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Can Investment Views Explain Why People Insure Their Cell Phones But Not Their Homes?—A New Perspective on the Catastrophe Insurance Puzzle

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Abstract: The consistently missing demand for catastrophe insurance and for coverage of other low-probability–high-consequence risks is often referred to as the catastrophe insurance puzzle. People show reluctance to insure low-probability–high-consequence events, even with some disastrous consequences, yet insure against small high-probability–low-consequence events. There has been no convincing explanation of this puzzle to this date. This article points out that the underlying rationale may be that individuals interpret insurance contracts with low payout probability as an investment with negative expected net present value. While premium payments start with the conclusion of the contract, usually there is only one loss payment in the near or far future. Using a simple annuity model with fixed annual premiums and expected indemnity payouts, it is found that even an individual characterized by the degree of risk aversion found in the literature is unlikely to purchase insurance with these characteristics. To alleviate this unfavorable insurance purchase syndrome, combining a low-probability with a high-probability loss insurance contract may be a way to incentivize individuals to purchase catastrophe risk coverage.

Keywords: catastrophe insurance puzzle; insurance demand for low-probability events; investment view; risk aversion; biases in risk perception

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1. Introduction

Studies of insurance demand often suggest that individuals seem to either ignore or at least undervalue low-probability events. For rare but high-impact events, insurance is often not attractive. The consistently missing demand for catastrophe insurance and coverage of other low-probability–high-consequence risks is often referred to as the *catastrophe insurance puzzle* (CIP). People show reluctance to insure low-probability-high-consequence events even if they have disastrous consequences, yet insure against small high-probability losses.

A possible explanation for this observation may be that individuals tend to pay little attention to risks with a probability of occurrence below some perceived threshold (Kunreuther and Pauly 2004; Slovic et al. 1977). This threshold may serve as a gatekeeper, guiding individuals to purchase insurance only for risks that are worthwhile to insure (those perceived to happen in the near future). As first mentioned by Kunreuther and Slovic (1978), an explanation of this behavior may also be that insurance is interpreted as some form of an investment. Indeed, insuring against rare hazards may be a bad investment most of the time. As Kunreuther and Slovic (1978, p. 66) state,

> "there is evidence that people do not voluntarily insure themselves against natural disasters even when the rates are highly subsidized. The reasons for failure of insurance markets need to be understood, as they have important implications for policy."

Interestingly, this early explanation from 1978 has never been studied in detail or even been evaluated more carefully in the literature. It is the research question of this article. What are the consequences of individuals interpreting insurance contracts with low payout probability as an investment with negative expected net present value but those with high payout probability as an investment with positive expected net present value? Using a simple annuity model with fixed annual premiums and expected indemnity payouts, it turns out that even an individual characterized by a degree of risk aversion found in the literature is unlikely to purchase insurance covering a low-probability–high-consequence event. However, combining a low-probability with a high-probability loss insurance contract may be a way to incentivize individuals to purchase catastrophe risk coverage, thereby alleviating the catastrophe insurance puzzle.

This article is structured as follows. Section 2 discusses the literature on the CIP and related questions. The subsequent section deals with the case of corporate insurance, where risk aversion does not play a role if management acts in the interest of well-diversified owners of the firm (Doherty 1985; Zweifel et al. 2021, chapter 5). Section 4 is devoted to the case of a consumer characterized by risk aversion and willing to pay a risk premium for a high-probability–low-consequence policy (exemplified by cell phone insurance). Section 5 pursues the idea of combining the former with a low-probability–high-consequence policy to overcome the behavior giving rise to the CIP. The last section discusses findings and draws conclusions.

2. Related Literature

Several possible explanations of the CIP exist in the literature but none seems convincing enough to have established itself as the main CIP rationale so far. First, it has been argued that the high transaction costs in catastrophe insurance markets may hinder demand (Kunreuther and Pauly 2004; Akter et al. 2008; Pothon et al. 2019). Kunreuther and Pauly (2004) studied a modeling approach to the purchase of catastrophe insurance and argued that a reason for the non-purchase of such insurance coverage may be the insufficient magnitude of the potential loss relative to its probability and to the insurance premium. Since the probability is so low, the severity would need to be more than bankruptingly high to warrant purchase.

Slovic et al. (1977) note that, in order to change individuals' perspectives and possibly motivate them to purchase insurance for rare losses (Slovic et al. 1977, p. 256),

> "instead of describing the chances of a 100-year flood as 0.01 per year, one could note that an individual living in a particular house for 25 years faces a 0.22 chance of suffering 100-year damage at least once."

Akter et al. (2008) study the uptake of catastrophe insurance among 3000 residents in six different districts in Bangladesh facing various levels of exposure. They identify not only common misunderstandings of risk but also discuss the high cost of insurance for the poor as factors limiting the demand for coverage. Among the reasons for going without coverage, 'limited financial income' and 'dislike of terms and conditions' figured prominently.[1] Pothon et al. (2019) evaluate twenty years of data in their attempt at understanding why people do not purchase earthquake insurance. They find that homeowners do understand the risk but consider the annual premium 'too high': on average, they would have to decrease from USD 980 to USD 160 annually to be acceptable.

Second, information asymmetries such as adverse selection and moral hazard may lead to market failure (Antwi-Boasiako 2014; Lin 2020). Antwi-Boasiako (2014) discusses market failures including adverse selection, moral hazard, correlated risks, and time inconsistency as potential reasons for why people do not purchase catastrophe insurance. Lin (2020) demonstrates that there is a positive demand–risk correlation in the earthquake insurance market in California, a finding consistent with adverse selection.

Third, limited liability and anticipation of government relief may inhibit catastrophe insurance demand. Governments often feel a need for the provision of relief in the case of a major catastrophe ('Samaritan's Dilemma'). Andor et al. (2020) evaluate the issue that, in the aftermath of disasters, governments often offer financial assistance for affected households. If anticipated by households, this introduces a crowding-out effect on insurance demand and possibly even precautionary ex ante measures. This crowding-out effect is sometimes referred to as "charity hazard". While empirical studies offer mixed results, Andor and colleagues find a positive correlation between governmental relief and non-financial protection measures.

Last, behavioral biases may contribute to why people do not purchase low-probability event insurance (Kunreuther and Pauly 2004; Antwi-Boasiako 2014).[2] Kunreuther and Pauly (2004) argue that a possible reason is that consumers may not know or may be unable to evaluate and understand low loss probabilities. For instance, when psychological biases are at play, under- or overweighting of small probabilities may hinder demand for coverage. Kunreuther and Pauly (2004) point out that people tend to buy (more) catastrophe insurance right after a major disaster, when they revise their subjective probability estimates ('it does happen!'). This behavior is known as *salience bias*, meaning a focus on items or information that grab people's attention. In addition, the high deductibles common in catastrophe insurance make consumers feel a lack of financial protection. Indeed, rich context information must be made available to individuals to enable them to judge differences between low probabilities. The authors find that individuals need to be presented with "comparison scenarios that are located on the probability scale to evoke people's own feelings of risk". Individuals may indeed have difficulty processing very low probabilities or even fail to distinguish between low-probability and zero-probability events, and the missing demand for insurance covering low-probability events may indeed be due to this ignoring of risks with low probabilities.[3] As shown in several experiments and field surveys, individuals consistently buy insurance only when the probability of loss is above a certain threshold (Slovic et al. 1977; Kunreuther and Slovic 1978), even in cases where the premium is heavily subsidized. To our knowledge, there is only one experiment where this relationship is reversed (Laury et al. 2009).

However, all of these possible explanations in the literature of the CIP fail to convincingly explain the consistent lack of demand for insurance covering low-probability–high-consequence events *and* high demand for insurance covering high-probability–low-consequence events. It is this combination of phenomena that constitutes the *catastrophe insurance puzzle* (CIP). The objective of this contribution is to explain the CIP using a simple theoretical model that takes into account the time value of money while maintaining the assumption of a rational risk-neutral or risk-averse decision maker.

A case in point for this combined puzzle is homeowners' insurance against flooding, which is subsidized up to 50 percent (Brown 2011). Yet, after each major disaster, the question of why homeowners do not adequately insure against catastrophic losses comes up in the media again. Interestingly, a recent study by Browne et al. (2015) uses data from an insurer that offers add-on coverage for both a low-probability–high-consequence risk (a flood peril) and a high-probability–low-consequence risk (a bicycle theft). They find evidence consistent with the combined CIP in the sense that a significantly higher number of policyholders purchase add-on coverage to their homeowner's insurance to cover the risk of bicycle theft than to cover the risk of major loss due to flooding.

Another particularly striking instance of the combined CIP is the growing market for cell phone insurance in the presence of the continuing under-insurance of flooding risks. According to a recent report, the global mobile phone insurance market was estimated at USD 24.6 bn in 2020, with a growth rate of 11.8% for the following decade.[4] It is expected to reach USD 38.1 bn by 2024. This growth is puzzling because damage to or loss of a cell phone entails getting accustomed to a new phone in the extreme case, an event with minimal impact on life, contrary to most low-probability–high-impact losses such as natural and other disasters.

In the following, an explanation of this and other instances of the combined CIP is proposed which does not have to invoke any of the behavioral deviations from rationality cited above. It simply views insurance as a financial investment with expected returns that may be frequently negative.

3. The Corporate View of Insurance as an Investment

3.1. Low-Probability Insurance

The purchase of insurance is viewed as an investment with a *risky* net present value (PV) of returns, assuming no risk aversion, thus adopting the point of view of a risk neutral individual or a corporation. As a first step, a general result is derived (a realistic value for n, the number of years, will be introduced below). The per-period premium is P_I for coverage I of a low-probability–high-consequence type of event with loss size L. With a real rate of discount $r < 1$, the (certain) PV of the premium stream is

$$PV_I(Premia) = P_I + \frac{P_I}{(1+r)} + \frac{P_I}{(1+r)^2} + \ldots + \frac{P_I}{(1+r)^n} \quad (1)$$

Multiplying Equation (1) by $(1+r)$ and subtracting the result from Equation (1), one obtains

$$(1+r)PV_I(Premia) - PV_I(Premia) = r \cdot PV_I(Premia) = P_I - \frac{P_I}{(1+r)^n},$$

resulting in a standard annuity present value,

$$PV_I(Premia) = \frac{P_I}{r} - \frac{P_I}{r(1+r)^n} \quad (2)$$

Next, the expected PV of the benefit stream associated with a low-probability–high-consequence event is calculated. Given a binary distribution with (low) constant probability ρ_I, the expected waiting period Em for the first (and by assumption only) loss to materialize is given by $Em := 1/\rho_I$; before that, there are no benefits.[5] Assuming full coverage, one obtains the expected PV

$$EPV_I(Benefits) = 0 + 0 + \ldots\ldots \frac{\rho_I L_I}{(1+r)^m} + 0 + 0\ldots = \frac{\rho_I L_I}{(1+r)^{1/\rho_I}} \quad (3)$$

The high value of L_I is weighted by a small value of ρ_I and strongly discounted because the expected waiting period $1/\rho_I$ is long in principle. Neglecting risk aversion and assuming that the premium is fair and the loss is fully insured ($I = L$), the net EPV of buying catastrophic insurance amounts to

$$\begin{aligned} EPV_I(Benefits) - PV_I(Premia) &= \tfrac{\rho_I L_I}{(1+r)^m} - \left(\tfrac{P_I}{r} - \tfrac{P_I}{r(1+r)^n}\right) \\ &= \tfrac{\rho_I L_I}{(1+r)^m} - \left(\tfrac{\rho_I L_I}{r} - \tfrac{\rho_I L_I}{r(1+r)^n}\right) \\ &= \rho_I L_I \left(\tfrac{1}{(1+r)^m} - \tfrac{1}{r} + \tfrac{1}{r(1+r)^n}\right) \\ &= \rho_I L_I \left(\tfrac{r(1+r)^n - (1+r)^{m+n} + (1+r)^m}{r(1+r)^{m+n}}\right) < 0 \end{aligned} \quad (4)$$

due to $(1+r)^{m+n} > r(1+r)^n + (1+r)^m$. Therefore, in a realistic scenario, catastrophe insurance constitutes a bad investment with a negative expected present value (NPV). Note that this holds for all arbitrary (positive) values of ρ_I, L_I, m, n, and $r < 1$ and for all types of premium because the actuarially fair premium is the lowest possible, without any loading. Given the loss size has no impact here, the findings hold for both low-severity and high-severity loss insurance.

3.2. High-Probability Insurance

For maximum contrast, now assume that a loss J occurs (and a benefit is paid) in every period with probability $\rho_J > \rho_I$ but with loss amounting to $L_J < L_I$, characterizing the "high-probability-small-consequence characteristic" of the policy. With the average duration of a policy equal to four years, the EPV_J of the benefit stream is given by[6]

$$EPV_J(Benefits) = \rho_J L_J + \frac{\rho_J L_J}{(1+r)} + \frac{\rho_J L_J}{(1+r)^2} + \frac{\rho_J L_J}{(1+r)^3} \tag{5}$$

Multiplying by $(1+r)$, one obtains

$$(1+r)EPV_J(Benefits) = (1+r)\rho_J L_J + \rho_J L_J + \frac{\rho_J L_J}{(1+r)} + \frac{\rho_J L_J}{(1+r)^2}$$

Subtracting this from Equation (5) and dividing by r yields

$$EPV_J(Benefits) = \rho_J L_J \left(\frac{1+r}{r} - \frac{1}{r(1+r)^3} \right) \tag{6}$$

Since the premium stream starts in period no. 1 when the first loss occurs, it has the same PV as the EPV of the benefit stream, resulting in

$$EPV_J\ (Benefits) - PV_J\ (Costs) = 0. \tag{7}$$

Therefore, without the effect of risk aversion, investment in a stand-alone high-probability–low-consequence insurance just breaks even regardless of loss size. This result is in accordance with the basic model of insurance demand, which predicts zero willingness to pay (WTP) in the absence of risk aversion. Indeed, for risk-neutral parties, the net present value of an insurance contract is zero.

3.3. Combining Low-Probability and High-Probability Insurance

For a policy combining coverage of a low-probability loss I and a high-probability loss J, a natural simplifying assumption is uncorrelatedness of the two risks. This results in an addition of payments and premiums, yielding in a negative value of the investment as before because zero is added to Equation (4) according to Equation (7). Again, this result holds for arbitrary values of $\rho_I,\ L_I,\ m,\ n,$ and $r < 1$ and all types of premium.

Conclusion 1: From a corporation's perspective, being risk neutral, a low-probability loss insurance contract is unambiguously considered a bad investment and will not be undertaken regardless of loss size. A stand-alone high-probability insurance contract just breaks even, again regardless of loss size. Combining low- and high-probability insurance still results in a bad investment.

4. The Individual View of Insurance as an Investment

4.1. Low-Probability Insurance

While for a risk-neutral party, WTP to get rid of a risk (in excess of expected value) is zero, it is positive for risk-averse parties. It amounts to the risk premium, defined as the difference between expected wealth and the (lower) certainty equivalent of wealth (Schlesinger and Venezian 1986; Zweifel et al. 2021, chapter 2). Evidently, the risk premium increases with the individual's degree of risk aversion; however, the precise relationship depends on the higher-order moments of the wealth distribution (Stapleton and Zeng 2018). The expected net present value of the benefits now includes the risk premium denoted by $\pi_k > 0$, reflecting the individual's benefit of getting rid of the risk completely by paying the fair competitive premium P_I for k periods. As before, the average duration of a policy is equal to four years. Since the benefit of certainty has to be discounted to PV as well, Equation (3) becomes

$$\begin{aligned} EPV_I(Benefits) &= \pi_k + \frac{\pi_k}{1+r} + \frac{\pi_k}{(1+r)^2} + \frac{\pi_k}{(1+r)^3} + \frac{\rho_I L_I}{(1+r)^{1/\rho_I}} \\ &= \pi_k \left(\frac{1}{r} - \frac{1}{r(1+r)^3} \right) + \frac{\rho_I L_I}{(1+r)^{1/\rho_I}}. \end{aligned} \tag{8}$$

As to the premium stream, Equation (2) does not need to be modified because the premia can arguably be assumed to be risk-free. Combining Equations (8) and (9), one obtains

$$EPV_I(Benefits) - PV_I(Premia) = \pi_i \left(\frac{1}{r} - \frac{1}{r(1+r)^3} \right) + \frac{\rho_I L_I}{(1+r)^{\frac{1}{\rho_I}}} - P_I \left(\frac{1}{r} - \frac{1}{r(1+r)^3} \right), \tag{9}$$

which can be rewritten to become

$$\begin{aligned} EPV_I(Benefits) - PV_I(Premia) &= \frac{\rho_I L_I}{(1+r)^{1/\rho_I}} - (P_I - \pi_k) \left(\frac{1}{r} - \frac{1}{r(1+r)^n} \right) \\ &= \frac{\rho_I L_I}{(1+r)^{1/\rho_I}} - P_I \left(\frac{1}{r} - \frac{1}{r(1+r)^3} \right) + \pi_k \left(\frac{1}{r} - \frac{1}{r(1+r)^3} \right). \end{aligned} \tag{10}$$

From Equation (4), one has

$$\frac{\rho_I L_I}{(1+r)^{1/\rho_I}} - P_I \left(\frac{1}{r} - \frac{1}{r(1+r)^3} \right) < 0,$$

implying that the sum of the first two terms of Equation (10) is negative. Therefore, catastrophe insurance constitutes a good investment with a positive expected PV only as long as the individual is sufficiently risk-averse to exhibit a high-risk premium π_k.

Equation (10) can be evaluated further by inserting, e.g., $r = 0.05$ and $1/\rho_I = 20$. This means that, in Equation (10), the first term is multiplied by $1/2.65 = 0.377$ and the second and third by $20 - 17.38 = 2.72$. Given fair premiums, $P_I = \rho_I L_I$, so the sum of the negative terms amounts to $2.343 P_I$, but the positive last term amounts to $2.72\pi_k$. Therefore, the risk premium would have to be at least as large as 86% of the actuarially fair premium for low-probability–high-consequence insurance to constitute a good investment. However, in their review of estimates, Fracasso et al. (2023) report many instances where the risk premium is not significantly different from zero, making satisfaction of this condition unlikely. Yet it is known that the subjective rate of discount exceeds the market rate by far. A field experiment involving the general population in Denmark yielded a value of 28% Harrison et al. (2002). Using $r = 0.20$, $1/\rho_I = 20$, and $n = 4$ results in multipliers of $1/3.83 = 0.261$ and $5 - 17.38 = 2.72$, respectively.

Conclusion 2: From the perspective of risk-averse individuals, whether a low-probability–high-consequence insurance contract typical of catastrophe insurance is considered a good or bad investment importantly depends on their subjective rate of discount. For those with a rate close to the market rate, it constitutes a bad investment, while for those with a rate close to that found in the general population, it may be a good one.

The economic reason is that a high rate of subjective discount moves a future loss payment forward to the present.

4.2. High-Probability Insurance

The average time before damage to or loss of a cell phone occurs is a mere 10 weeks in the United States, making it an archetypical high-probability–low-consequence event. Globally, the market of cell phone insurance was estimated at USD 24.6 bn in 2020, with a growth rate of 11.8% for the following decade.[7] This dwarfs the market for catastrophe insurance with its USD 5.4 mn as of 2022 and a predicted 7% rate of growth until 2030.[8]

To explain this striking contrast, assume again that a loss J occurs (and a benefit is paid) in every period with probability $\rho_J > \rho_I$ but with loss amounting to $L_J < L_I$, characterizing the "high-probability-small-consequence characteristic" of the policy. In contrast to Section 3.1, $Em = 1/5$ reflects the finding cited above, implying $1/\rho_J = 5$ on an annual basis. However, most insurers cap coverage at two payments per year, while the average duration of a contract is about n = 1.5 years (https://www.nerdwallet.com/article/finance/surprising-things-cell-phone-insurance, accessed 2 December 2023). Finally, they impose a deductible of up to USD 299. Estimating its average value at USD 150, one obtains

$$EPV_J(Benefits) = \left(1 + \frac{1}{1+r/2}\right) 2(L_J - 150 + \pi_k) \tag{11}$$

Maintaining the assumption of fair premiums for consistency (which are paid annually in advance), their PV is given by

$$PV_J(Premia) = 2(L_J - 150)\left(1 + \frac{1}{1+r}\right) \tag{12}$$

In all, Equations (4) and (5) result in

$$\begin{aligned} EPV_J(Benefits) - PV_J(Premia) &= \left(1 + \tfrac{1}{1+r/2}\right) 2(L_J - 150 + \pi_k) - 2(L_J - 150)\left(1 + \tfrac{1}{1+r}\right) \\ &= \left(\tfrac{1}{1+r/2} - \tfrac{1}{1+r}\right) 2(L_J - 150) \\ &+ 2\pi_k(L_J - 150)\left(1 + \tfrac{1}{1+r/2}\right) > 0 \end{aligned} \tag{13}$$

Conclusion 3: A high-probability–low-consequence insurance contract, typical of damage or loss of a cell phone, is a good investment regardless of the individual's risk premium and hence the degree of risk aversion, provided the deductible is fully accounted for, as in the context of a fair premium. The reason is that the loss event occurs probably within weeks after the purchase of the policy on average.

This result gives rise to the question of why insurers offer this kind of policy. One reason may be that they charge a high loading, contrary to the assumption of a fair policy; another, that they see the opportunity to be in frequent contact with customers, with the associated possibility of selling coverage of other risks.

5. Combining Low-Probability and High-Probability Insurance

The idea of combining insurance policies to boost WTP for catastrophe insurance is not entirely new. When the launch of all-hazard policies covering catastrophic events is discussed, Conclusion 3 points to the importance of having a high-probability component in such a combined policy. Moreover, the size of the risk premium is crucial for its low-probability component, as stated in Conclusion 2. A first approach is to simply scale up the two risk premia to obtain the combined WTP value, in spite of the finding of Stapleton and Zeng (2018) that all moments of the wealth distribution enter the determination of the risk premium. In Section 4.2, this problem is avoided by applying the Arrow-Pratt (1964) formula for approximately deriving the maximum WTP for certainty. In return, the fact that, for individual consumers, the values of ρ_I, ρ_J, L_I and L_J are estimates and hence subject to uncertainty can be accounted for.

5.1. Combining the Risk Premia for Low-Probability and High-Probability Insurance

In this section, $\pi_{I,k}$ and $\pi_{J,k}$ denote the risk premium for low-probability–high-loss insurance and for high-probability–low-consequence insurance, respectively. From Equations (3) and (6), one has

$$\begin{aligned} EPV_I(Benefits) - & \; PV_I(Premia) + EPV_J(Benefits) - PV_J(Premia) \\ & = \frac{\rho_I I}{(1+r)^{1/\rho_I}} - P_I\left(\frac{1}{r} - \frac{1}{r(1+r)^3}\right) + \pi_{k,I}\left(\frac{1}{r} - \frac{1}{r(1+r)^3}\right) \\ & + \left(\frac{1}{1+r/2} - \frac{1}{1+r}\right)2(L_J - 150) + 2\pi_{k,J}(L_J - 150)\left(1 + \frac{1}{1+r/2}\right) > 0 \end{aligned} \tag{14}$$

almost certainly. The sum of the first three terms was found to be positive for $r = 0.20$, $1/\rho_I = 20$, and $n = 4$ provided $\pi_{k,I}$ is at least 10% of the premium P_I in Section 3.1, while the two last terms are positive for all values of r and $\pi_{k,J}$.

5.2. WTP for Certainty for Low-Probability and High-Probability Insurance Combined

In view of the findings of Stapleton and Zeng (2018), the maximum WTP value is derived using the Arrow-Pratt (1964) approximation, which does not depend on the higher-order moments of the wealth distribution. The WTP for certainty is given by $(1/2)Var(W)R_A$, where $Var(W)$ denotes the variance of the wealth distribution (which amounts to the variance of the loss if wealth is not subject to a background risk) and R_A, the coefficient of absolute risk aversion. However, estimates of R_A are few and far between. An early contribution by Friedman (1974) obtains $R_A = 3 \cdot 10^{-3}$ in the context of choices of health insurance policies (another high-probability type) in the United States. Using a negative exponential utility function (which makes R_A independent of wealth), Aditto (2011) comes up with values between $1.44 \cdot 10^{-5}$ and $1.35 \cdot 10^{-4}$ among farmers in Thailand. This means that estimates of R_A may diverge by as much as a factor of $2.1 \cdot 10^2 = 210$.

To avoid this problem, one may resort to the coefficient of relative risk aversion $R_R := W \cdot R_A$, with W denoting wealth, whose estimates differ much less. This is the appropriate risk measure (abstracting from higher-order measures such as prudence and temperance) if losses vary in proportion with wealth, which is the case for both the low-probability perils typical of catastrophe insurance and the high-probability ones typical of cell phone insurance, which both increase with income and wealth (Moscone and Tosetti 2010). From R_R, $R_A = R_R/W$ can be determined.

Meyer and Meyer (2005) note that a good deal of the divergence in estimates of R_R stems from different definitions of wealth (consumption, respectively) at risk. Using the estimates by Friend and Blume (1975) as their benchmark, they distinguish three types of wealth: (1) assets that are easily reallocated, (2) assets including housing, and (3) assets including housing as well as human capital. In the present context, category (2) is appropriate for the low-probability risk I and category (3) for the high-probability risk J (which is defined as healthcare expenditure here). After a series of adjustments, Meyer and Meyer (2005), Table 1 arrive at $R_R = 2.25$ for category (2) and $R_R = 2.82$ for category (3) in the USD 200,000-to-500,000 wealth bracket which is relevant in this context (see below). For simplicity, a common value $R_R = 2.5$ is used. As to wealth W, the mean value of real estate property in Florida's coastal communities was USD 340,000 as of 2021, while median non-housing wealth was USD 416,000 in 2020 (Hays and Sullivan 2022).[9]

For calculating $Var(\rho_I L_I) + Var(\rho_J L_J)$ (with the two risks uncorrelated and the deductibles imposed on both types of insurance for simplicity), one needs to have the variance of a product because consumers know ρ_I, ρ_J, L_I and L_J only approximately. This variance is given by

$$\begin{aligned} Var(\rho_I L_I) + Var(\rho_J L_J) & = \{Var(\rho_I) - E^2(\rho_I)\}\{Var(L_I) - E^2(L_I)\} - \{E(\rho_I)E(L_I)\}^2 \\ & + \{Var(\rho_J) - E^2(\rho_J)\}\{Var(L_J) - E^2(L_J)\} - \{E(\rho_J)E(L_J)\}^2 \end{aligned} \tag{15}$$

Table 1. Possible explanations for the catastrophe insurance puzzle discussed in the literature [1].

Study	*Possible Explanations*
(Slovic et al. 1977)	– experimental evidence: people refuse to protect against rare losses with probability below a threshold – convex utility function for losses
(Kunreuther and Slovic 1978)	– consumer disinterest – insurance as investment (only mentioned)
(Kunreuther 1984)	– insurers may not market catastrophe insurance as there may not be enough reinsurance capacity to absorb the probable maximum loss
(Theil 2000)	– insurance decisions in previous experiments may have been affected by the specific format of probabilities, losses, and premiums
(Kunreuther et al. 2001)	– individuals may fail to distinguish between low-probability and zero-probability events
(Kunreuther and Pauly 2004)	– individuals have difficulty processing small probabilities – salience bias
(Akter et al. 2008)	– limited financial resources
(Antwi-Boasiako 2014)	– adverse selection and moral hazard
(Pothon et al. 2019)	– catastrophe premium may be unaffordable for most people
(Lin 2020)	– adverse selection

[1] We would like to thank an anonymous referee for suggesting this table.

The value of Equation (15) is calculated on the basis of the following considerations.

(1) For the first component of the I variance term, the value of $1/\rho_I = 20$ was used for the low-probability event in Section 3.2, implying $\rho_I = 0.05$. For a binary random variable, one has $Var(\rho_I) = \rho_I(1-\rho_I) = 0.05 \cdot 0.95 = 0.0475$. Therefore, with $E^2(\rho_I) = 0.05^2 = 0.0025$, the bracket amounts to 0.045.
On the basis of the losses caused by ten major hurricanes[10] and assuming equal probabilities of their occurrence, one obtains $Var(L_I) = 449 \cdot 10^6$ and $E^2(L_I) = 1240^2 = 1.54 \cdot 10^6$, resulting in a value of $447.46 \cdot 10^6$ for the second bracket. After multiplication by 0.045, one obtains $20.14 \cdot 10^6$ for the product. After deduction of

(2) $\{E(\rho_I)E(L_I)\} = (0.05 \cdot 1240)^2 = 2460$, the I component of Equation (15) amounts to $20.14 \cdot 10^6$.

(3) For the high-probability J risk associated with the cell phone, $1/\rho_J = 5$ as stated in Section 3.2. Therefore, $Var(\rho_J) = \rho_J(1-\rho_J) = 0.2 \cdot 0.98 = 0.196$ and $E^2(\rho_J) = 0.2^2 = 0.04$, so the first bracket equals 0.192. For the second bracket, the average sales price of a cell phone in 2023 was USD 790.[11] On the basis of the 18 quotes listed there, the variance is $Var(L_J) = 116,843$; therefore, the value of the second bracket amounts to $116,843 - (0.2 \cdot 970)^2 = 37,636$, resulting in $0.196 \cdot 37,636 = 7377$ for the product. After deduction of $\{E(\rho_J)E(L_J)\} = (0.2 \cdot 0.2 \cdot 970)^2 = 1505$, one obtains 5872 for the J component of Equation (9). In all, $Var(\rho_I L_I) + Var(\rho_J L_J)$ amounts to $20.14 \cdot 10^6 + 5872 = 20.146 \cdot 10^6$. Multiplied by ½ and $R_R = 2.5$ and divided by $W = 416{,}000$, the maximum WTP for certainty is an estimated $0.0605 \cdot 10^3 =$ US\$ 60.5 p.a.

Conclusion 4: From a risk-averse individual's perspective, the combination of a low-probability–high-consequence and a high-probability–low-consequence insurance contract constitutes a good investment as indicated by the combined risk premium. Application of the Arrow-Pratt (1964) formula to the sum of the variances of catastrophe and cell phone insurance results in an estimated maximum willingness-to-pay of USD 60 p.a. as of 2020.

Therefore, the starting point of this analysis can be confirmed: the intuition that combining coverage of a low-probability–high-consequence with a high-probability–low-consequence event may be a worthwhile investment for a risk-averse decision maker and may therefore alleviate the catastrophe insurance puzzle.

6. Concluding Remarks

The consistent missing demand for catastrophe insurance and other low-probability–high-consequence risks is often referred to as the catastrophe insurance puzzle (CIP). People show reluctance to insure low-probability events, and this behavior is particularly pronounced for some disasters. Individuals rather prefer to insure against high-probability–low-consequence events.

According to Kunreuther and Slovic (1978), one driver of this behavior could be that people think of insurance as an investment. Interestingly, this early explanation from 1978 has never been studied in detail or even been evaluated more carefully in the literature. It was the research question of this article. Using a simple annuity model with fixed annual premiums and expected indemnity payouts, it turns out that even an individual characterized by a degree of risk aversion found in the literature is unlikely to purchase insurance covering a low-probability–high-consequence event. However, combining a low-probability with a high-probability loss event insurance contract may be a way to incentivize individuals to purchase catastrophe risk coverage, alleviating the catastrophe insurance puzzle.

Indeed, insuring against hazards which do not occur in most cases might be a bad investment most of the time. In this paper, this intuition is shown to be correct using a simple model of corporate investment in the absence of risk aversion for both low-probability–high-consequence and high-probability–low-consequence insurance, as well as their combination (Conclusion 1). Only for risk-averse individuals with a high subjective rate of discount is the benefit of certainty sufficiently moved towards the present to make coverage of a low-probability–high-consequence and high-probability–low-consequence event a good investment (Conclusion 2). In contrast, using cell phone insurance as an example, coverage of a high-probability–low-consequence event constitutes a good investment regardless of the degree of risk aversion, given fair premiums (which fully account for the rather high deductibles) (Conclusion 3). These findings go a long way towards explaining the CIP. Finally, demand for low-probability–high-consequence insurance can be enhanced by combining its coverage with coverage of a high-probability–low-consequence event in one policy. Indeed, the (problematic) summation of the risk premia as indicators of willingness-to-pay suggest this constitutes a good investment. When the Arrow-Pratt (1964) formula for deriving maximum willingness-to-pay for certainty is applied to the variances of the product of probability of loss and amount of loss, one arrives at a clearly positive value in the case of catastrophe and cell phone insurance (Conclusion 4).

To alleviate this unfavorable insurance purchase syndrome, combining a low-probability with a high-probability loss insurance contract may be a way to incentivize individuals to purchase catastrophe risk coverage. Depending on the country, such bundling of two very different risks within one single policy might, however, not always be possible due to regulation regarding multi-peril insurance contracts. Furthermore, as outlined by Kunreuther and Michel-Kerjan (2013), it seems worthwhile to evaluate catastrophe risk management strategies involving private–public partnerships to help overcome the lacking demand for low-probability–high-consequence insurance. These partnerships may include multi-year insurance contracts using risk-based premiums coupled with mitigation loans, or vouchers to address affordability for low-income homeowners, tax incentives, improved building codes, and other regulations.

There are a number of limitations to this analysis. First, corporate insurance is typically purchased by managers who may act in their own interest, reflecting risk aversion very similar to the demand for insurance by individuals. Second, the fact that catastrophe insurance imposes deductibles has been neglected throughout on the grounds that they are much smaller relative to the amount of loss than those characteristic of low-consequence (cell phone) insurance. Next, the assumption of fair prices can be justified only in view of its simplifying the analysis, because loadings tend to be substantial, especially in catastrophe insurance, where losses need to be verified by specialists (this may be changing due to the spread of index insurance and artificial intelligence). Finally, the analysis in this paper uses a constant discount rate; however, behavioral economics and neuroeconomics research have shown deviations from this assumption in favor of what is referred to as hyperbolic discounting. Under this assumption, individuals discount the value of a later payment by a factor increasing in the length of the delay. Under this more realistic depiction of human behavior when discounting the future, the results of this article would be even stronger.

Still, two findings prove to be robust: taking an investment approach regarding the purchase of insurance can explain the catastrophe insurance puzzle, and combining a low-probability with a high-probability insurance contract may well overcome the lacking demand for low-probability–high-consequence insurance indicated by this puzzle.

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Notes

1 Interestingly, the terms and conditions included a clause stating that there is no payment in the case of no disaster.

2 For instance, a purchaser of insurance may feel some regret when the covered loss does not occur even after years of having paid the annual premium. Whether this constitutes a behavioral bias is unclear because it can be derived from rational behavior reflecting a consistent preference structure Eeckhoudt et al. (2018).

3 See, for instance, Kunreuther et al. (2001). This argument seems in conflict with Prospect Theory which predicts that very small probabilities are *overestimated* rather than ignored Kahneman and Tversky (1979, 1992). Yet, overestimation does not necessarily entail preventive action (such as buying insurance coverage) if the estimated probability of occurrence is still very low.

4 See Kanhaiya et al. (2022).

5 Assume a coin to land head (=a loss) with probability ρ and tail (=no loss) with $(1-\rho)$. What is E_m, the expected number of tosses until the first head appears? With probability ρ, $m = 1$ and with $(1-\rho)$, one obtains tail, and a new independent toss is made. Thus, $E_m = \rho + (1-\rho)(1+E_m)$ which can be solved for $E_m = 1/\rho$.

6 See note 5.

7 See note 5.

8 See, for instance, DataIntelo (2019).

9 See, for instance, https://www.redfin.com/state/Florida/housing-market, last accessed 1 December 2023.

10 See, for instance, Insurance Information Institute (2023).

11 See note 5.

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