6. Risk Preferences and Natural Disasters: A Review of Theoretical and Empirical Themes

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1. INTRODUCTION

Experiences around the globe in the recent past have served as devastating reminders of the role that natural disasters play in shaping human existence. In 2020, overall global losses resulting from natural catastrophes totalled $210 billion across 980 different events, a notable increase from the $170 billion incurred across 860 events in 2019 (losses in 2020 USDs). The top five events based on insured losses in 2020 all occurred in the United States, where there were 22 weather and climate disasters that each resulted in at least $1 billion of losses, leading to roughly $95 billion in total damages across the 22 events. That said, the year's costliest natural disaster was severe flooding in China during the summer monsoon rains, which led to damages of $17 billion. In addition to the financial damages incurred, the catastrophic events of 2019 and 2020 led to a combined total of 17,635 fatalities. Not all regions of the world experienced catastrophic natural disasters in 2020, yet no continent has been immune from experiencing earthquakes, drought, flooding, heat waves, severe weather, tornadoes, tropical cyclones, tsunamis, or wildfires in the first two decades of the new millennium.[1]

Understanding decision-making under uncertainty is critical as societies around the world attempt to strike the right balance with policies and market behavior that lead to investments in capital with different exposure to the risk of natural disasters. Given the well-known risks of such catastrophic events in particular locations around the globe, it might appear surprising that individuals, corporations, and government agencies choose to invest in locations at risk of experiencing such disasters when safer alternatives exist. This empirical fact raises several questions about how individuals make decisions to manage these risks, including their decisions surrounding housing location, insurance coverage, and adaptation, which we will explore in some detail in this chapter.

Economists are generally comfortable assuming that individual choices are made to maximize the expected utility of the potential outcomes. For this assumption to hold in the context of natural disasters, individuals must have access to information about the risks and potential damages from different disaster events, this information must be sufficiently salient, subjective beliefs about risk exposure must be correlated with actual exposure levels, and this risk-exposure information must enter the decision-making process.

One implication of the preceding assumptions and underlying conditions is that market prices should convey information about disaster risk to rational and attentive agents. Then, we should expect that the value of land (and other related market products such as insurance coverage) in a given period should already reflect the risk of damages from natural disasters facing the land. While empirical support for this theory exists in the market for agricultural land in the United States (see, e.g., Mendelsohn et al., 1994, and Severen et al., 2018), data in other markets is less supportive of the idea that all of these conditions hold in practice, making a thorough understanding of the relation between risk preferences and preparation for/reactions to natural disasters critical to minimize the social costs associated with such events.

In this chapter, we first present a brief overview of the foundational theory on risk preferences and empirical approaches to elicit risk preferences from individuals. We then turn to three key decisions surrounding natural disaster risk management: insurance, location choice, and adaptation. We review the current state of each general literature with regard to natural disasters, present stylized models of optimal decision-making to highlight the relevance of risk preferences in each context, and lastly review the state of the empirical risk-preferences literature in each realm. We also note key research gaps and frontiers for future work. We conclude with final thoughts and implications for policy.

2. ECONOMIC THEORY OF RISK PREFERENCES

Economics is rooted in the philosophy of utilitarianism and generally asserts that individuals make consumption decisions to maximize their utility subject to the bundle of goods they are able to afford. Therefore, consumption is determined by individual preferences and wealth. Under the assumption that wealth is exhausted in pursuit of consumption (where savings can be thought of as consumption in future periods), an individual's utility as a function of wealth in period t is often written as follows:

$$U = U(W_t) \qquad (6.1)$$

It is frequently assumed that utility increases with consumption of a good, although the rate of increase decreases with additional consumption, namely the utility from consuming the first unit of the good exceeds the marginal utility of the second unit of consumption. This assumption can be carried through to the shape of the utility function with regard to wealth so that ($U(W)' > 0$, $U''(W) < 0$), implying that the utility function is concave in wealth, which has direct ramifications for how economists think about attitudes toward risk.

The following subsections will present the dominant model of behavior under risk, expected utility theory, and, briefly, prospect theory, an alternative to expected utility theory. After these alternative models of decision-making are presented, this section will conclude with a brief discussion of a fundamental, though increasingly questioned, assumption about the stability of preferences as well as an overview of empirical methods to elicit risk preferences in the real world.

2.1 Expected Utility Theory

Expected utility theory posits that even though individuals may claim to be motivated by the pursuit of wealth, in reality, utility derives from what the wealth is used to purchase. So, when a lottery is presented, individuals will not evaluate the lottery based solely on the dollar prize being offered but also on how much they personally value the prize. This fact suggests that expected utility, rather than the expected value of the lottery, will determine how an individual values a lottery, based on her attitude toward risk.

Figure 6.1 depicts how an individual's utility varies with wealth when facing a lottery that provides an equal chance of winning one of two cash prizes ($c_1 < c_2$). The figure illustrates several key values that are important to consider as an individual evaluates her willingness to pay to participate in the lottery.

The value $E[c]$ on the x-axis depicts the expected value of the lottery, where $E[c] = 1/2c_1 + 1/2c_2$. $E[c]$ would be the maximum amount that an individual would be willing to pay for the chance to play the lottery, if she were risk neutral, meaning that she cared only about the expected monetary payoff associated with the lottery and derived no utility or disutility from the risk in the lottery.

<Figure 6.1>

Note: Figure 6.1 depicts an individual's utility (y-axis) given different wealth levels (x-axis). The individual is risk averse because the utility function is concave: the individual would prefer a known payout relative to a lottery with equal expected payout that would pay out either a higher or lower value with equal probability.

Figure 6.1 Risk Aversion

The y-axis measures the utility associated with different wealth levels. As the individual considers her willingness to pay to participate in the lottery, expected utility theory assumes that she will make her decision based on the lottery's expected utility ($E[U(c)]$), which is simply the expected value of the utilities associated with the two possible lottery outcomes:

$$E[U(c)] = \frac{1}{2}U(c_1) + \frac{1}{2}U(c_2) .$$

The concave shape of the utility function in Figure 6.1 leads to the result that $U(E[c]) > E[U(c)]$. In words, this equation states that the utility of having the wealth level of $E[c]$ with certainty is greater than the expected utility associated with the lottery that pays off c_1 and c_2 with equal probability. This result follows from Jensen's inequality.

The preceding result illustrates that an individual with a concave utility function would not be willing to pay any more than the value leading to the utility level given by $U(E[c])$. This value is given by $U^{-1}(E[U(c)])$, and this amount is referred to as the certainty equivalent associated with the lottery, as it represents the guaranteed amount of money that would make the individual just as well off as she would be if she were to participate in the lottery. And we see that for risk-averse individuals who have concave utility functions, the certainty equivalent is less than the expected prize from the lottery.

For an individual with a linear utility function, the certainty equivalent would equal the expected prize from the lottery ($U^{-1}(E[U(c)]) = E[c]$). These types of individuals are known as *risk neutral*. For individuals with convex utility functions, the certainty equivalent is greater than the expected prize from the lottery ($U^{-1}(E[U(c)]) < E[c]$), as the risk of the gamble generates utility for these individuals, who are known as *risk loving*.

Two important quantities related to the certainty equivalent have to do with the risk premium associated with a particular lottery. The absolute risk premium, π_A, represents the difference between the expected value of the lottery and the certainty equivalent: $\pi_A = E[c] - U^{-1}(E[U(c)])$. The relative risk premium, π_R, depicts the size of the absolute risk premium relative to the expected value of the lottery: $\pi_R = \frac{\pi_A}{E[c]} = \frac{E[c] - U^{-1}(E[U(c)])}{E[c]} = 1 - \frac{U^{-1}(E[U(c)]}{E[c]}$. These two measures of risk premia in turn can be expressed as functions of absolute risk aversion, $A(c) = \frac{-U''(c)}{U'(c)}$, or relative risk aversion, $R(c) = \frac{-U''(c)\dot{c}}{U'(c)}$, respectively (Pratt, 1964; Arrow, 1965). U''(c) represents the concavity of the utility function, while $U'(c)$ represents its slope.

These measures of risk aversion can be incorporated into utility functions to describe individual attitudes toward risk. Common specifications of utility function that capture risk aversion are the constant absolute risk-aversion (CARA) utility and constant relative risk-aversion (CRRA) utility. CARA utility is given by $U(x) = \frac{1-e^{-ax}}{a}$ for $a \neq 0$, where a is the coefficient of absolute risk aversion $(a = \frac{-U''(x)}{U'(x)})$. If $a = 0$, then $U(x) = x$ to capture risk neutrality. The CRRA utility is given by $U_{(x)} = \frac{x^{1-\gamma} - 1}{1-\gamma}$ for $\gamma \neq 1$, where γ is called the coefficient of CRRA. If $\gamma = 0$, then $U(x) = x - 1$ to capture risk neutrality (Kreps, 1990).

Expected utility theory is broadly embraced and applied in economics, although the axioms upon which the theory is built have been challenged given observed behavior, notably in experimental settings. A classic example challenging the independence axiom of expected utility theory comes from Allais (1953). The independence axiom (Samuelson, 1952) states that if the lottery P' is preferred to the lottery P, then the mixture $\alpha P' + (1 - \alpha)P''$ will be preferred to the mixture $\alpha P + (1 - \alpha)P''$ $\forall$ $\alpha > 0$ and P''.

The Allais paradox arises from a scenario in which a person chooses between lotteries a_1 and a_2 and between lotteries a_3 and a_4, where a_1, a_2, a_3, and a_4 are as follows: a_1, 100% chance of \$1,00,000; a_2, 10% chance of \$5,000,000, 89% chance of \$1,000,000, and 1% chance of \$0; a_3, 10% chance of \$5,000,000, 89% chance of \$1,000,000, and 1% chance of \$0; and a_4, 11% chance of \$1,000,000, 89% chance of \$0. In this example, an agent preferring a_1 to a_2 and preferring a_4 to a_3 (or to a_1 and a_3 to a_4) exhibits behavior consistent with the agent having indifference curves that are parallel straight lines as surmised by expected utility theory (Machina, 1987).

Laboratory experiments have shown that agents commonly choose a_1 and a_3, violating the independence assumption. The paradox of these observed choices emerges when considering that the expected value of a_1 is \$1 million and the expected value of a_2 is \$1.39 million. By preferring a_1 *to* a_2, it appears that the agent is maximizing expected utility rather than expected value. If $a_1 > a_2$, then $u(1) > 0.1u(5) + 0.89u(1) + 0.01u(0)$, meaning that $0.11u(1) > 0.1u(5) + 0.1u(0)$, which then implies (as seen by adding $0.89u(0)$ to each side) that $0.11u(l) + 0.89u(0) > 0.1u(5) + 0.90u(0)$, meaning that an expected-utility maximizing agent must prefer a_4 to a_3. Given that the expected value of a_4 is higher than that of a_3, then an agent maximizing expected value should prefer a_4 to a_3, but the choice in the first lottery pair is inconsistent with the choice in the second stage (List and Haigh, 2005).

While the implications of the above example are still being explored (see, e.g., Andreoni and Sprenger, 2010; Gneezy et al., 2006), the results might suggest that individuals are not fully rational maximizers of expected utility. To more accurately depict human behavior might require modeling individuals as concerned with their own self-interest but unable to achieve the best outcome due to constraints imposed by their limitations and biases.

2.2 Prospect Theory

Prospect theory is a response to the gap between observed behavior and the predictions of expected utility theory. While there are similarities between the two approaches, the fundamental divergence is that prospect theory acknowledges limitations and biases that prevent individuals from making fully rational choices. One key difference is that prospect theory creates separate expected utility functions for gains and for losses (Kahneman and Tversky, 1979) based on a reference point. Each of these functions is motivated by loss aversion, which describes the tendency of individuals to prefer avoiding losses rather than acquiring equivalent gains, and it relates to the idea of an endowment effect, with the value of an object varying based on the framing of a transaction (Kahneman et al., 1990).

In describing how the utility function changes with gains in wealth, prospect theory assumes that the willingness to pay for access to a lottery associated with potential gains displays risk aversion, meaning that the function has a concave shape as the wealth associated with the lottery increases. Simultaneously, the willingness to accept needed to sell the lottery when facing certain losses is assumed to display risk-loving behavior, meaning that as the potential gains from the lottery increase, the utility of the lottery increases at a faster rate. The implication is that the utility effect of a loss of a particular amount of wealth is greater than that of an equivalent gain in wealth. See Figure 6.2 for a depiction of this S-shaped relationship between the utility from gains versus the disutility from losses.

Another difference between prospect theory and expected utility theory is the use of decision weights on probabilities rather than the use of probabilities of occurrence. This difference is based on the observation that people typically focus more on very rare events rather than on the common risks of everyday life. Third-generation prospect theory differs from first-generation (Kahneman and Tversky, 1979) and second-generation (Tversky and Kahneman, 1992) prospect theory by allowing for uncertain reference points and different decision weights for gains and losses that sum to one in order to account for the preference-reversal phenomenon that cannot be explained by expected utility theory (Schmidt and Hey, 2004, Schmidt et al., 2008).

<Figure 6.2>

Note: Figure 6.2 depicts an individual's utility (y-axis) given different levels of gains versus losses (x-axis). Prospect theory describes an S-shaped utility function where the absolute value of utility from a gain is less than the absolute value of utility from an equivalent loss.

Figure 6.2 Prospect Theory

2.3 Stability of Risk Preferences

In consumer choice theory, preferences are typically assumed to be stationary, so that observed differences in the choices of goods purchased over time are attributed to changes in the budget constraint. This assumption is useful in allowing economists to model causal relationships between changes in the opportunity sets available to consumers and their subsequent choices of bundles of goods via the use of comparative statics (Andersen et al., 2008). The seminal defense of this approach is offered by Stigler and Becker (1977), who argue that greater insights into the behavior responsible for changing consumption decisions over time are available via changes in the bundles of goods that are affordable (the opportunity set) than would be associated with the relaxation of the preference-stationarity assumption.

At first glance, this assumption may seem too disconnected from reality. However, the idea of preference stationarity can be relaxed by making the arguments of the utility function state contingent, meaning that choices can vary across different states of nature so long as these states are exogenous to consumer choices. This possibility can be used to explain apparent differences in risk preferences across lottery pairs, whose differences might relate to different states of nature, in a way that is consistent with expected utility theory (Andersen et al., 2008). While the early defenses of preference stability were made when data on preferences was sparse and challenging to collect, empirical work in personality psychology in subsequent years has led to a consensus on a wide range of topics, including empirical support for preference stability, as reviewed in Caplan (2003).

Still, stability of preferences, and the exogeneity of different states of nature are empirical questions (Schildberg-Hörisch, 2018), and the measurement of risk preferences, including changes in these preferences associated with natural disasters, is an active area of research. See Section 3.4 for a review of the empirical literature examining risk preference stability in the case of natural disasters. It must be noted that there are theoretical concerns about the researchers' ability to accurately capture risk attitudes in lab experiments or administrative data (Rabin and Thaler, 2001). This concern arises from the fact that the lotteries presented to elicit risk preferences typically involve payments in a relatively narrow range (possibly due to budget constraints for the researchers) over which expected utility theory would predict risk neutrality. Findings of risk aversion over this range of wealth levels would imply extreme concavity of the utility function that would lead to ludicrous outcomes. For example, a risk-averse individual who always turns down a 50–50 gamble of losing \$10 or gaining \$11 would never accept a 50–50 gamble of losing \$100 or gaining \$$Y$, no matter the value of Y (Rabin and Thaler, 2001).

2.4 Eliciting Risk Preferences

In tandem with the theoretical literature, a vibrant empirical literature aims to elicit risk preferences across a variety of settings. We provide a brief and nonexhaustive review of types of empirical methods to elicit risk preferences, including both stated and revealed preference approaches, using surveys, artifactual field experiments, and observational data.

A commonly used elicitation method is the survey, which is advantageous because it is typically less resource intensive to implement than data collection in the field and gives the researcher the ability to carefully craft the exact questions and controls needed rather than having potentially incomplete information sometimes found in observational data sets such as administrative data or proprietary data sets from the real world. Survey-based elicitation questions often contain a lottery or risky decision upon which individuals select their preferred option. Charness et al. (2013) provide a nice review of specific experimental methods in economics and psychology to elicit risk preferences, highlighting the advantages and disadvantages of a variety of methods. Dave et al. (2010) examine how the level of difficulty of the elicitation method needs to be appropriate for the level of numerical skill of the respondent. They find that simpler questions are less noisy for low-skilled respondents, and complex questions are more accurate with sufficient skill.

While advantageous in some contexts, experimental survey data is not without critics. Along with biases and errors that can manifest in surveys in general (Groves et al., 2011), risk preference elicitation can also suffer from additional concerns. A core decision researchers make early on surrounds respondents' incentives to participate. Namely, whether real money payoffs should be used for respondents. If real payoffs are not used, concerns over hypothetical bias leading to behaviors diverging from real-world decisions may occur (Harrison, 2006). Even if real money is used in the lottery setting, payoffs may be too small to be meaningful, while higher payoffs might preclude adequate sample size. Indeed, Rabin (2013) (among several papers) highlights that the scale of lottery payoffs can change the degree of risk aversion elicited, cautioning the assumption of an expected-utility theory framework. Davis and Holt (1993) offer a potential solution for researchers to use larger bets with a lower probability of winning as people may seem less risk averse if stakes are too low.

To increase the real-world relevance while still maintaining control over design, researchers have increasingly turned to artifactual field experiments—similar to conventional lab experiments except deployed in nontraditional real-world respondent pools (Harrison and List, 2004)—to elicit preferences. While often costlier to conduct than laboratory experiments, researchers are able to tap larger populations of respondents across different economic and social settings. An advantage of artifactual field experiments in contexts where the cost of living is low is that lottery payoffs are more significant, allowing for larger samples and examination of expanded theoretical perspectives (Tanaka et al., 2010). However, Harrison et al. (2020) highlight that classic survey issues of sample selection and attrition can have parallel consequences in risk preference elicitation approaches using longitudinal data. Thus, best practices for fieldwork must still be utilized (Harrison and List, 2004), including ethical considerations (Desposato, 2015).

While there are many specific protocols to elicit risk preferences in conventional and artifactual lab experiments, two main protocols used in both settings are the unitary (or single) lottery choice and the multiple price list (Charness et al., 2013; Holt and Laury, 2014). The unitary (or single) lottery choice elicits risk preferences through a single question for the respondent to answer, for example, allocation of assets across risky versus safe domains (Gneezy and Potters, 1997) or other binary gambles (Dave et al., 2010). Unitary lotteries are advantageous given their simplicity and are still able to differentiate risk preferences across individuals. In contrast, and based on seminal work by Holt and Laury (2002), multiple price list experiments have respondents choose between multiple consecutive binary outcomes where the expected payoff of one of the outcomes increases faster than the other. Risk preferences can be determined based on the point at which the respondent switches from preferring one outcome for the other (Drichoutis and Lusk, 2016). While these more complex methods of elicitation methods allow the researcher to examine more advanced risk preference questions relative to simpler methods, they demand higher sophistication from the respondent that, if not present, may lead to measurement error and limited predictive power (Charness et al., 2013). In addition, care must be taken with multiple price lists to accurately identify the utility function curvature versus nonlinear probability weighting by the respondents (Drichoutis and Lusk, 2016). Overall, there is no superior method, and the appropriate elicitation method depends on the context and researcher objectives (Charness et al., 2013).

Lastly, researchers also turn to revealed preference evidence using observational data, with the advantage that these decisions represent real-world choices with meaningful consequences. However, since researchers often use already existing behavioral data, a potential limitation is the reduction in researcher ability to control the setting or collect all relevant control variables. The latter is particularly important, as risk preferences have been found to correlate with a variety of other factors (Dohmen et al., 2010). Nonetheless, researchers have long utilized this data to examine decisions surrounding risk in many real-world contexts, including insurance and investment decisions (e.g., Einav et al., 2012; Szpiro, 1986).

3. THEMES IN RISK PREFERENCES AND NATURAL DISASTERS

Having reviewed foundational concepts and definitions in risk preference theory as well as briefly overviewed empirical methods to assess risk preferences, we now apply these concepts to the case of natural disasters. In particular, we examine the cases of insurance, location choice, and adaptation. We first briefly review frontiers that are not based on risk preferences in each case. We then present a simple theoretical model for each case to highlight the contribution of a risk preferences lens. We then review the empirical risk preferences literature in each case as well as highlight key research gaps and opportunities. Lastly, we examine the empirical evidence surrounding the stability of risk preferences in the context of natural disasters. Altogether, this section motivates and examines key research themes and opportunities relating to risk preferences and natural disasters.

3.1 Insurance

In theory, insurance could play a prominent role in mitigating the economic damages caused by natural disasters, either through the simple reimbursement of claims in the wake of catastrophic events or through increased costs of building or purchasing property in areas at risk of disaster events. In practice, some features of insurance markets might impede insurance policies from conveying the true risk of disaster events to policyholders.

The total economic damages from natural disaster events have been shown to be drawn from a fat-tailed distribution (see, e.g., Conte and Kelly, 2018, regarding tropical cyclone damages). Without going into too much detail, the probability of extreme events in a fat-tailed distribution decays at a much slower rate than in a normal distribution. One implication of this result is that extreme events (e.g., storms that occur once in 200 years) are much more likely in a fat-tailed distribution than in a thin-tailed distribution, like the normal. Another challenging implication is that it is difficult to learn about the potential impacts of extreme events in a fat-tailed distribution, as the damages associated with a 1% tail event might be orders of magnitude less than the damages associated with a 0.5% tail event. See Conte and Kelly (2021) for more details about fat tails and natural disasters.

These features of damages from natural disasters mean that firms offering disaster insurance are forced to hold costly financial reserves in order to maintain solvency in the wake of catastrophic events. As a result of these costly reserves, insurers will not be able to provide coverage at actuarially fair prices (see Section 3.1.1 for a definition of actuarially fair insurance). A direct implication of this fact is that risk-averse homeowners will not fully insure. An additional implication arises when we consider the salience of risk posed by natural disasters in practice.

Because natural disasters are relatively rare events, it is quite possible that the risk of catastrophic disasters may not be salient to economic agents, although the intensity of natural disasters appears to be increasing with climate change (Coronese et al., 2019). Evidence to support this possibility comes from flooding risk and unexpectedly low participation levels among eligible properties in the National Flood Insurance Program (NFIP) in the United States (Kriesel and Landry, 2004; Petrolia et al., 2013). While it has been shown that policy uptake increases in the immediate wake of flood events (Gallagher, 2014), much of this increase has been shown to be due to regulatory requirements for disaster aid eligibility (Kousky, 2017), which might be taken as further evidence that this source of risk is not driving the decision-making process for homeowners.

Insurance policies that reflect the true risk of damages could serve to increase the salience of disaster risk and potentially reduce the damages caused by disaster by promoting adaptations to such risk or by affecting the location choice of homeowners and firms. As mentioned previously, the fat-tailed nature of disaster damages makes this possibility less likely. Further limiting the potential role of insurance in motivating more efficient responses to disaster risk is the political economy of the situation that finds many politicians and regulators interested in maintaining robust property values in at-risk areas (e.g., coastal zones), meaning that they might apply pressure to keep insurance rates low. The fact that the state-run insurance firm increased insurance rates across the state of Florida in response to the 2004 hurricanes, while private insurers tended to only increase rates in those counties with the greatest claims, might be taken as evidence of this political-economy mechanism (Conte and Kelly, 2020).

3.1.1 Model of Insurance Demand

As mentioned in previous sections, natural disasters place people at risk of potentially catastrophic damages in many locations around the globe. And yet, many people live in places that are at disproportionately higher risk of being impacted by natural disasters (e.g., coastal Florida). Embracing the assumption that economic agents are fully rational actors, this fact suggests that the amenities associated with living in these locations must be greater than the costs, including those associated with the risk of natural disasters.

The results described in the preceding section suggest that perhaps economic agents are not capable of fully rational decision-making or that the information necessary to make such decisions is not always available (or seems too costly to obtain). The latter possibility is particularly worthy of consideration given the previous discussions of when and how property value and the price of disaster insurance fail to provide adequate signals of the risk of damages due to natural disasters. Interestingly, as noted earlier, the literature exploring this topic, a fundamental example of decision-making under uncertainty, has generally proceeded under the assumption that households are risk neutral.

To highlight the importance of accounting for risk preferences when attempting to explain behavior in markets related to natural disaster impacts (e.g., housing, insurance), we will now present simple models of decision-making under uncertainty. The models in this section will also allow us to briefly comment on the importance of insurance pricing in providing accurate risk information under real-world conditions.

We begin with a canonical example of decision-making under uncertainty: demand for insurance (see, e.g., Deaton and Muellbauer, 1980; Kreps, 1990). Let an agent with wealth W face a financial loss L with probability p. The agent can protect himself against this loss through the purchase of insurance, with a policy that will provide payment in the event that a loss occurs. Let a policy associated with a payment of X dollars in the event of a loss cost qX dollars. The optimal amount of insurance for this agent can be determined by viewing this as an optimization problem under uncertainty, where the agent must choose how much coverage to purchase to maximize expected utility, as given by the following:

$$\max_X pu(W - qX - L + X) + (1 - p)u(W - qX) \qquad (6.2)$$

If we allow $U(X)$ to represent the agent's objective function, then the first-order condition is

$$\frac{dU}{dX} = p(1-q)u'(W - qX - L + X) - (1-p)qu'(W - qX) = 0 \qquad (6.3)$$

This condition is necessary and sufficient for an interior solution if the utility function u is concave. Rearranged, the condition reveals that the marginal benefit of an extra dollar of insurance in the loss state multiplied by the probability of loss is equal to the marginal cost of the extra dollar of insurance in the no loss state.

Actuarially fair insurance provides coverage at a price such that the expected payout for the insurer just equals the cost of insurance, that is, $p = q$. Under this condition, the first-order condition simplifies to

$$u'(W - qX - L + X) = u'(W - qX) \qquad (6.4)$$

The agent will set $X = L$, fully insuring against the loss.

A concave utility function corresponds to an agent who is risk averse, so (6.4) reveals the well-known result that risk-averse agents will fully insure when offered actuarially fair insurance. This result is potentially quite significant because for insurance to play a role in providing signals about risk from natural disasters that might be more salient than previous experience, households must purchase insurance.

Of course, it is also well known that risk-neutral agents will be indifferent between insurance purchase and no insurance when insurance is actuarially fair. The prevalence of different attitudes toward risk in communities threatened by damages from natural disasters will impact the ability of insurance to increase the salience of these intermittent events whose damages may be drawn from fat-tailed distributions, making it even more difficult to learn about extreme events.

Even among risk-averse agents, demand for insurance falls when prices are no longer actuarially fair (namely $q > p$). To see this, recall that for interior solutions, the optimal level of coverage X satisfies the first-order condition:

$$\frac{u'(W - qX - L + X)}{u'(W - qX)} = \frac{(1-p)q}{p(1-q)} > 1 \qquad (6.5)$$

And we see that even a risk-averse agent will not fully insure ($X^* < L$) under these conditions. Given the costly transfer of wealth to the loss state, the agent prefers to live with less wealth there and more wealth in the no loss state. Insurance priced above actuarially fair levels is likely to occur for several reasons, including the need for insurers to hold costly reserves to cover claims in the wake of tail events. On the other hand, there are also many conditions under which the price of insurance will understate the true risk facing the agent.

For example, NFIP prices have long been criticized for being discounted for some policies, and plans by the Federal Emergency Management Agency (FEMA) to raise rates recently have come under fire from politicians because they do not want to harm their constituents in the short term, which aligns with election cycles. The impact of offering coverage at artificially low prices on policy uptake depends on the risk preferences of the agent. Specifically, the results depend on whether the individual has increasing or decreasing absolute risk aversion.

Absolute risk aversion is a measure of the local curvature of the utility function, as defined in Section 2.1. Specifically, for a twice-differentiable utility function $u()$, the Arrow-Pratt coefficient of absolute risk aversion is given by the following:

$$A(x) = \frac{-u''(x)}{u'(x)} \qquad (6.6)$$

A key concern is how an individual's risk aversion varies with her wealth level. The utility function $u()$ is said to have decreasing (constant, increasing) absolute risk aversion if $A(x)$ is a decreasing (constant, increasing) function of x. The implications of decreasing absolute risk aversion (DARA) are that an individual's tolerance for risk is increasing in her wealth levels. In the case of demand for insurance, we would expect that an individual with DARA preferences would prefer to purchase less insurance as her wealth increases. To see this, we turn to comparative statics, noting the following:

$$\frac{d^2U}{dXdW} = p(1-q)u''(W-qX-L+X) - (1-p)qu''(W-qX) \qquad (6.7)$$

While the sign of the preceding expression is indeterminate, we can use the first-order condition for an optimal amount of coverage to help illustrate that it must be the case that if $\frac{d^2U}{dXdW} > 0$ for $X^*(W)$, then, if $W' > W$, it must be that $X^*(W') > X^*(W)$. To see this, note that when $X = X^*(W)$,

$$(1-p)q = \frac{p(1-q)u'(W-qX-L+X)}{u'(W-qX)}. \qquad (6.8)$$

Then,

$$\frac{d^2U}{dXdW}\Big|_{X=X^*(W)} = p(1-q)u'(W-qX-L+X)\left(\frac{u''(W-qX-L+X)}{u'(W-qX-L+X)} = \frac{u''(W-qX)}{u'(W-qX}\right). \qquad (6.9)$$

And, we see that

$$\frac{d^2U}{dXdW}\Big|_{X=X^*(W)} \overset{sign}{=} [A(W-qX) - A(W-qX-L+X)]. \qquad (6.10)$$

The final expression allows us to explore how coverage varies with wealth, and we see that when $p = q$, $X = L$ $\forall W$, so the choice of coverage is independent of wealth. When $p < q$, we know that $X < L$, and we see that the purchase of coverage decreases with more wealth for individuals with DARA preferences and that the coverage purchased increases with additional wealth for individuals with increasing absolute risk averse (IARA) preferences, while remaining unchanged for those with CARA preferences.

Having considered how the demand for insurance varies with regard to wealth based on different risk preferences, we now consider how the optimal amount of coverage varies in response to the price of coverage, q. To do so, we will adopt the same approach that we used to explore how demand for coverage varied with wealth.

We begin by differentiating the first-order condition for the optimal level of coverage, evaluated at the optimal level of coverage, X^*, with respect to q:

$$\frac{d^2U}{dXdq} = (-p)u'(W-qX-L+X) + P(1-q)(-X)u''(W-qX-L+X) - [(1-p)u'(W-qX) - (1-p)q(-X)u''(W-qX)]$$

(6.11)

Noting that $\frac{d^2U}{dXdW} = p(1-q)u''(W - qX - L + X) - (1-p)qu''(W - qX)$, we can rearrange (6.11) to yield the following:

$$-[pu'(W - qX - L + X) + (1-p)u'(W - qW)] - \frac{d^2U}{dXdW} \qquad (6.12)$$

The bracketed term in (6.12) represents the substitution effect associated with an increase in q. The effect on coverage demanded is negative due to the increase in the price of insurance. With insurance now relatively more expensive, an individual can be made better off by reducing the amount of coverage purchased in order to buy other goods. The second term in (6.12) represents the income effect of the increase in q, as a higher price for coverage would decrease overall wealth, ceteris paribus.

Assuming a positive level of coverage purchased, the income effect will have the opposite sign of $\frac{d^2U}{dXdW}$. Accordingly, we see that the sign of this effect will depend on an individual's attitude toward risk. For an individual with DARA preferences, the reduction in wealth due to the price increase makes the individual more risk averse, leading to a positive income effect, as the price increase results in an increased purchase of coverage. If this positive income effect is sufficiently strong to outweigh the negative substitution effect, then insurance can be considered a Giffen good.

We see that the income effect is nonpositive for individuals with IARA or CARA preferences, as the reduction in wealth associated with the increase in the price of insurance either makes the individual less risk averse (IARA preferences) or has no effect on the individual's attitude toward risk (CARA preferences). In these cases, the second term will be nonpositive, and the overall effect of the increase in the price of coverage will be to reduce the amount of coverage purchased. See Schlesinger (2013) for a more thorough treatment of this subject in the context of loading factors and varying degrees of coinsurance.

3.1.2 Empirical Evidence

In contrast to the wide and active literature on risk preference and insurance in risk settings outside of natural disasters—for example, health (Kairies-Schwarz et al., 2017), retirement savings (Einav et al., 2012), and home and auto insurance (Barseghyan et al., 2013; Cohen and

Einav, 2007)—a small but important strand of literature examines the impact of risk preferences on demand for natural disaster insurance. The main results are consistent with the hypotheses generated from our model of insurance demand presented earlier. Attanasi and Karlinger (1979) provide both theoretical and empirical evidence on disaster insurance and risk preferences using data from four towns in New Jersey. They find that as risk aversion increases, demand for insurance shifts outward and becomes more price-inelastic, implying that optimal insurance coverage increases are conditional on a given premium. In their sample, they observe average risk preferences parameters across townships consistent with CARA preferences. In addition, Petrolia et al. (2013) examine household demand for flood insurance coupled with experimental-based estimates of risk preferences across a sample of US residents across the Gulf Coast and Florida. They find that risk-averse individuals are significantly more likely to have flood insurance policies.

In an agricultural context, Jianjun et al. (2015) and Jin et al. (2016) both find that among their sample of farmers in Yongqian, China, the average farmer was risk averse, and the level of risk aversion was significantly and positively related to the purchase of weather-indexed crop insurance. Lastly, Hellerstein et al. (2013) use a sample of 68 farmers from the US Corn Belt (Indiana, Ohio, and Iowa) to examine the impact of risk preferences in farming decisions, including insurance. They find the unexpected result that risk aversion is negatively related to the likelihood that farmers have crop insurance policies. However, they explain this not as a contradiction to the theory but rather as a consequence of the lottery-choice experiment that they used to elicit risk preferences in the lab.[2] They conclude that this commonly used laboratory measure of risk preferences may not perform well as a proxy for real-world preferences. Table 6.1 displays a summary of the theoretical and empirical results surrounding the quantity of insurance purchased across moderating variables, as well as key research opportunities.

Despite the theoretical rationale, a large amount of literature examines why farmers purchase below-optimal levels of insurance, even in cases when it is priced far below the actuarially fair rates and therefore should appeal to a wide range of risk preferences. Alternative products have been developed to increase insurance take-up among farmers, including in developing country contexts. Index insurance, for example, sets payouts based on easily observable metrics (e.g., rainfall levels or average yields in a location) rather than individual-level losses. This is especially appealing to small farms as it lowers the costs in verifying claims that might make traditional insurance premiums too costly (Basis, 2021). Microinsurance is another tool offering small policies to poor households at low cost (Janzen and Carter, 2019). The literature offers a variety of plausible explanations as to why low take-up occurs, despite innovations (Carter et al., 2014). Related to risk preferences, Clarke (2016) highlights that highly risk-averse individuals may not purchase insurance contracts if the basis risk—that is, the risk that the payout index may not correlate with farm-level conditions, leading to the possibility that farmers pay for insurance and have a bad crop but receive no payout—is high. In addition, other preferences, such as for time and ambiguity, and behavioral factors can explain why expected utility theory fails to predict insurance take-up (Clarke et al., 2012). Lastly, risk preferences may not be known to the policy maker or researcher, thereby limiting evaluation of the optimal level of insurance. Even when risk preferences are elicited, difficulty in estimation may lead to measurement error that distorts third-party evaluation of the optimality of decision-making. Regardless of the insurance type, care must be taken to overcome these challenges to insurance take-up, including those driven by risk preferences.

Table 6.1 Summary of Theoretical and Empirical Insurance Results

Variable	**Theoretical Direction**	**Empirical Direction**
Risk Aversion	+	+
Wealth, DARA preferences	−	−, RO
Wealth, IARA preferences	+	+, RO
Premium Price, DARA preferences	+	+, RO
Premium Price, IARA Preferences	−	−, RO

Note: Table 6.1 displays the relationship (positive [+] or negative [-]) between each variable and the amount of insurance purchased. RO: Research opportunity given limited empirical evidence.

3.2 Location Choice

Since Tiebout (1956), researchers have been interested in how individuals sort over heterogeneous local (dis)amenities, including a growing literature on sorting and migration in response to natural disaster risk and events (Boustan et al., 2012; Hornbeck, 2012). A growing literature examines sorting over climatological natural disaster risks such as floods (Bakkensen and Ma, 2020), hurricanes (Fan and Bakkensen, 2021), sea level rise (Bakkensen and Barrage, 2022), and other types of extreme weather (Fan et al., 2018), as well as local disaster mitigation efforts (Fan and Davlasheridze, 2016). A parallel literature examines housing market impacts from disaster events.[3] Broadly, the literature finds heterogeneity in disaster risk beliefs characterized by a majority of residents underestimating the true probability of event occurrence (Bakkensen and Barrage, 2022; Bernstein et al., 2019) that leads to volatility in housing market prices following events as disaster risk salience increases (Bakkensen et al., 2019; Bin and Landry, 2013; McCoy and Walsh, 2018). A comparative dearth of empirical literature examines how risk preferences impact location choice surrounding both long-run disaster risk as well as disaster events, the latter of which can lead to risk belief updating if individuals were not perfectly attentive (Gallagher, 2014). In this subsection, we examine the theoretical rationale for why risk preferences may matter in location-choice decisions as well as review the empirical literature.

3.2.1 Location Choice as an Application of Portfolio Theory

The risk of damage from natural disasters varies across space, with certain locations being more at risk to damages from tropical cyclones (e.g., coastal properties), earthquakes (e.g., properties on fault lines), and wildfires (e.g., properties at the wildland-urban interface). In making their decision about where to purchase property, individuals have an opportunity to manage their level of risk from natural disasters. While the papers mentioned previously have presented evidence of changes in prices and beliefs in the wake of natural disasters, they have tended to do so without accounting for the impact of risk preferences on these outcomes. In this subsection, we use the framework of portfolio theory to explore how people's attitudes toward risk, in conjunction with their preferences for the amenities associated with property purchase, will affect the composition of communities in areas at risk from natural disasters. The results here are motivated by descriptions of consumer choice across financial assets with varying degrees of risk (see, e.g., Deaton and Muellbauer, 1980; Kreps, 1990).

Consider an individual facing a decision about how to allocate his wealth, W, between the purchase of property in two locations. Property purchased in the safe location provides a constant, known stream of benefits, r. Property purchased in the at-risk location offers amenities beyond those available in the safe location (e.g., coastal living, serenity in remote locations, etc.)

but also faces the risk of damages from natural disasters. Let the random variable z with CDF F reflect the stream of benefits associated with property purchased in the at-risk location.

Assume that the individual's utility is described by $U()$, an increasing and concave utility function. Given his initial wealth of W, the individual is capable of purchasing X units of property in the at-risk location and $W - X$ units of property in the safe location.[4] Then, the individual's objective function is given by

$$\max_X \int U(Xz + (W - X)r)dF(z) \quad . \qquad (6.13)$$

This objective function leads to the following first-order condition:

$$\int U'(Xz + (W - X)r)(z - r)dF(z) = 0 \qquad (6.14)$$

If we begin by considering a risk-neutral individual, meaning that $U(X) = \alpha X$ for some constant a, we see that the returns to the purchase of property are given by $\alpha[Wr + X(E[z] - r)]$. This quantity will either always be positive ($E[z] > r$) or always negative. From the perspective of a risk-neutral individual, the purchase of property is determined purely by the expected rate of return, so that he will put all of his wealth toward the purchase of property in the at-risk location (if $E[z] > r$) or in the safe location.

Now, if we assume the individual is risk averse, so that $U''() < 0$, then the first-order condition shown in (6.14) is necessary and sufficient to identify the optimal quantity of property purchased. In this case, we see that a risk-averse investor will allocate some of his wealth to the purchase of property in the at-risk location, as long as property in the at-risk location has a positive return.

Another way to think about this problem is to split the returns to property in the at-risk location into two components. The first piece is the nonmonetary amenity value of living in the at-risk location, $\phi(i)$, which we can allow to vary across individuals, indexed by i. The second piece is the potential damages caused by a natural disaster striking the property in the at-risk location, which we leave to be denoted by random variable z with CDF F. With this modification, the individual's objective function becomes

$$\max_X \int U(Xz + (W - X)r)dF(z) + v(\phi(i)X) \quad . \qquad (6.15)$$

This new objective function leads to the following first-order condition:

$$\int U'(Xz + (W - X)r)(z - r)dF(z) + v'(\phi(i)X)\phi(i) = 0 \qquad (6.16)$$

This leads to the following condition defining the optimal purchase of property in the at-risk location (assuming $X > 0$):

$$-\int U'(Xz + (W - X)r)(z - r)dF(z) = v'(\phi(i)X)\phi(i) \quad (6.17)$$

The left-hand side of (6.17) represents the marginal cost of an additional unit of property in the at-risk location. Now that we are letting z represent the damages from a natural disaster, these expected damages might be less than r. The right-hand side of (6.17) shows the increase in utility, due to increased nonmonetary amenities, associated with the purchase of an additional unit of property in the at-risk location.

Within this modified framework, we see that the purchase of property in the at-risk location is dependent on an individual's attitude toward risk, as well as his appreciation of the amenities associated with living in the at-risk location. So, for individuals who do not value these amenities (i.e., $\varphi(i) = 0$) the risk of damages from natural disasters may be sufficient to preclude any purchase of property in the at-risk location. On the other hand, individuals with very strong preferences for these amenities may decide to purchase property uniquely in the at-risk location, despite their attitude toward risk.

Having established a framework for thinking about an individual's location-choice problem, we can now turn to the question of how an individual's attitude toward risk impacts the decision about how much property in the at-risk location to purchase.

Consider individuals a and b who both face the decision about how to allocate their wealth across property in the at-risk and safe locations. Their objective functions are given by the following:

$$\max_X \int U_a(Xz + (W - X)r)dF(z) + v(\phi(i)X) \quad (6.18)$$

$$\max_X \int U_b(Xz + (W - X)r)dF(z) + v(\phi(i)X) \quad (6.19)$$

To simplify things, we assume that the two individuals have the same preferences for the nonmonetary amenities of life in the at-risk location, so we focus our attention on the first term in each objective function. Then, a sufficient condition for individual b to invest more wealth than a in property in the at-risk location is as follows:

$$\int U_a'(Xz + (W - X)r)(z - r)dF(z) = 0 \Rightarrow \int U_b'(Xz + (W - X)r)(z - r)dF(z) \geq 0 \quad (6.20)$$

This condition could follow from the concavity of U_b.

If a is more risk averse than b, then U_b can be expressed as a function of U_a and a nondecreasing convex function h (i.e., $U_b = h \circ U_a$). Then, (6.19) can be rewritten as follows:

$$\int h'(u(Xz+(W-X)r))u'(Xz+(W-X)r)(z-r)dF(z) \geq 0 \quad (6.21)$$

It turns out that (6.21) will always hold. The first term $h'()$ is positive and increasing in z. The second set of terms is negative when $z < r$ and positive when $z > r$, so multiplying the second set of terms by $h'()$ places more weight on draws for which $z > r$. The result of this fact is that the product of these two terms $h'()$ and $u'()$ will integrate to a greater amount than the value of the second term alone, or 0. So, for two individuals with the same preferences for the nonmonetary amenities of living in the at-risk location, with one individual more risk averse than the other, it turns out that the more risk-averse individual will optimally purchase less property in the at-risk location than the other individual, for any initial wealth level.

Given the preceding result, it is natural to inquire about how the amount of property purchased in the at-risk location by a risk-averse individual will change in response to an increase in wealth. To do so, we turn to the comparative statics of the first-order condition for our location-choice problem presented as an application of portfolio theory. Then, we want to know if $\frac{d^2U}{dXdW} \geq 0$. We see that

$$\frac{d^2U}{dXdW} = \int rU''(X(z-r)+Wr)(z-r)dF(z), \quad (6.22)$$

which we can rewrite as

$$\frac{d^2U}{dXdW} = \int r\frac{U''(X(z-r)+Wr)}{U'(X(z-r)+Wr)}U'(X(z-r)+Wr)(z-r)dF(z) \quad . \quad (6.23)$$

We see that, as before, the second term is negative when $z < r$ and positive when $z > r$. Now, the first term is negative. So, the preceding relation will hold when the first term is decreasing in z. This condition is the definition of DARA preferences. So, we see that the amount of property purchased in the at-risk location at higher levels of wealth will increase for individuals with DARA preferences, remain constant for individuals with CARA preferences, and fall for individuals with IARA preferences.

3.2.2 Empirical Evidence

The theoretical underpinnings of heterogeneous risk preferences and location choice are clear. Indeed, Sheldon and Zhan (2019) note (although do not empirically explore) that individuals sort based on preferences for disaster risk, leading risk-averse households to be more likely to live in safer areas. A comparatively small amount of literature explores empirical evidence of sorting over natural disaster risk based on risk preferences. However, clear evidence in related applications highlights the likelihood of this phenomena, including in the labor sector. Bellemare and Shearer (2010) find that workers in British Columbia who face more significant daily income risk in their jobs are more risk tolerant than the average population, indicative of sorting over occupational risk. Similar sorting over risk preferences in labor markets is found by Bonin et al. (2007) in the case of German occupational sectors and by DeLeire and Levy (2004) in the case of on-the-job mortality risk in the United States.

Risk preferences also matter in deciding to migrate. Jaeger et al. (2010) find a negative relationship between risk aversion and likelihood of migration in Germany. In the case of Indonesia and Ghana, Goldbach and Schlüter (2018) also find migrants are less likely to be risk averse relative to nonmigrants. Similarly, Arcand and Mbaye (2013) find that risk aversion is negatively correlated with willingness to pay for illegal migration in Senegal. However, a fruitful area of future research could expand empirical tests of these observations in a natural disaster context. Table 6.2 displays a summary of the theoretical and empirical results surrounding high-risk location-choice decisions across key moderating variables, as well as key research opportunities.

Table 6.2 Summary of Theoretical and Empirical Location Choice Results

Variable	**Theoretical Direction**	**Empirical Direction**
Risk Aversion	–	–
Wealth, DARA preferences	+	RO

Wealth, IARA preferences	−	RO

Note: Table 6.2 displays the relationship (positive [+] or negative [−]) between each variable and the amount of property in a risky location purchased. RO: Research opportunity given limited empirical evidence.

3.3 Adaptation

We lastly consider the important case of adaptation as a final lens to examine risk preferences and natural disasters. Adaptation to natural disaster is a key private mechanism and policy lever to increase resilience and decrease disaster harm. Adaptation to natural disasters can be broadly conceptualized as activities or adjustments in response to current or future disaster risks in order to reduce harm (Field et al., 2012).[5] Indeed, adaptation can take many forms across both private and public actors, including physical strengthening and public works interventions, natural capital, as well as evacuations and migration (Bakkensen and Blair, 2021).[6] The effectiveness of adaptation in reducing natural disaster losses remains an active area of research (Bakkensen and Mendelsohn, 2016); however, it is commonly found that individuals tend to be underprepared for natural disasters (Meyer and Kunreuther, 2017), leaving them more vulnerable to disaster impacts than is efficient. An active research area examines how risk preferences impact adoption of natural disaster adaptation technologies, especially in agricultural risk settings. This subsection provides a theoretical motivation as to why risk preferences might matter for adaptation decisions and follows with a review of relevant themes in the literature.

3.3.1 Model of Risk Preferences and Adaptation

We define adaptation as any activities to reduce the expected damages from a disaster, conditional on a disaster event occurring. For the purposes of this chapter, we abstract away from the decision of optimal levels of insurance versus adaptation versus location choice. Lewis and Nickerson (1989) provide a theoretical treatment of optimal adaptation (called "self-insurance") to natural disasters in the context of other factors such as the level of risk aversion, uncertainty, post-disaster aid, and individual wealth. However, the interaction between optimal adaptation, insurance, and location choice remains an open area of future research.

To explore the impact of risk aversion on adaptation decisions, assume an individual with wealth, w, is at risk of a natural disaster with probability p. She can install adaptive technology, A, at cost c per unit of A. If a disaster hits with no adaptation, it will lead to disaster losses equal to L. If adaptation is employed, it will lead to losses equal to $L - A$, where losses L are reduced from their no-adaptation baseline by magnitude A. We also assume utility is concave. Thus, if there is no adaptation, expected utility of the individual is

$$E(U \mid A=0) = (1-p)U(w) + pU(w-L) \quad (6.24)$$

If the individual has adaptation, expected utility is instead

$$E(U \mid A=1) = (1-p)U(w-cA) + pU(w-L+A-cA) \quad (6.25)$$

The individual's objective to maximize expected utility is thus

$$\max_A E(U) = (1-p)U(w-cA) + pU(w-L+A-cA) \quad (6.26)$$

The first-order condition is thus

$$-c(1-p)U'(w-cA) + (1-c)pU'(w-L+A-cA) = 0 \quad (6.27)$$

Rearranging, it appears as

$$(1-c)pU'(w-L+A-cA) = c(1-p)U'(w-cA) \quad (6.28)$$

Assuming that the individual is risk averse and that $c \leq p$, the individual will fully adapt until L=A. This ensures that her utility is constant regardless of the state of the world. Similar to the insurance case, a risk-neutral individual would be indifferent to full adaptation or no adaptation if c=p. This finding is highlighted in previous literature, including that the risk premium increases in the level of risk aversion (Pratt, 1978).[7] However, if adaptation leads to greater reductions in expected losses than its cost, then a risk-neutral or even risk-loving individual may still engage in adaptation to reduce expected losses if the technology were effective enough relative to its cost. Empirical literature has highlighted that many such adaptive technologies exist. However, while not formally derived here, the optimal level of adaptation when insurance is available is an important area of active research, including how insurance policies can incentivize adaptation if premium rates are reduced to account for lower expected losses following adaptation (Hudson et al., 2016).

Unlike insurance, adaptive technologies have some probability of failure (e.g., hurricane shutters can break, levees can be breached). In addition, some newer technologies may have greater uncertainty regarding their performance or failure rates. Assume with some probability,

π, the new adaptive technology, A_n, will fail. Expected utility in the case of no adaptation remains the same:

$$E(U \mid A_n = 0) = (1-p)U(w) + pU(w-L) \quad (6.29)$$

However, expected utility in the case of the risky adaptation is

$$E(U \mid A_n = 1) = (1-p)U(w-cA_n) + p(1-\pi)U(w-L+A_n-cA_n) + p(\pi)U(w-L-cA_n)\,. \quad (6.30)$$

The individual's objective function thus becomes

$$\max_{A_n} E(U) = (1-p)U\left(w-cA_n\right) + p\left(1-\pi\right)U\left(w-L+A_n-cA_n\right) + p\left(\pi\right)U\left(w-L-cA_n\right),$$

(6.31)

with a first-order condition of

$$(1-p)(-c)U'(w-cA_n) + p(1-\pi)(1-c)U'(w-L+A_n-cA_n) + p(\pi)(1-c)U'(w-L-cA_n) = 0\,. \quad (6.32)$$

Rearranged, this becomes

$$(1-p)(c)U'(w-cA_n) = p(1-\pi)(1-c)U'(w-L+A_n-cA_n) + p(\pi)(1-c)U'(w-L+A_n-cA_n)\,. \quad (6.33)$$

Compared with the risky technology and all else equal, all individuals would prefer the sure option regardless of risk preferences. However, new risky technologies often have a higher benefit from utilization. Thus, there would exist some minimum higher level of adaptation efficacy, $\underline{A}_n$, where $\underline{A}_n > A$, that would entice individuals to use the riskier technology. Given their risk preferences, someone with a higher degree of risk aversion would need a higher effectiveness of the technology to overcome the reduction in utility from the adaptation technology's inherent riskiness. Thus, all else equal, we can expect to see heterogeneity in utilization of a new high risk, high reward adaption technology across user risk preferences, with more risk-averse individuals holding out adoption (i.e., preferring proven but lower return technologies) unless either the benefit of the adaptation is clearly high enough or the riskiness is low enough.

3.3.2 Empirical Evidence

Relative to insurance and location choice, a comparatively large and active literature examines the impact of risk preferences on the adoption of adaptation technologies and other risk reduction strategies, especially in agricultural settings. Consistent with our simple stylized model presented previously, Bozzola (2014) finds empirical evidence in the case of Italian cereal producers that individuals with higher aversion to downside risk are more willing to adopt irrigation and other adaptive technologies to reduce profit variance and/or downside risk exposure, even if some profit is sacrificed.[8] Similarly, Asravor (2019) finds that in Northern Ghana, risk-averse farmers are significantly more likely to have greater crop diversification.

As highlighted by our theoretical model earlier, risk aversion does not always correlate with higher levels of adaptation technology adoption. Liu (2013) examines how risk preferences across cotton farmers in China impact the adoption of the newer, genetically modified Bt cotton that promised higher yields and less loss from pests. She finds that individuals with higher levels of risk or loss aversion are slower to adopt the Bt cotton, highlighting that uncertainty surrounding technological performance will encourage more risk-loving individuals to take the gamble on a newer or less-proven adaptation technology. In a follow up paper, Liu and Huang (2013) find that risk-averse farmers are more likely to use higher amounts of pesticides to reduce crop loss from pests. However, loss-averse individuals used less quantities, prioritizing losses to health from pesticides over the financial losses from the increased consequences of pests.

Connecting adaptation with insurance, as expected by theory and the previous findings, Jianjun et al. (2015) find that risk-averse Chinese farmers were less likely to adopt climate innovations, such as new technologies or crop types, and were instead significantly more likely to purchase weather index crop insurance. Using the case of South African farmers, Brick and Visser (2015) also find that risk-averse individuals are more likely to use traditional agricultural products instead of newer high-yield varieties that necessitate financing even despite insurance availability, highlighting that insurance is not necessarily a cure-all to increase technological adoption and combat poverty traps.

However, some countervailing findings exist. Ross et al. (2012) show that among rice farmers in Laos, ambiguity aversion and not risk aversion inhibits the adoption of new technologies despite the potential for higher profits, highlighting the importance of controlling for other correlated factors. Similarly, He et al. (2020) use the case of Chinese farmers and find that while risk aversion is significantly related to adaptation cognition, it does not have a significant impact on adaptive behaviors. Instead, they find loss aversion explains risk and adaptation cognition as well as adaptation. Vieider et al. (2019) explore evidence amongst Vietnamese farmers, finding that risk aversion does not necessarily reduce new technology adoption. They note that their sample is closer to risk neutral than typical Western subject pools, thus highlighting the importance of context in analyzing risk decisions. Finally, Vieider et al. (2019) also find that risk aversion does not correlate with wealth (although it does correlate with income). This is in contrast to existing literature that finds risk aversion can be a key mechanism in the poverty trap where poorer individuals may also be risk averse and thus less likely to adopt new innovations that could raise them from poverty (Giné and Yang, 2009; Mosley and Verschoor, 2005).

Outside of agriculture, de Blasio et al. (2020) examine risk preferences among Italian households, finding that increased risk aversion following a disaster event inhibits entrepreneurship among Italian households. Wibbenmeyer et al. (2013) examine how risk preferences impact fire management and suppression strategies among US federal wildfire managers. They find overall risk decisions are better modeled on nonexpected utility decision-making as managers tend to over-allocate resources when the probability or likely magnitude of fires is low rather than minimizing expected losses. Table 6.3 displays a summary of the theoretical and empirical results surrounding the quantity of adaptive technology employed across moderating variables.

Table 6.3 Summary of Theoretical and Empirical Insurance Results

Variable	**Theoretical Direction**	**Empirical Direction**
Risk Aversion	+	+
High Risk, High Return Technology	−	−
Insurance	−	−, 0

Note: Table 6.3 displays the relationship (positive [+], negative [−], or no relationship [0]) between each variable and the amount of adaptation.

3.4 Risk Preference Stability

As explored in Section 2.3, researchers long believed preferences to be permanent, including Stigler and Becker’s famous paper “De gustibus non est disputandum” (1977), meaning “in matters of tastes, there can be no disputes.” More recently, however, a growing body of theoretical and empirical evidence has shown that risk preferences may be malleable given a large enough shock (Schildberg-Hörisch, 2018). If true, this can have significant implications for welfare. If monumental negative events lead to reductions in risk tolerance, this can lead to adoption of less-risky behaviors that, in some cases, may be suboptimal, including in investment decisions, reduced entrepreneurship, increased skepticism of new technologies, and distortions in migrations decisions (Schildberg-Hörisch, 2018).[9] As suggestive evidence, Falk et al. (2018) find that countries with higher levels of risk aversion also have lower total factor productivity.

Empirical findings highlight that tail-event natural disasters are often sufficient shocks to observably impact risk preferences.[10] In addition, given the arguably exogenous nature of their realizations, natural disasters are often used as natural experiments in identifying the impacts of changes in risk preference. For example, Cassar et al. (2017) examine the case of the 2004 tsunami in Thailand, finding that individuals from villages hardest hit by the tsunami had long-lasting increases in risk aversion as well as prosocial behavior and impatience. Bchir et al. (2013) find that a massive earthquake in Peru led to an increase in risk aversion. They then exploit the earthquake as an instrumental variable to overcome the potential endogeneity of risk preferences and labor sector to examine the arguably causal effect of risk aversion on entrepreneurship. Bourdeau-Brien and Kryzanowski (2020) find that extreme weather events in the United States lead to significant increases in risk aversion, which, in turn, had consequences for investors in municipal bonds. They also highlight that these changes in investment behavior led to larger macroeconomic and fiscal consequences as it reduced the effectiveness of post-disaster aid and slowed disaster recovery. In turn, Chuang and Schechter (2015) conduct a thorough literature review on risk preferences after natural disasters, highlighting some disagreement in empirical literature findings, with some studies finding post-disaster increases in risk aversion (e.g., Cameron and Shah, 2015), decreases in risk aversion (e.g., Eckel et al., 2009), and no change in risk aversion (e.g., Becchetti et al., 2012).

Given the occasionally contradictory findings, additional literature has parsed these conclusions through examination of mediating response channels that can explain how and why risk preferences shift, although a comprehensive theory is still an active area of research. Using the case of a hypothetical disaster shock on specialty producers in Indiana, Wahdat et al. (2021) find income to be a key risk aversion mechanism: farmers who receive a randomly assigned (hypothetical) disaster shock have an increase in absolute (but not relative) risk aversion risk premium relative to the nontreated group. Brown et al. (2018) use the case of the December 2012 Cyclone Evan that devastated Fiji, finding the event increased subjective risk perception and levels of risk aversion, but only for the Indo-Fijian residents and not Indigenous Fijian residents. They propose moderating mechanisms: Indigenous Fijians have a comparatively more collectivist social structure, and these stronger social networks helped to better insulate them from the disaster shock, thus leading to insignificant changes in risk aversion following the event. Finally, Shupp et al. (2017) use a combination of survey and experimental approaches to study how risk, loss, and ambiguity aversion change after a large 2013 tornado in Oklahoma City, Oklahoma. They find heterogeneity in impacts: individuals who were injured, themselves, had an increase in risk aversion. However, individuals who knew a friend or neighbor who perished became less risk averse, highlighting that the impact of disasters on risk preferences can be different and need to be carefully studied.

Instead of looking at the impact of disaster events on risk preferences, a second strand of literature examines the correlation between risk preferences and background disaster risk. As Gollier and Pratt (1996) show theoretically (called "risk vulnerability") and Lee (2008) shows empirically, even in the absence of an event, background risk can make risk-averse individuals more risk averse. In the context of natural disasters, Bchir et al. (2013) find a positive correlation between the background risk of lahars (volcanic landslides) in Peru and risk seeking, but the relationship is mitigated among higher-income individuals. Thus, while a preponderance of the literature has focused on the relationship between disaster strikes and risk preferences, a fruitful area of future inquiry could expand the understanding and empirical identification of the endogenous relationship between disaster risk and risk preferences, as individuals may sort over natural disaster risk based on their risk preferences but also have preferences shaped by disaster events and even underlying disaster risk in risky areas. This has important implications for how to define a counterfactual empirical control group as groups in, for example, low-risk or less-impacted regions may be ex ante different from impacted groups.

4. CONCLUSION

Natural disasters lead to devastating losses to humans around the globe and these impacts are expected to increase with upcoming changes to climate and human communities (Field et al., 2012). Thus, it is critical to understand why and how humans cope with these risks, as well as how response patterns may differ based on context and preferences. While comparatively more is known about the impact of risk perception and salience on decision-making surrounding natural disasters, much less is known about how risk preferences may moderate decision-making surrounding natural disasters. This chapter summarizes key themes and knowledge gaps through a review of the relevant theoretical and empirical literature. After providing a brief summary of the theory and empirical methods behind risk preferences, we examine three disaster-relevant cases: insurance, location choice, and adaptation decisions. For each, we provide both theoretical and empirical motivation for the relevance of a risk preference lens in each context, as well as highlight key gaps, including in the empirical literature. The difficulty in eliciting risk preferences in survey and real-world data—given that it is not typically included in many experimental and administrative data sets due in part to the potential limitations of hypothetical risk decisions or real payoffs that are trivially small as well as the high cost to implement a large lottery payment across a big sample—is a hindrance to expanding empirical evidence. Finally, we examine the stability of risk preferences, including the recent evidence that these preferences may be impacted by natural disaster events.

Risk preferences also hold key implications for natural disaster policy. Risk preferences constitute another form of heterogeneity across individuals in society and help to explain why otherwise similar individuals may make different decisions surrounding management of disaster risk mitigation and recovery. Thus, understanding how risk preferences impact decision-making across a variety of settings can allow policy makers to craft better policy to achieve policy goals. From an insurance perspective, risk-loving individuals would need additional incentive to take up a policy relative to risk-averse individuals, so tools such as insurance mandates or price regulation can help increase insurance adoption and may explain, in part, why disaster insurance take-up remains low in some countries, such as the United States, despite a history of insurance premiums set at below actuarially fair rates.

Coupling the findings from location-choice and adaptation theory, which show that risk-loving individuals are more likely to live in risky areas and less likely to adapt, ceteris paribus, risk preferences highlight an additional reason why individuals in harm's way may be less prepared for natural disasters. This can motivate policy intervention from both a paternalistic perspective to encourage additional protection, and also an externality perspective to mitigate the broader societal costs of natural disasters that may be larger due to lower levels of individual protection. The findings that risk preferences may not be stable offers an additional avenue for policy levers. This highlights how natural disasters can be windows of opportunity to achieve policy goals to, for example, increase adaptation, insurance, or population in lower risk settings, when society may be more risk averse. In addition, public support for disaster policy reform may also be greater following a significant disaster due to even temporary changes in levels of risk aversion in society.

A key obstacle that policy makers must overcome to better leverage risk preferences as a tool remains lack of data on individuals' risk preferences. Indeed, few administrative surveys contain risk preference elicitation questions. Even a simple hypothetical risk preference lottery embedded in existing administrative survey instruments could lead to valuable information for policy makers to better craft effective disaster policy. In addition, given that risk preferences are often correlated with other individual characteristics (e.g., risk perception, preferences for other (dis)amenities, time preferences, cognition), disentangling the role of risk preferences versus other factors will be important for future research to better ascertain the causal mechanisms as well as provide better policy recommendations. Natural disasters have long imposed terrible hardship and damage around the world. Better understanding the arguably understudied role of risk preferences is thus critical in mitigating disaster losses and improving societal resilience that will have consequences for decades to come.

NOTES

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1. These statistics were all provided by Munich Re, Geo Risks Research, NatCatSERVICE, 2021, and were accessed via https://www.iii.org/fact-statistic/facts-statistics-global-catastrophes.

2. This result is based on a coarser measure of risk preferences. Using a finer measure, they find no relationship between lab-elicited risk preferences and real-world insurance take-up.

3. See review of how, for example, flood risk is capitalized in house prices by Beltrán et al. (2018).

4. Note that, in this setup, the individual will own property in both locations. This outcome may not be consistent with the experience of most individuals in practice. It is possible to separate those who buy property in the at-risk locations from those who buy property in the safe location by introducing an individual-specific enjoyment of the amenities in the at-risk location; however, this comes at some cost of distraction from the main intention of this section. See Conte and Kelly (2018) for details.

5. Adaptation can also be used to amplify benefits, but we focus on harm reduction here.

6. Insurance is also considered adaptation, but we treat the two separately in this chapter (Thomas and Leichenko, 2011).

7. We note that while this relationship holds for the risk premium, this property does not always hold for willingness to pay for risk reduction across risk preferences (Eeckhoudt et al., 1997; Langlais, 2005).

8. Downside risk is a risk that can lead to losses great than the critical threshold even if there is potential for gains (Menezes et al., 1980).

9. Of course, if individuals were under-perceiving the risks of natural disasters, they may have been taking on a suboptimally low level of preparedness in advance of a disaster. Therefore, in some cases, the disaster shock could lead to decisions closer to the optimal if individuals then take on less risky endeavors. The level of ex ante risk perception is therefore an important ingredient in the welfare impacts.

10. A parallel literature similarly has found that war and large-scale violence are significant shocks sufficient to impact risk preferences (e.g., Callen et al., 2014).

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