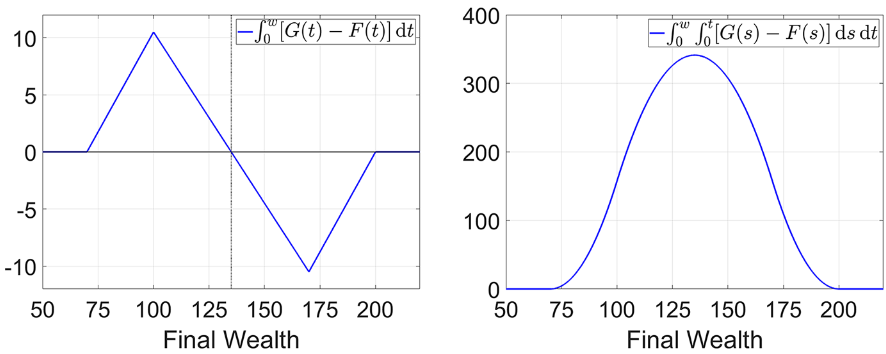


Fig. 1 Self-protection leads to double-crossing CDFs of final wealth



(a) Integral over $G - F$.

(b) Double integral over $G - F$

Fig. 2 Integral and double integral over the difference between G and F

downside risk increase, assuming downside risk aversion. Their paper was recognized with the SCOR-GRIR Best Paper Award in 2017. It was also the inaugural recipient of the Harris Schlesinger Prize for Research Excellence in 2019. The latter award is dedicated to the memory of Harris Schlesinger, a founding Editor of the GRIR and a past president and avid supporter of EGRIE. The recognition of Denuit et al. (2016)'s work could not be more fitting as they show how to fully leverage the notion of downside risk inherent in self-protection, which was first exposed by Briys and Schlesinger (1990).

3.3 The role of prudence/downside risk aversion

The simple example in the previous section reveals that the sign of u''', not the sign of u'', determines whether DMs take up the self-protection opportunity. Menezes et al. (1980) refer to the property $u''' > 0$ as downside risk aversion. In an influential paper, Kimball (1990) coins the term prudence for $u''' > 0$ and shows its equivalence to a precautionary saving motive in the time-separable discounted expected utility model. The concepts of prudence and downside risk aversion are thus equivalent under expected utility because each is characterized by $u''' > 0$. When it comes to their intensity measurement, Kimball (1990) suggests the ratio $-u'''(w)/u''(w)$

for prudence, whereas a whole range of intensity measures exists for downside risk aversion, see Keenan and Snow (2018). It is thus possible that, when comparing two DMs, the one who is more prudent is *less* downside risk-averse than the other one, even if both have a positive third derivative of utility.[12]

Given that any increase in self-protection increases the downside riskiness of the final wealth distribution plus a residual stochastic change (see Denuit et al. 2016), it seems more fitting to label the sign of u''' as the DM's downside risk attitude in the context of self-protection. Several articles elaborate on the negative link between downside risk aversion and self-protection. Chiu (2000) defines the willingness to pay for a given reduction in the loss probability and derives from it the average and marginal propensity to self-protect. He finds that an increase in risk aversion raises the propensity to self-protect if the initial loss probability is less than a threshold value. This threshold depends on the DM's aversion to downside risk increases and on her aversion to riskiness in the wealth distribution. An earlier version of Chiu (2000)'s paper was presented at the 25th EGRIE Seminar in Vienna in 1998.[13]

Eeckhoudt and Gollier (2005) isolate the role of downside risk aversion very clearly by focusing on a risk-neutral benchmark DM (see also Dionne and Li 2011). If the loss probability of the risk-neutral DM is 0.5, all downside risk-averse DMs choose less self-protection, whereas all downside risk-loving DMs choose more self-protection, just like in the example in Sect. 3.2. When the risk-neutral DM's loss probability is less than 0.5, the effect of risk aversion is positive, whereas that of downside risk aversion is negative.

Chiu (2010) provides a skewness-comparability condition under which the DM's preference over risky prospects depends only on the mean, variance, and third moment. He shows that all Bernoulli distributions are mutually skewness comparable, which makes his results applicable to self-protection. An earlier version of the paper was presented at the 32nd EGRIE Seminar, which was part of the inaugural WRIEC in Salt Lake City in 2005. Chiu (2010) is the second recipient of the Harris Schlesinger Prize for Research Excellence in 2020.

Chiu (2012) connects risk aversion and downside risk aversion to a DM's willingness to pay (WTP) for stochastic improvements. He then links the DM's WTP to her optimal purchase of stochastic improvements, which puts him in a position to apply all results to the demand for self-protection. An earlier version of his work was presented at the 36th EGRIE Seminar in Bergen in 2009. The discussant was Paan Jindapon. This paper received the SCOR-GRIR Best Paper Award in 2013. Using Taylor approximations, Crainich et al. (2015) find a tension between risk aversion and downside risk aversion for the value of risk reduction. They consider both financial and non-financial risks. An earlier version of their paper was presented at the 40th EGRIE Seminar in Paris in 2013. I served as the discussant.

Peter (2021c) relaxes the risk-neutral benchmark assumption in Eeckhoudt and Gollier (2005) with the help of risk-neutral or distorted loss probabilities that are used extensively in asset pricing. The sign of the third derivative of the

---

12 On the occasion of the 38th EGRIE Seminar in Vienna in 2011, Eeckhoudt (2012) emphasized the distinction between direction and intensity of risk preferences in his Geneva Risk Economics Lecture.

13 The program does not list discussants in that year.

transformation function k then plays the same role as the DM's downside risk attitude in Eeckhoudt and Gollier (2005). Keenan and Snow (2009) show that $k''' \geq 0$ can be interpreted as a measure of greater downside risk aversion in the large. I presented an earlier version of my paper at the 47th EGRIE Seminar, which was part of the 4th WRIEC in 2020 (virtual). Tim Boonen discussed.

3.4 Some other puzzles

This section features some other puzzles in self-protection including some hidden gems from the literature. Dionne and Eeckhoudt (1988) analyze the effect of increasing risk on self-protection. In particular, they study a marginal increase in ℓ that is compensated by an increase in w_0 such that expected final wealth stays constant. Contrary to intuition, such a change has no definitive effect on self-protection and may well lead to a decrease in its optimal level. I show in Appendix B that the problem posed by Dionne and Eeckhoudt (1988) is amenable to threshold analysis, which allows me to make more definitive predictions.

Sweeney and Beard (1992a) pose an interesting puzzle. They define one DM to be more cautious than another one if the first DM chooses a higher level of self-protection than the second one for all self-protection technologies that are nonincreasing and continuously differentiable. They show the following impossibility result: Under expected utility no two DMs can be ranked in the cautiousness order. In other words, for any two DMs, there is always a self-protection technology for which the first DM invests more and another self-protection technology for which the second DM invests more.

Sweeney and Beard (1992b) study the wealth effects on self-protection. Unlike insurance (see Mossin 1968), DARA is neither necessary nor sufficient for an increase in wealth to reduce the optimal demand for self-protection. Given Dionne and Eeckhoudt (1985)'s finding, this negative result is, of course, unsurprising. Sweeney and Beard (1992b) find a probability threshold. For DARA, the wealth effect on self-protection is negative (positive) if and only if the loss probability is below (above) this threshold value. Lee (2005) extends the analysis to self-insurance and self-protection when losses can have non-monetary consequences. Peter (2022) revisits Sweeney and Beard (1992b)'s threshold result and presents two main findings. First, the threshold can be calibrated for various classes of utility functions. Those parametric results suggest that self-protection is an inferior good.[14] Second, when taking into account that the value of assets subject to preventable losses is increasing in income, self-protection is more plausibly a normal good. I presented this paper at the 49th EGRIE Seminar in 2022 in Vienna. Georges Dionne provided comments.

Using a dynamic model, Immordino (2000) examines the effect of information about the severity of loss on self-protection and finds that more information has, in general, ambiguous effects. Under constant absolute risk aversion, the investment in self-protection decreases with a better information structure. This result

[14] Self-protection can even be Giffen, which is, however, not empirically plausible, see Peter (2021b).

makes it difficult to reconcile the Precautionary Principle with self-protection. In a health context, Crainich and Eeckhoudt (2017) find that personalized health information raises the average WTP for self-protection. This paper was presented at the 41st EGRIE Seminar in St. Gallen in 2014 and discussed by Kangoh Lee. Li (2021) introduces a causal model of self-protection. Knowledge about risk determinants improves the DM's ability to predict the success of self-protection. In the model, technological transparency leads to more efficient self-protection decisions but may reduce social welfare. This paper was presented at the 46th EGRIE Seminar in Rome in 2019 and discussed by Kili Wang. The work was recognized with the SCOR-EGRIE Young Economist Best Paper Award in that year.

4 Self-protection in non-expected utility models

While expected utility rests on compelling arguments from a normative standpoint, it has well-known descriptive shortcomings (Starmer 2000). Konrad and Skaperdas (1993) are the first to analyze self-insurance and self-protection under non-expected utility preferences. Under Yaari (1987)'s dual theory, an increase in risk aversion, represented by a concave transformation of the probability weighting function, has an indeterminate effect on self-protection. However, as in the case of expected utility, a probability threshold arises that separates a positive from a negative effect, depending on whether the loss probability is below or above the threshold. An earlier version of the paper was presented at the 19th EGRIE Seminar held in London in 1992. The discussant was Roland Eisen.[15]

It may come as a surprise that EGRIE witnessed the first experimental analysis of self-insurance and self-protection. Di Mauro and Maffioletti (1996) find weak evidence that ambiguity in the probability affects the valuation of risk-management tools. There is no evidence that changes in the representation of ambiguity matter, and neither is there support of the anchoring and adjustment model, which appears to explain market insurance well under ambiguity (Hogarth and Kunreuther 1992). Di Mauro and Maffioletti (1996)'s paper was presented at the 21st EGRIE Seminar in Toulouse in 1994 and discussed by Kip Viscusi.

These two themes, probability weighting and ambiguity, have since been related several times to the self-protection decision. Courbage (2001) revisits Ehrlich and Becker (1972)'s question about the relationship between self-protection and market insurance under the dual theory. The results are robust and the two tools can either be substitutes or complements. This paper was presented at the 26th EGRIE Seminar held in Madrid in 1999. Louis Eeckhoudt discussed. Bleichrodt and Eeckhoudt (2006) show that probability distortions may lead to unstable monetary valuations of reductions in health risks. They presented their paper at the 31st EGRIE Seminar in Marseille in 2004 and received comments from Stéphane Luchini. Etner and Jeleva (2014) characterize underestimation of changes in probabilities in various models of decision-making under risk and highlight the role of the probability weighting

15 According to my records, 1992 was the first year that the EGRIE Seminar had two concurrent sessions on Wednesday, September 23.

function. They presented their work at the 38th EGRIE Seminar in Vienna in 2011 and received comments from Fred Schroyen. Etner and Jeleva (2016) study the role of fatalism for self-protection decisions against a long-term care risk and derive policy implications. This paper was presented at the 34th EGRIE Seminar in Cologne in 2007 and discussed by Christophe Courbage. In his Geneva Risk Economics Lecture, Bleichrodt (2022) emphasized the role of likelihood insensitivity as a root cause for underprevention against health risks, see also Baillon et al. (2022). He gave his lecture at the 48th EGRIE Seminar, which was held virtually due to Covid-19. I offered some comments.

The 37th EGRIE Seminar was part of the 2nd WRIEC in Singapore in 2010. Two papers about self-insurance and self-protection under ambiguity were presented in the same session. Snow (2011) finds that greater ambiguity aversion raises the demand for self-protection, whereas Alary et al. (2013) provide a sufficient condition for a negative effect. The discussants were, respectively, David Alary and Stephen Diacon. The session gave clear evidence that discussions at EGRIE meetings are both rigorous and vigorous. Each of the two papers uses smooth ambiguity aversion by Klibanoff et al. (2005) but models ambiguity differently. Snow (2011) assumes that ambiguity is multiplicatively separable from the self-protection technology so that effort reduces not only the probability of loss but also the uncertainty surrounding it. Alary et al. (2013) make no such assumption.[16] Berger (2016) analyzes the effect of ambiguity prudence on self-protection in a two-period model, see also Sect. 5. He presented his paper at the 41st EGRIE Seminar in St. Gallen in 2014. I served as discussant. In the framework of Choquet expected utility, Peter and Toquebeuf (2020) use mean-preserving capacities to provide a simple necessary and sufficient condition for ambiguity aversion to decrease optimal self-protection. The condition compares the decay rate of ambiguity in effort against the DM's risk aversion. The paper was presented at the 47th EGRIE Seminar, which was part of the 4th WRIEC (virtual), and discussed by Paul Thistle. The work received the SCOR-EGRIE Young Economist Best Paper Award in that year.

Other behavioral topics include regret and loss aversion. Zheng (2021) finds that disproportionate aversion to large regrets inflates WTP estimates for reductions in health risks. He presented the paper at the 45th EGRIE Seminar in Nuremberg in 2018, and received comments from Alexander Muermann. In his Geneva Risk Economics Lecture, Bleichrodt (2022) looks at loss aversion under prospect theory with a linear value function, no probability weighting, and the maxmin reference point. In this simplified setting, loss aversion always reduces the demand for self-protection. Macé and Peter (2021) use expectation-based loss aversion à la Kőszegi and Rabin (2006, 2007) instead. In their model, a probability threshold arises and loss aversion leads to overreaction to low-probability risks. I presented the paper at the 50th EGRIE Seminar in Málaga in 2023, and received comments from François Pannequin.

[16] In fact, an earlier version of Alary et al. (2013)'s paper was already presented at the 35th EGRIE Seminar in Toulouse in 2008 and discussed by Keith Crocker.

5 Self-protection in two periods

As pointed out by Briys and Schlesinger (1990), the term loss prevention is more common in the insurance economics literature than self-protection. The Latin root of the word prevention is *praevenire*, which translates to come before or precede and suggests an intertemporal dimension of self-protection. In fact, most of the examples of self-protection in the introduction involve a cost now to reduce the chance of loss in the future.

Menegatti (2009) proposes a two-period model of self-protection. In particular, he revisits Eeckhoudt and Gollier (2005)'s results in the following model:

$$\max_{e\in[0,w_0^1]} U(e) = u(w_0^1 - e) + p(e)u(w_0^2 - \ell) + (1 - p(e))u(w_0^2),$$

where w_0^1 and w_0^2 denote riskless income in the first and second periods. Let e_n be the optimal level of self-protection for a risk-neutral DM, which is characterized by $-1 - p'(e_n)\ell$, and let $p_n = p(e_n)$ denote the associated loss probability. Menegatti (2009) shows that it is possible to reverse the results by Eeckhoudt and Gollier (2005) under the additional assumption that $w_0^1 - e_n = w_0^2 - p_n\ell$, which mutes consumption smoothing. In fact, he finds that risk aversion and prudence work hand in hand to stimulate self-protection when $p_n \leq 0.5$.

Another way to address consumption smoothing is to allow DMs access to the capital market so they can borrow and save as they please. Peter (2017) studies the following extension of Menegatti (2009)'s model:

$$\begin{aligned}\max_{e\geq 0,s} U(e,s) =& u_1(w_0^1 - e - s)\\ &+ \beta\left[p(e)u_2(w_0^2 + sR - \ell) + (1 - p(e))u_2(w_0^2 + sR)\right].\end{aligned}$$

Parameter $\beta \in (0, 1]$ is a utility discount factor, u_1 and u_2 are consumption utility in the first and second periods, $R > 0$ is the gross interest rate, and s is the amount of saving or borrowing. In the extended model, all results by Eeckhoudt and Gollier (2005) go through. The reason is a substitution effect between self-protection and saving (Menegatti and Rebessi 2011). A prudent DM reacts to risk by accumulating precautionary savings (Kimball 1990). An increase in saving raises the marginal cost of self-protection because both activities are funded out of first-period income. It also lowers the marginal benefit of self-protection because the utility gap between the no-loss state and the loss state shrinks as income increases in the second period. Prudent DMs thus substitute saving for self-protection.

Even though Menegatti (2009)'s result is not robust to the inclusion of saving, he makes a very compelling point: Self-protection involves an *intertemporal* cost–benefit trade-off. For insurance, this aspect was recognized much earlier by Dionne and Eeckhoudt (1984), who presented their work at the 9th EGRIE Seminar in Geneva in 1982. Denis Kessler gave the discussion. It almost seems puzzling that it took the profession 25 years before it explicitly realized that the same perspective can be taken for the self-protection decision.

The two-period self-protection model has stimulated a stream of research over the last 15 years. Eeckhoudt et al. (2012), Courbage and Rey (2012), and Wang and Li (2015) show that, much like precautionary saving, precautionary self-protection effort can serve as a characterizing trait for prudence. Hofmann and Peter (2016) find that the presence of saving also matters for the effect of utility curvature on self-insurance and self-protection. Their paper was presented at the 40th EGRIE Seminar in Paris in 2013 and discussed by Peter Zweifel. Courbage et al. (2017) study the interaction of precautionary effort for different sources of risk. Their paper was presented at the 41st EGRIE Seminar in St. Gallen in 2014 and discussed by Harris Schlesinger. Peter and Hofmann (2022) analyze the interaction between saving and self-protection for income, inflation, and interest rate risk. Their paper was presented at the 39th EGRIE Seminar in Palma de Mallorca in 2012. The discussant was Roland Eisen. Heinzel and Peter (2023) characterize precaution under recursive preferences and show that precautionary saving and self-insurance can crowd out precautionary self-protection under reasonable assumptions. Their paper was presented at the 41st EGRIE Seminar in St. Gallen in 2014 and discussed by Ray Rees. Huber (2022) revisits the question of comparative risk aversion in two periods with the help of Kihlstrom and Mirman (1974) preferences. His paper was presented at the 45th EGRIE Seminar in Nuremberg in 2018 and discussed by Claudio Bonilla. At the 46th EGRIE Seminar in Rome in 2019, Kit Pong Wong presented on “Optimal effort in a two-period model” and received comments from Michiko Ogaku. Even though it took some time until its discovery, Menegatti (2009)’s intertemporal view has been giving renewed impetus to the economic analysis of self-protection.

6 Other topics related to self-protection

The analysis of self-protection started with Ehrlich and Becker (1972) who wondered about the relationship between market insurance and self-protection. This topic has also been explored by various EGRIE members over the years. Schlesinger and Venezian (1986) analyze profits, market structure, and consumer welfare in insurance markets with self-protection opportunities. An earlier version of this paper was presented at the 11th EGRIE Seminar in Geneva in 1984. Two discussants are noted, Frederick W. Schroath and A.B.E. Voute. In a well-cited paper, Lakdawalla and Zanjani (2005) discuss the rationale for government intervention in the terrorism insurance market due to negative externalities in self-protection. Hofmann (2007) studies self-protection and insurance in the presence of positive externalities. When own self-protection also reduces the risk exposure of others, DMs will undertake too little self-protection. An insurance monopoly can rectify this inefficiency and implement the social optimum via premium discrimination. This paper was presented at the 33rd EGRIE Seminar in Barcelona in 2006 and discussed by Pierre Picard. It was reprinted for the 40-year anniversary collection of the GRIR. In a similar vein, Ferranna (2017) investigates the effect of risk sharing on the incentive to invest in a public self-protection policy. If self-protection reduces the risk of inequality, then absence of risk sharing increases the investment in self-protection under some conditions on risk aversion and prudence.[17]

The topic of externalities in self-protection has recently seen renewed interest motivated by Covid-19. Hofmann and Rothschild (2019) extend the work by Hofmann (2007). Competitive insurance markets and a perfectly price-discriminating insurance monopoly always exhibit overinsurance and underinvestment in self-protection compared to what is socially efficient. A non-price-discriminating monopoly may lead to socially optimal levels of insurance and self-protection. In the special issue on "COVID-19: The economics of pandemic risks and insurance," Salanié and Treich (2020) analyze public and private incentives for self-protection. Based on a simple model, they provide a necessary and sufficient condition for the probability of infection to decrease with the compulsory level of self-protection. They also show when it is optimal for public policy to support mandatory self-protection efforts. In the same special issue, Echazu and Nocetti (2020) study the WTP for morbidity and mortality risk reductions during an epidemic. They extend the standard model of WTP for risk reduction by incorporating health care capacity constraints, dynamic aspects of prevention, and distributional concerns due to heterogeneity in baseline risk. Their model calibration yields a WTP in the order of 24% of GDP. At the 47th EGRIE Seminar, which was part of the 4th WRIEC in 2020 (virtual), Lu Li presented the paper "Public knowledge, private information, and the prevention of interdependent risks," coauthored with Andreas Richter and Alexander Muermann. Comments were made by Jihong Ding.

Several articles discuss self-protection decisions by firms. Schneider (1992) considers a risk-averse firm who decides about the level of employment and the level of self-protection to prevent occupational injuries. Despite many simplifying assumptions, he has a hard time making definitive predictions. This paper was presented at the 16th EGRIE Seminar in Jouy-en-Josas in 1989 and discussed by Cristos Pitelis. In an extension, Mauro (1994) finds that uncertainty about wage and accident costs reduces the amount of labor and raises the level of safety investments. Haritchabalet (2000) studies the optimal output choice of a risk-averse firm that produces a number of goods that can be defective. The firm fixes capacity upfront. The problem can be interpreted as a form of self-protection so that production and insurance are complements under reasonable assumptions. This paper was presented at the 24th EGRIE Seminar in Paris in 1997. The discussant was Olivier Mahul.

Contests can be interpreted as the strategic analog of self-protection. Treich (2010) derives conditions under which risk aversion always decreases rent-seeking efforts and highlights the role of prudence in the analysis. This paper was presented at the 35th EGRIE Seminar in Toulouse in 2008 and discussed by Matthias Lang. Liu et al. (2018) show that the effect of risk aversion on contesting efforts reverses when only winners pay for resources used to compete. This paper was presented at the 44th EGRIE Seminar in London in 2017. The discussant was Nicolas Treich.

[17] It is interesting that a similar paper was presented two years earlier at the 42nd EGRIE Seminar, which was part of the 3rd WRIEC in Munich in 2015. Wei Hu presented "Self-protection, insurance, and risk sharing - A case of catastrophe risks" and received comments from Georges Dionne. I was unable to find out the publication status of this paper nor the whereabouts of its author.

Liu and Treich (2021) analyze the role of risk attitudes in contest design, specifically the optimality of winner-take-all contests. This paper was presented virtually at the 47th EGRIE Seminar in 2020, which was part of the 4th WRIEC. Andreas Richter discussed. At the 48th EGRIE Seminar in 2021, which was also held virtually, the paper "Ambiguous prizes in contests" by Yoichiro Fujii, Mahito Okura, and Yusuke Osaki was presented. The discussant was Sebastian Hinck.

Finally, it is not surprising that the topic of self-protection is also discussed in environmental economics. A well-cited paper in that space is Shogren and Crocker (1991) who develop three propositions about the ex-ante value of risk reduction. Their results highlight the critical role of risk endogeneity in empirical work. Adler et al. (2014) compare different welfarist frameworks in how they assess the social value of mortality risk reduction. The value of a statistical life approach ranks risk-reduction measures in a particular way that does not necessarily coincide with the way they are ranked in other frameworks. This paper was presented at the 39th EGRIE Seminar in Palma de Mallorca in 2012. The discussant was Harris Schlesinger. Treich and Yang (2021) analyze the distortions caused by taxation and taxpayer heterogeneity on the cost–benefit analysis of mortality risk reductions. This paper was presented at the 44th EGRIE Seminar in London in 2017 and discussed by Liqun Liu.

7 Directions for future research

In terms of the classical analysis of self-protection, there is a need for simplification. The tension between risk aversion and downside risk aversion is well understood but the existing body of theory is hard to apply. It would be useful to have simple rules of thumb to make quick predictions how risk aversion and downside risk aversion modify the WTP for self-protection and its optimal level compared to risk neutrality. Second, most of the existing probability-threshold results suffer from endogeneity concerns because the quantity that is compared against the threshold is endogenous and the threshold itself is often even "more endogenous."[18] Already Briys and Schlesinger (1990) articulate this concern in Footnote 6. They say the following about Sweeney and Beard (1992a): "However, exactly how small p must be differs on a case by case basis. Therefore, this result is of little value." My own verdict on the literature is not as devastating but it would indeed be helpful to keep applicability in mind as the profession develops the theory further.

Regarding self-protection in non-expected utility models, I expect further applications and new results as the arsenal of decision-making criteria keeps expanding. From an applied standpoint, it would be useful to relate behavioral paradigms like probability weighting, ambiguity, loss aversion, and regret to actual choice contexts. If the profession could produce direct evidence from the field about areas where

[18] An exception is the case of small risks. Using a second-order Taylor expansion, Courbage and Rey (2008) find that the WTP to reduce small risks is increasing in risk aversion if the loss probability is below one half. This paper was presented at the 34th EGRIE Seminar in Cologne in 2007 and discussed by Nicolas Treich.

behavioral biases lead to lack of self-protection and other areas where they lead to overreaction and excessive investments in self-protection, one could harness behavioral insights to develop interventions and nudges that improve the quality of self-protection decisions in practice and lead to a better management of risk. I also think there is a role to play for behavioral economics in the understanding of how self-protection interacts with insurance decisions at the household and corporate level.

I believe there is much room for further theorizing when it comes to the intertemporal analysis of self-protection. Menegatti (2009)'s approach with two periods is a first step in the right direction. In insurance choices, an annual time horizon is often implicit especially in the context of property coverages. Taking Ehrlich and Becker (1972)'s self-protection example of a burglar alarm system, a homeowner or store owner would certainly hope to extract many years of useful life from such an investment and the exact lifetime is, of course, uncertain.[19] Does a two-period model do justice to this type of intertemporal cost–benefit trade-off? Furthermore, the time horizon matters critically for the interpretation of probability thresholds. According to the FBI, about 1.4 million home burglaries occurred in 2017. Using 142 million housing units as the denominator yields an annual probability of burglary of 0.986%. Over the course of 15 years, assuming independence across time periods, the probability of being broken into at least once rises to 13.81%. While this example makes heroic assumptions, the point is that probability thresholds cannot be interpreted without reference to a specific time horizon. Lastly, self-protection oftentimes involves a series of small investments over time to accomplish desired outcomes. In the health domain, lifestyle choices like healthy eating habits, exercising regularly, following a proper sleep schedule, etc., require the cultivation of healthy habits and demand commitment, discipline, and resistance to temptation on a daily basis. There appears to be a fundamentally dynamic aspect of self-protection in this context. Recently, actuarial researchers have proposed a dynamic model of self-protection (Bensalem et al. 2023), but economists have yet to explore the dynamics of self-protection to a greater extent.

The topic of externalities in self-protection certainly deserves further attention, for example, in the context of climate risk mitigation. Berger et al. (2017) use a two-period self-protection model under uncertainty to study the role of risk and model uncertainty preferences on optimal emission abatement decisions. In their model, policymakers benefit from abatement because it reduces the probability of catastrophic climate outcomes where the environment is severely affected. Abatement thus helps reduce the chance of large losses to macroeconomic consumption. Climate change is a global phenomenon, and the benefits of one country's abatement efforts will spill over onto others. In fact, the role of externalities in climate risk mitigation is well recognized (see Nordhaus 2019) but it would be interesting to explore whether the self-protection literature can bring additional insights here.

The biggest shortcoming of the literature is the lack of empirical work on self-protection. Courbage et al. (2013) made this point already ten years ago, and Courbage et al. (2024) arrive at a similar conclusion. In an experimental study, Krieger

[19] According to www.howtolookatahouse.com, the lifetime of a home security system ranges from 12 to 20 years with an average of 15 years.

and Mayrhofer (2017) find that prudence had a negative effect on self-protection, whereas risk aversion had no effect. Masuda and Lee (2019) draw the same conclusion but found violations of expected utility. Probability weighting explains their data better. Mayrhofer and Schmitz (2019) relate risk preferences to influenza vaccination decisions, a form of primary prevention. They detect a weakly negative link between prudence and the take-up of flu shots but no relation with risk aversion. Lambregts et al. (2021) find that risk aversion increases self-protection, and particularly so for loss probabilities below 0.5. They also find a negative effect of prudence. Ambiguity aversion and ambiguity prudence had no effect.[20] Bleichrodt (2022) provides several thoughts on further experimentation on self-protection, which I fully endorse.

At the same time, the literature on self-protection would clearly benefit from tying in evidence from the field. Are there household level data sets that contain information about who invests in safety features and to what extent? What is known empirically about corporate loss control investments? Are there interesting empirical patterns that would help us resolve some of the existing puzzles or direct the theory towards areas where new puzzles need resolution or where further predictions are needed? In my opinion, the way to elevate the literature on self-protection is through careful empirical work, which can then inform theory about where to go next. Of course, readers who know my work will quickly realize that it probably won't be me who will produce such evidence from the field.

8 Conclusion

In this article, I provided a selective survey of the literature on the economic analysis of self-protection. I developed a conceptual framework that allowed me to catalog existing models of self-protection. I presented classical puzzles that revolve around the tension between risk aversion and downside risk aversion and often involve probability thresholds. I discussed self-protection in non-expected utility models, in two periods, and showed some other related topics. Throughout the entire presentation, I emphasized how the annual EGRIE Seminar served as an important platform for research on self-protection and that many influential contributions in this space were made by former and current EGRIE members. Over the years, the GRIR has featured valuable research on self-protection including some hidden gems that I tried to uncover. It is my hope that I was able to amass enough evidence to conclude that the economics of self-protection is a topic that is a true tribute to EGRIE. I close this article in anticipation of what the next 50 years hold in stock for the economic analysis of self-protection. I am certain that EGRIE and its members will continue to exert effort to raise the odds of further progress on the topic.

[20] Lambregts et al. (2021) study the take-up of full insurance under nonperformance risk, which is formally equivalent to the take-up of self-protection. While the theory on self-protection has largely focused on the intensive margin (i.e., how much self-protection?), Peter (2024) shows that the extensive margin is subject to the same tension between risk aversion and downside risk aversion.

Appendix A: The top ten papers on self-protection

Table 1 ranks papers about self-protection published in economics journals by Google Scholar citations. I am fully aware that Google Scholar citations do not correlate perfectly with quality. Furthermore, citations accumulate over time, which introduces a bias in favor of old papers. At the same time, readership generally increases over time, and researchers tend to cite contemporary authors and colleagues, which favors new papers. I am shamelessly admitting that I resort to Google Scholar citations because they are readily available. Whoever is offended by my list will hopefully accept my sincerest apologies.[21]

Appendix B: Increasing risk and self-protection

Dionne and Eeckhoudt (1988) consider a marginal increase in ℓ that keeps expected final wealth unchanged. I refer to this change as a compensated increase in loss severity. Expected final wealth is given by $w_0 - e^* - p^*\ell$. A one-unit increase in ℓ needs to be accompanied by a p^*-unit increase in w_0 for expected final wealth to stay constant before the adjustment in self-protection occurs. The behavioral effect of a compensated increase in ℓ follows from the implicit function rule by signing the following expression:

$$\begin{aligned}\Delta =& p^* \cdot \left\{-p'(e^*)\left[u'(w_N^*) - u'(w_L^*)\right] - \left[p^* u''(w_L^*) + (1-p^*)u''(w_N^*)\right]\right\} \\ &+ \left\{-p'(e^*)u'(w_L^*) + p^* u''(w_L^*)\right\}.\end{aligned}$$

Solve first-order condition 3 for $-p'(e^*)$ and substitute in Δ, let $\alpha = -(u'(w_L^*) - u'(w_N^*))^2 + (u''(w_N^*) - u''(w_L^*))(u(w_N^*) - u(w_L^*))$ and $\beta = u'(w_L^*)u'(w_N^*)$. I then obtain

$$\Delta = \frac{1}{u(w_N^*) - u(w_L^*)} \cdot \left[\alpha \cdot (p^*)^2 - \alpha \cdot p^* + \beta\right],$$

which is quadratic in p^*. Because of $\beta > 0$, I find immediately that Δ is positive if p^* is close to zero or close to one. In other words, a compensated increase in loss severity raises optimal self-protection if the variance of final wealth is small.

Further analysis is possible on the sign of α. Let

$$v(w) = \frac{1}{\ell}\int_{-\ell}^{0} u(w+t)\,\mathrm{d}t$$

denote the indirect utility function for a risk that is uniformly distributed between $-\ell$ and zero. The fundamental theorem of calculus yields

[21] The biggest shortcoming of Table 1 is actually that it contains no paper that was written by the author of this survey, which makes the invitation to write about the economics of self-protection for the 50-year anniversary of EGRIE even more humbling than it already is.

Table 1 The top ten most cited papers on self-protection in economics

Author(s)	Year	Journal	Citations
Ehrlich and Becker	1972	Journal of Political Economy	2623
Dionne and Eeckhoudt	1985	Economics Letters	435
Briys and Schlesinger	1990	Southern Economic Journal	303
Eeckhoudt and Gollier	2005	Economic Theory	259
Shogren and Crocker	1991	Journal of Environmental Economics and Management	256
Jullien et al	1999	Geneva Risk and Insurance Review	242
Alary et al	2013	The Economic Journal	202
Lakdawalla and Zanjani	2005	Journal of Public Economics	183
Menegatti	2009	Mathematical Social Sciences	142
Snow	2011	Journal of Risk and Uncertainty	135

$$\ell \cdot v'(w) = \int_{-\ell}^{0} u'(w+t)\,\mathrm{d}t = u(w) - u(w-\ell),$$

and likewise for $v''(w)$ and $v'''(w)$. I rearrange $\alpha \geq 0$ to

$$-\frac{u''(w_N^*) - u''(w_L^*)}{u'(w_N^*) - u'(w_L^*)} \geq -\frac{u'(w_N^*) - u'(w_L^*)}{u(w_N^*) - u(w_L^*)},$$

which is equivalent to

$$-\frac{v'''(w_N^*)}{v''(w_N^*)} \geq -\frac{v''(w_N^*)}{v'(w_N^*)}.$$

If u has constant absolute risk aversion (CARA), then v has CARA as well so that $\alpha = 0$ and $\Delta > 0$ regardless of the size of p^*. If u has DARA, then v inherits DARA from u (Nachman 1982), and $\alpha > 0$. In this case, $\Delta < 0$ cannot be ruled out.

In the DARA case, one can study the discriminant of Δ, which is given by $\alpha(\alpha - 4\beta)$. The discriminant is negative if $4\beta > \alpha$. In this case $\Delta > 0$ for all values of p^*, and a compensated increase in loss severity always raises self-protection. DARA implies prudence so that

$$\frac{1}{2}(u'(w_L^*) + u'(w_N^*)) > \frac{1}{\ell}(u(w_N^*) - u(w_L^*)),$$

see Lemma 1 in Eeckhoudt and Gollier (2005). Let $\eta = \ell / w_N^*$ be shorthand for the share of riskless final wealth that the loss puts at risk. Suppose that

$$\eta^2 \cdot \left(-w_N^* \frac{v'''(w_N^*)}{v''(w_N^*)}\right) \cdot \left(-w_N^* \frac{v''(w_N^*)}{v'(w_N^*)}\right) \leq 4; \tag{5}$$

it is straightforward to show that (5) implies $4\beta > \alpha$ if u is prudent. For example, if relative prudence of v is bounded by 2 and relative risk aversion of v is bounded by one, condition (5) is satisfied. Given that v is an indirect utility function, the same restrictions on u do not guarantee that (5) holds. If u and $-u'$ are risk vulnerable (Gollier and Pratt 1996), relative risk aversion and relative prudence of v are larger than those of u.

To dig deeper, I assume power utility, $u(w) = w^{1-\gamma}/(1-\gamma)$ for $\gamma \neq 1$ and $u(w) = \ln(w)$ for $\gamma = 1$. In this case, $\alpha > 0$ because u satisfies DARA. The sign of the discriminant of Δ coincides with the sign of $\alpha - 4\beta$. I rewrite $w_L^* = w_N^*(1-\eta)$ and find that the sign of $\alpha - 4\beta$ is the same as that of

$$-((1-\eta)^{-\gamma} + 1)^2 + \frac{\gamma}{1-\gamma}\left(-1 + (1-\eta)^{-\gamma-1}\right)\left(1 - (1-\eta)^{1-\gamma}\right) \qquad \text{for } \gamma \neq 1,$$

and

$$-\left((1-\eta)^{-1} + 1\right)^2 - \left(-1 + (1-\eta)^{-2}\right)\ln(1-\eta) \qquad \text{for } \gamma = 1.$$

Figure 3 illustrates. Consistent with condition (5), the discriminant of Δ is only positive if risk aversion is high and the loss puts a significant share of final wealth at risk. In particular, it is positive for $\eta > 88\%$ if $\gamma = 0.5$, for $\eta > 65.4\%$ if $\gamma = 2$, and for $\eta > 45\%$ if $\gamma = 5$. For η below these values, the discriminant of Δ is negative, Δ is uniformly positive, and the effect of a compensated increase in loss severity on self-protection is positive for any value of p^*.

If the discriminant of Δ is positive, there are two roots between zero and one,

$$p_1 = \frac{1}{2}\left(1 - \sqrt{1 - 4\beta/\alpha}\right) \qquad \text{and} \qquad p_2 = \frac{1}{2}\left(1 + \sqrt{1 - 4\beta/\alpha}\right).$$

A compensated increase in loss severity then raises self-protection for $p^* \in (0, p_1) \cup (p_2, 1)$, and lowers self-protection for $p^* \in (p_1, p_2)$. Given that $p_1 + p_2 = 1$, one can equivalently say that the effect is positive if and only if the variance of final wealth, normalized by ℓ^2, is less than $p_1(1-p_1)$. The following proposition summarizes these insights.

Proposition *A compensated increase in loss severity raises self-protection if and only if the variance of the final wealth distribution, normalized by* ℓ^2, *is below* β/α.

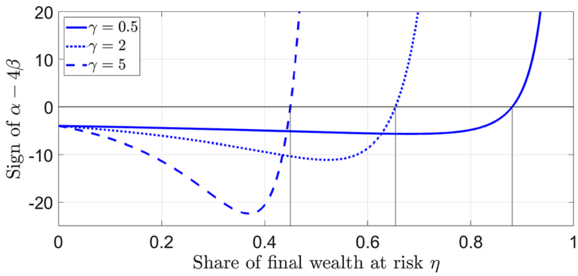


Fig. 3 Sign of $\alpha - 4\beta$ for power utility

For CARA utility, this condition is always satisfied because $\alpha = 0$. For DARA utility, condition (5) is sufficient because it implies $\beta/\alpha > 0.25$. For power utility, it is satisfied if risk aversion is low and the loss puts a small enough share of final wealth at risk. Otherwise, it is satisfied if the loss probability is far enough away from one half.

Data availability The article does not contain any data.

References

Adler, M.D., J.K. Hammitt, and N. Treich. 2014. The social value of mortality risk reduction: VSL versus the social welfare function approach. *Journal of Health Economics* 35: 82–93.

Alary, D., C. Gollier, and N. Treich. 2013. The effect of ambiguity aversion on insurance and self-protection. *The Economic Journal* 123 (573): 1188–1202.

Awondo, S., H. Hollans, L. Powell, and C. Wade. 2023. Estimating the effects of wind loss mitigation on home value. *Southern Economic Journal* 90 (1): 71–89.

Baillon, A., H. Bleichrodt, A. Emirmahmutoglu, J. Jaspersen, and R. Peter. 2022. When risk perception gets in the way: Probability weighting and underprevention. *Operations Research* 70 (3): 1371–1392.

Bensalem, S., N. Hernández-Santibáñez, and N. Kazi-Tani. 2023. A continuous-time model of self-protection. *Finance and Stochastics* 27 (2): 503–537.

Berger, L. 2016. The impact of ambiguity and prudence on prevention decisions. *Theory and Decision* 80 (3): 389–409.

Berger, L., J. Emmerling, and M. Tavoni. 2017. Managing catastrophic climate risks under model uncertainty aversion. *Management Science* 63 (3): 749–765.

Bleichrodt, H. 2022. The prevention puzzle. *The Geneva Risk and Insurance Review* 47 (2): 277–297.

Bleichrodt, H., and L. Eeckhoudt. 2006. Willingness to pay for reductions in health risks when probabilities are distorted. *Health Economics* 15 (2): 211–214.

Briys, E., and H. Schlesinger. 1990. Risk aversion and the propensities for self-insurance and self-protection. *Southern Economic Journal* 57 (2): 458–467.

Briys, E., H. Schlesinger, and J.-M.G. Schulenburg. 1991. Reliability of risk management: Market insurance, self-insurance and self-protection reconsidered. *The Geneva Papers on Risk and Insurance Theory* 16: 45–58.

Chiu, W.H. 2000. On the propensity to self-protect. *Journal of Risk and Insurance* 67 (4): 555–577.

Chiu, W.H. 2010. Skewness preference, risk taking and expected utility maximisation. *The Geneva Risk and Insurance Review* 35 (2): 108–129.

Chiu, W.H. 2012. Risk aversion, downside risk aversion and paying for stochastic improvements. *The Geneva Risk and Insurance Review* 37 (1): 1–26.

Courbage, C. 2001. Self-insurance, self-protection and market insurance within the dual theory of choice. *The Geneva Papers on Risk and Insurance Theory* 26 (1): 43–56.

Courbage, C., and H. Loubergé. 2021. Special issue of The Geneva Papers in memory of Orio Giarini. *The Geneva Papers on Risk and Insurance-Issues and Practice* 46: 173–176.

Courbage, C., and B. Rey. 2006. Prudence and optimal prevention for health risks. *Health Economics* 15 (12): 1323–1327.

Courbage, C., and B. Rey. 2008. On the willingness to pay to reduce risks of small losses. *Journal of Economics* 95 (1): 75–82.

Courbage, C., and B. Rey. 2012. Optimal prevention and other risks in a two-period model. *Mathematical Social Sciences* 63 (3): 213–217.

Courbage, C., B. Rey, and N. Treich. 2013. Prevention and precaution. In *Handbook of Insurance, Chapter 8*, 2nd ed., ed. G. Dionne, 185–204. New York: Springer.

Courbage, C., H. Loubergé, and R. Peter. 2017. Optimal prevention for multiple risks. *Journal of Risk and Insurance* 84 (3): 899–922.

Courbage, C., R. Peter, B. Rey, and N. Treich. 2024. Prevention and precaution. In *Handbook of insurance (forthcoming)*, 3rd ed., ed. G. Dionne. New York: Springer.
Crainich, D., and L. Eeckhoudt. 2017. Average willingness to pay for disease prevention with personalized health information. *Journal of Risk and Uncertainty* 55 (1): 29–39.
Crainich, D., L.R. Eeckhoudt, and J.K. Hammitt. 2015. The value of risk reduction: New tools for an old problem. *Theory and Decision* 79: 403–413.
Dachraoui, K., G. Dionne, L. Eeckhoudt, and P. Godfroid. 2004. Comparative mixed risk aversion: Definition and application to self-protection and willingness to pay. *Journal of Risk and Uncertainty* 29 (3): 261–276.
Denuit, M., L. Eeckhoudt, L. Liu, and J. Meyer. 2016. Tradeoffs for downside risk-averse decision-makers and the self-protection decision. *The Geneva Risk and Insurance Review* 41 (1): 19–47.
Di Mauro, C., and A. Maffioletti. 1996. An experimental investigation of the impact of ambiguity on the valuation of self-insurance and self-protection. *Journal of Risk and Uncertainty* 13: 53–71.
Dionne, G., and L. Eeckhoudt. 1984. Insurance and saving: Some further results. *Insurance: Mathematics and Economics* 3 (2): 101.
Dionne, G., and L. Eeckhoudt. 1985. Self-insurance, self-protection and increased risk aversion. *Economics Letters* 17 (1–2): 39–42.
Dionne, G., and L. Eeckhoudt. 1988. Increasing risk and self-protection activities. *Geneva Papers on Risk and Insurance* 13 (47): 132–136.
Dionne, G., and J. Li. 2011. The impact of prudence on optimal prevention revisited. *Economics Letters* 113 (2): 147–149.
Dobson, A.P., S.L. Pimm, L. Hannah, L. Kaufman, J.A. Ahumada, A.W. Ando, A. Bernstein, J. Busch, P. Daszak, J. Engelmann, et al. 2020. Ecology and economics for pandemic prevention. *Science* 369 (6502): 379–381.
Doherty, N. 2021. An appreciation of Orio Giarini: First Secretary General of the Geneva Association. *The Geneva Papers on Risk and Insurance-Issues and Practice* 46: 301–304.
Echazu, L., and D.C. Nocetti. 2020. Willingness to pay for morbidity and mortality risk reductions during an epidemic. Theory and preliminary evidence from COVID-19. *The Geneva Risk and Insurance Review* 45: 114–133.
Eeckhoudt, L. 2012. Beyond risk aversion: Why, how and what's next? *The Geneva Risk and Insurance Review* 37: 141–155.
Eeckhoudt, L., and C. Gollier. 2005. The impact of prudence on optimal prevention. *Economic Theory* 26 (4): 989–994.
Eeckhoudt, L., R.J. Huang, and L.Y. Tzeng. 2012. Precautionary effort: A new look. *Journal of Risk and Insurance* 79 (2): 585–590.
Ehrlich, I., and G.S. Becker. 1972. Market insurance, self-insurance, and self-protection. *Journal of Political Economy* 80 (4): 623–648.
Etner, J., and M. Jeleva. 2014. Underestimation of probabilities modifications: Characterization and economic implications. *Economic Theory* 56 (2): 291–307.
Etner, J., and M. Jeleva. 2016. Health prevention and savings: How to deal with fatalism? *Annals of Economics and Statistics/Annales d'Économie et de Statistique* 121/122: 67–90.
Fagart, M.-C., and C. Fluet. 2013. The first-order approach when the cost of effort is money. *Journal of Mathematical Economics* 49 (1): 7–16.
Ferranna, M. 2017. Does inefficient risk sharing increase public self-protection? *The Geneva Risk and Insurance Review* 42: 59–85.
Gollier, C., and J.W. Pratt. 1996. Risk vulnerability and the tempering effect of background risk. *Econometrica* 64 (5): 1109–1123.
Gougeon, P. 1983. Assurance et prévention: une approche portefeuille. *Geneva Papers on Risk and Insurance* 8 (29): 350–370.
Haritchabalet, C. 2000. The production of goods in excess of demand: A generalization of self-protection. *The Geneva Papers on Risk and Insurance Theory* 25 (1): 51–63.
Heinzel, C. 2023. Self-protection and self-insurance with multiplicative foreground and background risks. Working Paper (Institut national de la recherche agronomique).
Heinzel, C., and R. Peter. 2023. Precaution with multiple instruments: The importance of substitution effects. *Journal of Economic Behavior & Organization* 207: 392–412.
Hofmann, A. 2007. Internalizing externalities of loss prevention through insurance monopoly: An analysis of interdependent risks. *The Geneva Risk and Insurance Review* 32 (1): 91–111.

Hofmann, A., and R. Peter. 2015. Multivariate prevention decisions: Safe today or sorry tomorrow? *Economics Letters* 128: 51–53.
Hofmann, A., and R. Peter. 2016. Self-insurance, self-protection, and saving: On consumption smoothing and risk management. *Journal of Risk and Insurance* 83 (3): 719–734.
Hofmann, A., and C. Rothschild. 2019. On the efficiency of self-protection with spillovers in risk. *The Geneva Risk and Insurance Review* 44: 207–221.
Hogarth, R.M., and H. Kunreuther. 1992. Pricing insurance and warranties: Ambiguity and correlated risks. *The Geneva Papers on Risk and Insurance Theory* 17: 35–60.
Holmström, B. 1979. Moral hazard and observability. *The Bell Journal of Economics* 10 (1): 74–91.
Holmström, B., and P. Milgrom. 1991. Multitask principal-agent analyses: Incentive contracts, asset ownership, and job design. *The Journal of Law, Economics, and Organization* 7: 24–52.
Hong, J., K. Kim, 2024. Self-protection against a health risk and saving: An analysis of income and health effects. The Geneva Risk and Insurance Review (forthcoming).
Huber, T. 2022. Comparative risk aversion in two periods: An application to self-insurance and self-protection. *Journal of Risk and Insurance* 89 (1): 97–130.
Immordino, G. 2000. Self-protection, information and the precautionary principle. *The Geneva Papers on Risk and Insurance Theory* 25 (2): 179–187.
Jewitt, I. 1989. Choosing between risky prospects: The characterization of comparative statics results, and location independent risk. *Management Science* 35 (1): 60–70.
Jindapon, P. 2013. Do risk lovers invest in self-protection? *Economics Letters* 121 (2): 290–293.
Jones-Lee, M.W., M. Hammerton, and P.R. Philips. 1985. The value of safety: Results of a national sample survey. *The Economic Journal* 95 (377): 49–72.
Jullien, B., B. Salanié, and F. Salanié. 1999. Should more risk-averse agents exert more effort? *The Geneva Risk and Insurance Review* 24 (1): 19–28.
Keenan, D.C., and A. Snow. 2009. Greater downside risk aversion in the large. *Journal of Economic Theory* 144 (3): 1092–1101.
Keenan, D.C., and A. Snow. 2018. Direction and intensity of risk preference at the third order. *Journal of Risk and Insurance* 85 (2): 355–378.
Kihlstrom, R.E., and L.J. Mirman. 1974. Risk aversion with many commodities. *Journal of Economic Theory* 8 (3): 361–388.
Kimball, M.S. 1990. Precautionary saving in the small and in the large. *Econometrica* 58 (1): 53–73.
Klibanoff, P., M. Marinacci, and S. Mukerji. 2005. A smooth model of decision making under ambiguity. *Econometrica* 73 (6): 1849–1892.
Konrad, K.A., and S. Skaperdas. 1993. Self-insurance and self-protection: A nonexpected utility analysis. *The Geneva Papers on Risk and Insurance Theory* 18 (2): 131–146.
Kőszegi, B., and M. Rabin. 2006. A model of reference-dependent preferences. *The Quarterly Journal of Economics* 121 (4): 1133–1165.
Kőszegi, B., and M. Rabin. 2007. Reference-dependent risk attitudes. *American Economic Review* 97 (4): 1047–1073.
Krieger, M., and T. Mayrhofer. 2017. Prudence and prevention: An economic laboratory experiment. *Applied Economics Letters* 24 (1): 19–24.
Lakdawalla, D., and G. Zanjani. 2005. Insurance, self-protection, and the economics of terrorism. *Journal of Public Economics* 89 (9–10): 1891–1905.
Lambregts, T.R., P. van Bruggen, and H. Bleichrodt. 2021. Insurance decisions under nonperformance risk and ambiguity. *Journal of Risk and Uncertainty* 63 (3): 229–253.
Lazear, E.P., and S. Rosen. 1981. Rank-order tournaments as optimum labor contracts. *Journal of Political Economy* 89 (5): 841–864.
Lee, K. 1998. Risk aversion and self-insurance-cum-protection. *Journal of Risk and Uncertainty* 17 (2): 139–151.
Lee, K. 2005. Wealth effects on self-insurance and self-protection against monetary and nonmonetary losses. *The Geneva Risk and Insurance Review* 30 (2): 147–159.
Lee, K. 2019. Prudence and precautionary effort. *Journal of Risk and Insurance* 86 (1): 151–163.
Li, L. 2021. Opening up the black box: Technological transparency and prevention. *Journal of Risk and Insurance* 88 (3): 665–693.
Li, L., and R. Peter. 2021. Should we do more when we know less? The effect of technology risk on optimal effort. *Journal of Risk and Insurance* 88 (3): 695–725.
Liu, L., and N. Treich. 2021. Optimality of winner-take-all contests: The role of attitudes toward risk. *Journal of Risk and Uncertainty* 63: 1–25.

Liu, L., and J. Wang. 2017. A note on the comparative statics approach to *n*th-degree risk aversion. *Economics Letters* 159: 116–118.
Liu, L., A.J. Rettenmaier, and T.R. Saving. 2009. Conditional payments and self-protection. *Journal of Risk and Uncertainty* 38 (2): 159–172.
Liu, L., J. Meyer, A.J. Rettenmaier, and T.R. Saving. 2018. Risk and risk aversion effects in contests with contingent payments. *Journal of Risk and Uncertainty* 56: 289–305.
Loubergé, H. 2013. Developments in risk and insurance economics: The past 40 years. In *Handbook of insurance, chapter 2*, 2nd ed., ed. G. Dionne, 1–40. New York: Springer.
Macé, S. and R. Peter. 2021. The impact of loss aversion on optimal prevention. University of Iowa (Working Paper). SSRN 388220.
Masuda, T., and E. Lee. 2019. Higher order risk attitudes and prevention under different timings of loss. *Experimental Economics* 22 (1): 197–215.
Mauro, C.D. 1994. Risky production processes and demand for preventive safety measures under uncertainty. *The Geneva Papers on Risk and Insurance Theory* 19: 35–51.
Mayrhofer, T., and H. Schmitz. 2019. Prudence and prevention—Empirical evidence. Working Paper (Stralsund University of Applied Sciences).
Menegatti, M. 2009. Optimal prevention and prudence in a two-period model. *Mathematical Social Sciences* 58 (3): 393–397.
Menegatti, M. 2018. Prudence and different kinds of prevention. *Eastern Economic Journal* 44: 273–285.
Menegatti, M., and F. Rebessi. 2011. On the substitution between saving and prevention. *Mathematical Social Sciences* 62 (3): 176–182.
Menezes, C., C. Geiss, and J. Tressler. 1980. Increasing downside risk. *American Economic Review* 70 (5): 921–932.
Mossin, J. 1968. Aspects of rational insurance purchasing. *Journal of Political Economy* 46 (4): 553–568.
Nachman, D.C. 1982. Preservation of "more risk averse'' under expectations. *Journal of Economic Theory* 28 (2): 361–368.
Newhouse, J.P. 2021. An ounce of prevention. *Journal of Economic Perspectives* 35 (2): 101–118.
Nordhaus, W. 2019. Climate change: The ultimate challenge for economics. *American Economic Review* 109 (6): 1991–2014.
Peter, R. 2017. Optimal self-protection in two periods: On the role of endogenous saving. *Journal of Economic Behavior & Organization* 137: 19–36.
Peter, R. 2021. A fresh look at primary prevention for health risks. *Health Economics* 30 (5): 1247–1254.
Peter, R. 2021. Prevention as a Giffen good. *Economics letters* 208: 110052.
Peter, R. 2021. Who should exert more effort? Risk aversion, downside risk aversion and optimal prevention. *Economic Theory* 71 (4): 1259–1281.
Peter, R. 2022. When is safety a normal good? Working Paper (University of Iowa). SSRN 44147815.
Peter, R. 2024. The self-protection problem. In *Handbook of Insurance (Forthcoming)*, 3rd ed., ed. G. Dionne. Berlin: Springer.
Peter, R. and A. Hofmann. 2022. Precautionary risk reduction and saving: Two sides of the same coin? Working Paper (University of Iowa). SSRN 4061859
Peter, R., and P. Toquebeuf. 2020. Separating ambiguity and ambiguity attitude with mean-preserving capacities: Theory and applications. Working Paper (University of Iowa).
Pratt, J.W. 1964. Risk aversion in the small and in the large. *Econometrica* 32 (1–2): 122–136.
Salanié, F., and N. Treich. 2020. Public and private incentives for self-protection. *The Geneva Risk and Insurance Review* 45: 104–113.
Schlesinger, H., and E. Venezian. 1986. Insurance markets with loss-prevention activity: Profits, market structure, and consumer welfare. *The Rand Journal of Economics* 17 (2): 227–238.
Schneider, T. 1992. Economic behaviour of the firm and prevention of occupational injuries. *The Geneva Papers on Risk and Insurance Theory* 17: 77–85.
Shogren, J.F., and T.D. Crocker. 1991. Risk, self-protection, and ex ante economic value. *Journal of Environmental Economics and Management* 20 (1): 1–15.
Snow, A. 2011. Ambiguity aversion and the propensities for self-insurance and self-protection. *Journal of Risk and Uncertainty* 42 (1): 27–43.
Starmer, C. 2000. Developments in non-expected utility theory: The hunt for a descriptive theory of choice under risk. *Journal of Economic Literature* 38 (2): 332–382.
Sweeney, G., and T.R. Beard. 1992. Self-protection in the expected-utility-of-wealth model: An impossibility theorem. *The Geneva Papers on Risk and Insurance Theory* 17: 147–158.

Sweeney, G.H., and T.R. Beard. 1992. The comparative statics of self-protection. *Journal of Risk and Insurance* 59 (2): 301–309.
Treich, N. 2010. Risk-aversion and prudence in rent-seeking games. *Public Choice* 145 (3–4): 339–349.
Treich, N., and Y. Yang. 2021. Public safety under imperfect taxation. *Journal of Environmental Economics and Management* 106: 102421.
Vollaard, B., and J.C. Van Ours. 2011. Does regulation of built-in security reduce crime? Evidence from a natural experiment. *The Economic Journal* 121 (552): 485–504.
Wang, J., and J. Li. 2015. Precautionary effort: Another trait for prudence. *Journal of Risk and Insurance* 82 (4): 977–983.
Yaari, M.E. 1987. The dual theory of choice under risk. *Econometrica* 55 (1): 95–115.
Zheng, J. 2021. Willingness to pay for reductions in health risks under anticipated regret. *Journal of Health Economics* 78: 102476.

Richard Peter is an Associate Professor of Finance at the University of Iowa's Tippie College of Business. His research interests are in risk management and insurance. He uses microeconomic theory models to answer descriptive and normative questions. He has studied topics such as genetic testing, insurance demand, higher-order risk effects, and prevention. He has earned his Ph.D. in risk management and insurance from Ludwig Maximilian University of Munich.