

Article

Economic Analysis of Global Catastrophic Risks Under Uncertainty

Wei-Chun Tseng *, Chi-Chung Chen and Tsung-Ling Hwang 

Department of Applied Economics, National Chung-Hsing University, Taichung 402, Taiwan

* Correspondence: tweichun@nchu.edu.tw

Abstract

Background: Despite the apparent importance of global catastrophe risks (GCRs), human society has invested relatively little to reduce them. One possible reason is that we do not understand the significance of reducing GCRs, especially when measured in the monetary terms that we typically use to make decisions. Consequently, we cannot compare them to other issues that influence our decision making and well-being. **Purpose:** In this study, we quantified the benefits of reducing all non-natural GCRs to highlight their importance. **Method:** We used a probabilistic model for simulation. Due to limited information, we introduced concepts and assumptions to aid the calculations, such as steady-state economics and sensitivity analyses. In addition, we converted expert opinions to help us focus on a narrower range of risk levels. **Results:** Within a considerably plausible range of the GCR, we found the following: 1. The benefits of halving the overall non-natural GCR over the next 100 years are substantial. 2. The expected human survival years are sensitive to the mitigation effort but robust to the horizon length. 3. The higher the population growth rate, the larger the expected life years saved. 4. The expected monetary benefits are positively related to the GWP per capita growth rate, mitigation period, and magnitude of natural GCRs but are negatively related to the discounting rate. **Significance:** The human species is actually facing multiple GCRs simultaneously. In the literature, there is still a gap in quantifying the benefits of reducing all non-natural GCRs/ERs in the coming century while accounting for the very long run on a million-year scale. This article fills such a gap, and the results may serve as a reference for global policymaking to handle this global public issue.



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1. Introduction

A global catastrophic risk (GCR) is one with the potential to cause death on a global scale, such as global warming, general artificial intelligence, asteroid impacts, and biological weapons (Bostrom and Cirkovic 2008; Häggström 2016; Ord 2020; Alexandrie and Eden 2025; Jehn et al. 2025). Any risk that has the potential to cause the extinction of the human species is known as an existential risk (ER) (Bostrom 2002). Despite the apparent importance of global catastrophic risks (GCRs), human society has invested relatively little to reduce them. One possible reason is that we do not understand the significance of reducing GCRs, especially when measured in the monetary terms that we typically use to make decisions. Consequently, we cannot compare them to other issues that influence our decision making and well-being.

There were about 10 studies on GCR/ER published in 2010; however, this number rapidly increased to about 150 in 2023 (Jehn et al. 2025). While the early literature concentrated on natural GCRs/ERs, the focus shifted to climate change around 2010, and in the last decade, it has shifted to artificial intelligence (AI). Global catastrophic risks have become a central field of inquiry in risk science and macroeconomic policy, and benefit–cost analysis (BCA) has emerged as a key tool for prioritizing interventions under deep uncertainty as governments and international institutions increasingly confront transboundary and intergenerational threats.

Unlike typical disaster risk assessment (ex. Abou Ltaif et al. 2024), GCR analysis must integrate low-frequency but high-severity outcomes, systemic interdependencies, and potential irreversibility. Early GCR research emphasized uncertainty and conceptual frameworks, mid-period contributions expanded the empirical evidence on the efficiency of risk reduction interventions, while recent works have highlighted tipping-point dynamics, tail risk distributions, and existential risk economics. Some risk-related issues are difficult to estimate, especially when there is insufficient data (de Andrés-Sánchez and Puchades 2025). This is more frequently encountered in GCR research, making quantification challenging (no historical frequency-like data are available to quantify the risk levels). Thus, most studies rely on heavy assumptions, simulations, or specialist opinions.

1.1. GCR/ER Benefit–Cost Analysis Has Increasingly Attracted Attention

Posner was one of the first to posit the usefulness of benefit–cost analysis (BCA) to the analysis of GCR/ER, pointing out that extinction risks can be analyzed using benefit–cost frameworks despite the widely bounded probability and consequence estimates and slightly informed speculation (Parson 2007). The more formally numerical estimation work of benefits–costs regarding GCRs/ERs was performed by Matheny, who suggested that the benefit associated with reducing the possibility of an extinction-level asteroid event in this century by 50% is much higher than the associated cost, and thus actions to prevent asteroid impacts should be taken (Matheny 2007).

Around 2012, BCA became increasingly embedded in national and international disaster risk reduction frameworks. While not always explicitly addressing existential risks, the accumulation of empirical studies provided strong evidence for BCA as a risk reduction measure tool. This institutionalization expanded the practical relevance of BCA and laid the foundation for its application in GCR contexts. Szymanski et al. (2015) synthesized earlier modeling efforts to show how cascading failures in global networks can produce losses that far exceed initial shocks. Their model demonstrated the inadequacy of independent-hazard benefit–cost analysis and introduced a systems approach that considers interlinked vulnerabilities. In a major methodological contribution, Mechler (2016) reviewed decades of BCA studies and found median benefit–cost ratios of approximately 4:1 across disaster risk mitigations. Their findings suggest that even highly uncertain risk mitigation strategies are economically justified.

Ord (2020) reframed existential risk mitigation as a rational economic priority, arguing that even very small annual existential risk probabilities justify significant present-day investment when considering the impacts on all future generations.

Recently, the number of GCR/ER benefit–cost studies has increased significantly. One example is Kemp et al.’s “Climate Endgame” (Kemp et al. 2022), in which the authors critically examine the underrepresentation of catastrophic climate scenarios in contemporary economic studies, particularly under deep uncertainty and tipping-point dynamics. The authors argue that expected-value BCA is insufficient for assessing climate GCRs.

Jones (2024) uses social welfare functions in models and suggests that we should take great care with existential risk when adopting AI technology in production, unless

it leads to new innovations that significantly improve human life expectancy. [Shulman and Thornley \(2025\)](#) support standard cost–benefit analysis and argue that governments should spend much more on reducing GCRs. In addition, [Graham et al. \(2025\)](#) found that the money lost due to the pandemic risk for Australia is about USD 4.45 billion, while that lost due to nuclear war is about USD 3.58 billion.

Finally, AI by far presents the most significant GCR of the last two decades. Around USD 50 million was spent on reducing the catastrophic risks from AI in 2020, while billions were spent advancing AI capabilities ([Growiec and Prettnner 2025](#)). [Growiec and Prettnner \(2025\)](#) tested a variety of scenarios at the global level for the single risk item AI and found that we should invest a significant portion of our income to prevent the extinction risk it poses.

BCA and economic analysis have now expanded to multihazard frameworks that cover AI risks, biorisks, geopolitical instability, and climate GCRs. Research databases, such as those compiled by global risk policy organizations, illustrate an increasingly integrated and policy-oriented economic approach that emphasizes robustness, scenario diversity, and governance failures.

1.2. Literature Gaps and Contributions of This Article

From 2004 to 2025, the economic analysis of global catastrophic risks matured from foundational conceptual work into a more empirical, policy-relevant field. Nonetheless, the methodological gaps remain substantial, particularly those involving systemic interactions, catastrophic tail risks, and long-term welfare economics. Addressing these challenges will require interdisciplinary collaboration and novel modeling techniques capable of capturing the profound uncertainty and complexity inherent in global catastrophic risks. Three research gaps are drawing particular attention: 1. Most economic models still treat hazards independently, and while network- and agent-based approaches offer promise, they remain underdeveloped for GCRs. 2. Debate persists regarding ethical discount rates for existential risk interventions, especially those with multi-century horizons. 3. Most GCR/ER benefit–cost analyses focus on a single risk, such as AI, a pandemic, or climate change, while only a few focus on multiple risks. However, human beings are actually facing multiple GCRs/ERs simultaneously. In the literature, there is still a gap to quantify the benefits of reducing all non-natural GCRs/ERs in the coming century and accounting for the very long term at the million-year scale. This article fills these gaps. To the best of our knowledge, this paper is the first to quantify the benefits of all non-natural GCRs.

2. Conceptual–Ethical Framework

2.1. Postulate 1: Ethical Obligations to Future Generations

Discounting is usually used to perform mid-term (several decades) environmental valuations and is an important technique for obtaining the total benefit when the project being evaluated involves at least two periods. A lower discount rate implies that more weight is attached to the latter periods. However, we think the issue regarding the survival of the human species might be different. The timeframe involved is very long (on a scale of thousands of years), and the typical discount rates (e.g., 3%, 5%, or 8%) used in mid-term benefit–cost analysis are generally far higher than the total probability of GCRs. Thus, the use of these discount rates in human survival analysis could lead to an overemphasis on living for the current moment and a lack of consideration for the future due to the low risk probability and high discount rate.

It seems to be rational to ignore the future—even though it is unethical—and so most people and processes do ignore it and our impact on future generations in most of the ways important for human survival, for example, by living according to a high-consumption

and -pollution pattern at the individual level, and via the lack of institutions or official organizations tending to the global and intergenerational public good: human survival. Tonn (2009) believes that our obligation to future generations is the prevention of human extinction, and we agree. He found that acceptable risks are all extremely small regarding the obligation to future generations. Thus, mankind should devote itself to reducing extinction risks. Matheny (2007) believes it is not necessary to use discounting to study the human extinction issue. Standing (i.e., whose benefits are being taken into account) is an important issue (McKay et al. 1991). Valuing all humans equally despite age or wealth or whether of future or current generations is a fundamental basis for maximizing the expected number of years of human survival (Stern 2006; Leggett 2006; Ng 2011); thus, we assume pure altruism toward all generations in the baseline mode and assign the zero discount rate. Later, we conduct sensitivity analyses to relax this assumption by adding positive discount rates to the calculations.

2.2. *Alternative: Future-Oriented Choices*

A negative discount rate can also reflect a preference for the well-being of future generations, such as one's own children, implying that future well-being is more highly valued than present well-being, a concept that is discussed in intergenerational equity debates. Later, we will also test the negative-discounting assumption.

2.3. *Postulate 2: Zero Weight Assigned to the Post-Human Species*

It is interesting to question whether the post-human species (Bostrom 2005; Kramer 2009; Ng 2011) will be the offspring of the human species, or, at the very least, whether a large portion of their genes will be obtained from the human species (Pearce 2012; Kramer 2009), and whether we should attach weights to their well-being? Some researchers, for example (Kramer 2009), believe that we should. However, the literature attaches virtually no weight to the welfare of the post-human species, and we follow suit throughout this article.

2.4. *Postulate 3: A Total Utilitarian Life Years Framework*

We adopt a total utilitarian life years framework, which economists and philosophers often rely on (Jones 2024). We apply no pure time discounting and a very long horizon in the baseline model. Later, we relax this assumption by adding discounting.

2.5. *Postulate 4: Unknown GCRs Included*

It might be true that some unknown extinction risks exist. For example, mankind did not know that a huge volcanic eruption could lead to the extinction of mankind until about three decades ago, nor did mankind know that a full-scale nuclear war could lead to its extinction until about seven decades ago. These examples indicate that it is likely that there are still currently unknown extinction risks to be discovered in the future.

2.6. *Categorizing Global Catastrophic Risks (GCRs)*

There are various sorts of global catastrophic risks (GCRs), including massive asteroid impacts, nuclear annihilation, genetically modified agents, and others. Avin et al. (2018) advanced classification frameworks for GCRs, enabling economists and policymakers to differentiate risk categories and assign appropriate modeling approaches.

For a better understanding and to facilitate further estimation, we categorize the risks into four categories: A, B, C, and D (Table 1). Categories A and B are natural risks, with category A consisting of single GCRs (causing human extinction) and category B consisting of multiple GCRs. Some GCRs are anthropogenic, such as nuclear war, while climate change is partially anthropogenic. Category C is defined by a single GCR caused

by anthropogenic or partially anthropogenic factors (PGCRs), while category D contains the multi-cause version of category C.

Table 1. Categorizing global catastrophic risks (GCRs).

	Yearly Probability	Subtotal Probability
<i>Category A. Single natural GCR:</i>		
1. Initiation of a transition to a lower-vacuum state (Hut and Rees 1983; Posner 2004; Tegmark and Bostrom 2005)	Not available	
2. A black hole or gravitational singularity (Hut and Rees 1983; Tegmark and Bostrom 2005; Posner 2004)	Not available	
3. A stable strangelet (Dar et al. 1999; Posner 2004)	Not available	
4. Massive asteroid or comet impacts (Bostrom 2002; Posner 2004; Leggett 2006; Coates 2009; Ng 2011; Jehn et al. 2025)	$10^{-8} \sim 10^{-9}$	$(A+B) \sim 10^{-9}{}^a$
5. Supernova explosions (Tegmark and Bostrom 2005; Beech 2011)	$< 10^{-11}$	
6. Gamma-ray bursts (GRBs) (Tegmark and Bostrom 2005; Beech 2011)	$< 5 \times 10^{-11}$	
7. Hostile extraterrestrial civilization (Tegmark and Bostrom 2005)	Not available	
8. Supervolcanoes (Beech 2011)	Not available	
9. Natural pandemic risks (Bostrom 2002; Jehn et al. 2025)	Not available	
10. Other and currently unknown single natural extinction risks	Not available	
<i>Category B. Several natural semiextinction GCRs together become one extinction risk:</i>		
11. For example, supervolcano eruption plus asteroid impacts kill the world's population, except for a small number of persons, but a tsunami later eliminates them.	Not available	
12. Other and currently unknown natural semiextinction catastrophes together become an extinction risk	Not available	
<i>Category C. Single GCR caused by anthropogenic or partially anthropogenic factors (PGCRs):</i>		
13. Artificial general intelligence (AGI) (Jehn et al. 2025)	$< 10^{-3}{}^c$	
14. High-energy physics experiments, such as Relativistic Heavy Ion Collider (RHIC) (Tegmark and Bostrom 2005; Posner 2004), LHC (Leggett 2006)	$< 10^{-12}$ for RHIC	$(C+D) > 10^{-9}{}^b$
15. Nuclear annihilation (Bostrom 2002; Tegmark and Bostrom 2005; Parson 2007; Leggett 2006) (Jehn et al. 2025)	Not available	
16. Extreme scenario of climate change risk (also known as GCR) (Tegmark and Bostrom 2005; Posner 2004; Jehn et al. 2025)	Not available	
17. Genetically modified pandemic risks (also known as APRs) (Tegmark and Bostrom 2005; Posner 2004; Tegmark and Bostrom 2005; Jehn et al. 2025)	$< 3 \times 10^{-4}{}^c$	
18. Eco-system collapses (Jehn et al. 2025)	Not available	
19. Other and currently unknown single PGCRs	Not available	
<i>Category D. Several semiextinction GCRs with at least one PGCR together become an extinction risk:</i>		
20. Several semiextinction catastrophes with at least one manmade component (Carpenter and Bishop 2009; Tonn and MacGregor 2009; Lopes et al. 2009)	Not available	
21. Several semiextinction catastrophes with at least one manmade component and at least one currently unknown component together become an extinction risk.	Not available	

Note: All GCRs (even currently unknown ones) are included, as there are items 10, 12, 19, and 21. ^a Applying the loose-approximation assumption (LAA), which will be explained in the text. ^b It is crucial in our estimations; ^c subjective estimation by Ord (2020). Jones (2024) tested some AI risks around this magnitude. Note: the numbers in categories C and D are subjectively estimated, but most GCR/ER experts believe that PGCRs (i.e., C+D) > natural GCRs (i.e., A+B), and we agree.

Sometimes, a single catastrophe may not result in the extinction of the human species, but several catastrophes together could do so (Leslie 1996; Lopes et al. 2009). For example, Lopes et al. (2009) used scenario planning to list three combinations of natural mega-

catastrophes and manmade semiextinction events and found that each combination could eliminate the entire human species (Lopes et al. 2009). In another study, Carpenter and Bishop (2009) used scenario events consisting of a combination of natural megacatastrophes and manmade semiextinction risks that together will eliminate the human species by 2080 (Carpenter and Bishop 2009).

Natural global catastrophic risks (GCRs) have always existed, from ancient times until now. However, it has not been until recently that scientific and technological changes have given humans the ability to eliminate their entire species through anthropogenic GCRs. Most of the economic loss from climate change may result from the catastrophic damage, which has only a small chance of occurring (Weitzman 2009). The catastrophes that might result despite the avoidance of climate change should be emphasized. Artificial intelligence (computational neuroscience or supercomputers) capable of eradicating the human species is partially hypothetical right now but might be developed in the next 100 years (Bostrom 2002; Leggett 2006; Matheny 2007).

The controversy over genetically modified avian flu viruses that are easily transferable among mammals demonstrates the severity of the concern about the risks associated with biotechnology that may be learned by bioterrorists (Fouchier et al. 2012; Kawaoka 2012). It is possible to generate viruses that combine the H5 haemagglutinin (HA) gene with the remaining genes from a pandemic 2009 H1N1 influenza virus (Kawaoka 2012). Laboratories are working with H5N1 viruses that may only require one to three mutations before the viruses can become transmissible via aerosols (Fouchier et al. 2012). Their studies are important for the identification of naturally emerging killer flu viruses and to prepare for potential pandemic catastrophes.

Semiextinction risks on their own are not sufficient to bring about the extinction of the human race, but together they might. Thus, risks with the same terminology but under different categories are not double counted.

2.7. Probability of Global Catastrophic Risks (GCRs)

Researchers have estimated the global catastrophic risk (GCR) magnitude. Melott et al. (2004) estimated that the Earth encounters a gamma-ray burst (GRB) extinction once every 1 billion years on average. In addition, over the remaining lifetime of the biosphere (~2 Gyr), the Earth might experience one GRB and 20 supernova detonations within their respective harmful threat ranges. These calculations are based on generally accepted human death dosages of gamma rays and X-rays of 8 Gray as well as other data (Beech 2011). Given that supernovas have their pre-stages and can often be observed in advance, that it is highly unlikely that one will be found within a threat range (150 pc) during the next several million years, and the relatively much shorter timescale considered in the current paper (around 2 million years), the probability of a supernova is trivial. We translate Beech's findings into a very conservative upper bound of 10^{-11} for the supernova risk. Moreover, given the jet core angle, the one GRB that Earth has a chance of encountering over the remaining lifetime of its biosphere may have no effect on it at all (Beech 2011). Thus, we also translate Beech's findings into an upper bound of 5×10^{-11} per year for GRBs. In addition, the yearly probability of asteroids and comets impacting the extinction risk is about 10^{-8} , or $10^{-8} \sim 10^{-9}$ (Kent 2004; Matheny 2007), and is the greatest known natural extinction risk that can be reasonably well measured (Kent 2004).

2.8. Postulate 5. The Loose-Approximation Assumption

Observation selection effects are important when studying global catastrophic risks (GCRs) (Ćirković et al. 2010). Tegmark and Bostrom (2005) brilliantly avoided the selection bias by using planetary age distributions and the relatively late formation of Earth, finding

that the upper bound of all natural global catastrophic risks (GCRs) is about 10^{-9} , under a 99.9% confidence interval. Our translation of their bound includes categories A and B in Table 1.

Some estimates listed in Table 1 do not seem able to co-exist, as the probability of a subset is larger than the probability of the whole set. Specifically, the probability of the subset (Category 4, number 4, massive asteroid or comet impacts) risk is larger than the probability of all natural extinction risks (categories A and B). However, if these scientific studies have a certain credibility and allow us a certain range of estimation error, then, viewed together, they bind the total natural risks around 10^{-9} with a range of $10^{-8} \sim 10^{-10}$. We give this a terminology—the loose-approximation assumption (LAA). The LAA allows us to pursue challenging topics with insufficient numbers and information. In addition, experts in GCR/ER research and ordinary people generally believe that the chances of PGCRs are higher than the natural extinction risks and that the risks of extinction with manmade components will likely increase as technology changes (Tegmark and Bostrom 2005; Rees 2003). Thus, if we accept the assumption that the total natural risks are roughly around 10^{-9} per year, then we consequently only need to focus on the total PGCR higher than 10^{-9} per year.

In addition, we should pay more attention to the dominant extinction risks because they have a more substantial impact on the survival of the human species—i.e., a magnitude gap (MG) exists. For example, suppose the largest extinction risk is 10^{-5} per year, the second largest extinction risk is 10^{-10} per year, and the other extinction risks are even smaller. If we can reduce the dominant extinction risk by 10%, the chances of the human species surviving would increase more than if we could reduce all the other extinction risks by half. The risk perception gap, which refers to “the gap between the actual size of risk and the perceived size of risk”, is a standard concept in risk analysis. In contrast, the MG means that the difference in the “real” dominant risks and “real” non-dominant risks is huge. Finally, as Matheny (2007) suggests, it makes more sense to reduce the risk of extinction by 50% than to completely eliminate the risk, and we follow suit. Later, we relaxed this 50% mitigation magnitude assumption.

2.9. Other Related Articles

There are specific actions aimed at reducing PGCRs. By far the largest and most important one is the global effort to mitigate climate change by reducing greenhouse gas emissions. Another example is the effort to prevent nuclear annihilation. Other actions, such as restricting information about genetically modified viruses (Fouchier et al. 2012; Kawaoka 2012) and seed banks (Charles 2006), are also being pursued to some extent. These efforts could reduce the risk of human species extinction from extreme climate change scenarios and other climate-related extinction risks. Catastrophic risk bonds, such as CAT bonds (Tang and Yuan 2019; Marvi and Linders 2021; Tang et al. 2023) and risk insurance (Schmidt 2014; Kanchai et al. 2024), designed to protect human species from GCRs, may be a promising approach. However, they may require specialized designs due to their large scale and multicountry implications.

2.10. Space Colonization

Finally, we agree with the view that space colonization is itself an effective means of preventing various extinction risks (McKay et al. 1991; Kent 2004). In addition, Bostrom (2003) emphasizes that space colonization may significantly increase human populations. Our analysis can be applied either with or without space colonization and with low population increases. However, our analysis does not apply to space colonization with significantly high population increases.

2.11. The Model Reduces Only PGCRs (Categories C and D)

Our model targets reductions exclusively in PGCRs (categories C and D). Natural GCRs (categories A and B) are incorporated as background risks but are not subject to mitigation within the model.

3. Model

Increase in Expected Human Survival Years with a 50% Reduction in GCRs Between 2026 and 2125

Researchers (Matheny 2007; Posner 2004) have used cost–benefit analysis techniques to provide rough estimates of the value of reducing the human extinction risk from asteroid impacts and high-energy experiments. The current paper borrows many assumptions from (Matheny 2007) due to the author’s comprehensive contributions regarding the benefits and costs of the human extinction issue. However, we develop an innovative approach based on probabilities to calculate the increase in human survival years as a result of reducing all the non-natural GCR categories and the corresponding life years saved and benefits. We assume the pure altruism of human beings. In other words, we place equal weights on the well-being of all future generations, even though that they are not yet born, and the generations that are currently living. The human species (*homo sapiens*) and our closest relative species (*homo erectus*) have both faced natural extinction risks and competing species. Let us assume that the human species, like *homo erectus*, can also live 1.8 million years with natural extinction risks. This is a conservative number of years for the survival of the human species, as *homo sapiens* are more geographically widespread, have a larger population, and are more technologically advanced. On the negative side, technology is a part of the PGCR and is handled in our model. We also assume that zero weight is attached to the welfare of the post-human species. The human species has survived 0.2 million years, and so it may survive another 1.6 million years with natural extinction risks. A previous study (Matheny 2007) assumes that *Homo sapiens* would, in the absence of preventable extinction events during the century, survive for as long as our closest relative, *Homo erectus*. By contrast, we assume that *homo sapiens* (the current human species) can survive another 1.6 million years under external extinction risks, including competing (post-human) species. These two assumptions are actually similar, due to the fact that all PGCRs are preventable and the total PGCR dominates the total natural extinction risks. We later relaxed this 1.6-million-year assumption and tested a wide range of time horizons, including 10 thousand, 50 thousand, and 0.37 million years.

However, since the last century, the human species (*homo sapiens*) has been at risk of extinction due to a new type of threat, namely, PGCRs. Let R be the annual probability of the total PGCR. Then, the chance that the human species will survive the first year but will become extinct in the second year is $(1 - R) \times R$; the chance that the human species will survive two years but become extinct in the third year is $(1 - R)^2 \times R$; the chance that the human species will survive for three years but become extinct in the fourth year is $(1 - R)^3 \times R$; and so on and so forth. Therefore, the expected survival years of the human species are the summation of the number of survival years times the associated chance:

$$EHSY_1 = \sum_{i=1}^{1.6 \text{ million}} (i) \times ((1 - R)^{i-1} \times R) \quad (1)$$

We adjust Equation (1) via the truncation factor ($\tau = \left(\sum_{i=1}^{1.6 \text{ million}} ((1 - R)^{i-1} \times R) \right)$), due to the truncation of the distribution in the equation at 1.6 million instead of infinity. Then,

the summation of the probabilities is equal to unity and is consistent with the probability theory. Thus, the expected human survival years can be expressed as follows:

$$EHSY_1 = \sum_{i=1}^{1.6 \text{ million}} (i) \times (((1-R)^{i-1} \times R) / \tau) \quad (2)$$

Similarly, the expected human survival years within the next 1.6 million years with all PGCR extinction risks but a 50% reduction in PGCRs from 2026 to 2125 can be expressed as follows:

$$\begin{aligned} EHSY_2 &= \sum_{i=1}^{100} (i) \times ((1 - 0.5 \times R)^{i-1} \times (0.5 \times R)) / \omega \\ &+ \sum_{i=101}^{1.6 \text{ million}} (i) \times (1 - 0.5 \times R)^{100} ((1 - R)^{i-100-1} \times R) / \omega, \text{ where} \\ \omega &= \sum_{i=1}^{100} ((1 - 0.5 \times R)^{i-1} \times (0.5 \times R)) \\ &+ \sum_{i=101}^{1.6 \text{ million}} (1 - 0.5 \times R)^{100} ((1 - R)^{i-100-1} \times R) \end{aligned} \quad (3)$$

Then, we obtain the increase in the expected human survival years, $EHSY_3$, via $EHSY_2 - EHSY_1$. The truncation and renormalization of the extinction-time distribution in equations indeed have important implications: all expected-survival calculations become conditional on extinction occurring within the 1.6-million-year horizon, rather than unconditional expectations. This choice materially affects the interpretation of the results (e.g., the finite limiting values of $EHSY_3$ as $R \rightarrow 0$). Also note that the difference between unconditional and conditional expectations may be significant, particularly for smaller PGCR levels such as 10^{-7} , 10^{-8} , or 10^{-9} , because the truncation is substantial.

4. Numerical Results

Table 2 presents the expected human life years saved and the expected benefits of reducing the total PGCR by 50% from 2026 to 2125. The expected life years saved ($EHSY_3$) in Equation (3) increased as the total PGCR decreased and reached the top value, 49.98, at 10^{-5} . Then, the expected life years saved decreased as the total PGCR decreased further. At first glance, the non-monotonicity of the results (e.g., the expected human survival years peak around 10^{-5} and then decrease) seems counterintuitive. However, the smaller total PGCR is actually a double-edged sword: when the total PGCR is smaller, it increases the expected survival life years, and the mitigation force (halving the risks) is also smaller when the total PGCR is smaller. Mathematically, it is mainly due to the differences from year 1 to year 100: $\sum_{i=1}^{100} (i) \times ((1 - 0.5 \times R)^{i-1} \times (0.5 \times R)) - \sum_{i=1}^{100} (i) \times ((1 - R)^{i-1} \times R)$ is non-monotonic.

Table 2. Increase in expected human survival years.

Total PGCR (Pper Year)	Increase in Expected Human Survival Years Due to Reducing Total GCR by 50% from 2026 to 2125
10^{-2}	39.23
10^{-3}	48.75
10^{-4}	49.87
10^{-5}	49.98
10^{-6}	37.28
10^{-7}	26.33
10^{-8}	25.13
10^{-9}	25.01

4.1. Life Years Saved and the Corresponding Monetary Benefits

By assuming a steady state of the global population (SSGP), we obtain the expected human life years saved as $HLYS = SSGP \times EHSY_3$. Lutz et al. (2004) estimated the global population and suggest a peak of nine to ten billion people around 2070 and then a slow decrease to 8.4 billion by 2100. Moreover, there is a 60% probability that the world's population will not exceed 10 billion people before 2100 (Lutz et al. 2001), and the probability that the growth of the world's population will end during this century is 88% (Lutz et al. 2008). Therefore, in this study, we assumed the steady-state population to be about 8.4 billion. We wrote the commands using GAUSS 5.0 statistical software to conduct the estimation based on the year 2025 and a population of 8.2 billion, and the results are listed in Table 3. We later relaxed the zero-population-growth-rate assumption. Although we reduced the level of extinction risks by a small probability, the effects were summed over 1.6 million years, and thus the total effects are substantial.

Table 3. Expected human life years saved and expected monetary benefit.

PGCR (per Year)	Expected Human Life Years Saved by Reducing GCR by 50% from 2026 to 2125 (Billion Life Years)	Expected Monetary Benefit of Reducing GCR by 50% from 2026 to 2125 (USD Trillion)
10^{-2}	324.24	4259.96
10^{-3}	400.21	5258.04
10^{-4}	409.01	5373.67
10^{-5}	409.90	5385.40
10^{-6}	305.78	4017.38
10^{-7}	215.92	2836.79
10^{-8}	206.09	2707.64
10^{-9}	205.10	2694.71

Note: We follow the short scale convention, in which 1 billion equals 1,000,000,000 and 1 trillion equals 1,000,000,000,000.

When applied to the estimation, if one assumes a fixed sustainable population, the number of years that humans are expected to survive become the expected life years. Furthermore, if one assumes a zero gross domestic product growth rate or a zero growth rate, then one can calculate the benefits based on the expected human survival years and life years saved. The value of a statistical life year is a better concept for representing the benefit from saving a life year. However, while it is difficult to find a representative global value of a statistical life year, one can find the global gross domestic product. Thus, the benefit was estimated using the global gross domestic product while recognizing that the estimates of the benefit using the value of the statistical life year may be twice as large as the US example shown by Jones (2024).

We use the value of the GWP per capita to multiply the life years saved to obtain the monetary benefit. According to the International Monetary Fund (IMF), the World GDP (GWP) was USD 106.2 trillion in 2023 and is projected to be USD 113.8 trillion in 2025. Meanwhile, the global real GDP was USD 92.6 trillion in 2023 and is projected to be USD 117.17 trillion in 2025 at the current price. According to the IMF World Economic Outlook October 2025, the annual real GDP growth rate is 3.2%, and the global GDP per capita is projected to be USD 13,138.33 (IMF). This is the most up-to-date projection and is thus the one used in this article.

Conceptually, the gross domestic product (GDP) per capita is the market value of the things a person makes in a year. However, some useful things that a person makes are not on the market, and a person can enjoy an ecological system for free or at low cost. Assume that the benefit of a survival year of an individual is equivalent to a fixed global GDP

per capita; then, one obtains the benefit from reducing the extinction risk from manmade components by 50% from 2026 to 2125 (also = $GWP \times EHSY_3$). We assume that the gross world product will be fixed so that the monetary values of the benefits can be calculated. Later, we will relax the fixed population growth and the fixed GWP per capita growth assumptions.

4.2. Subjective Estimates of Probabilities of Global Catastrophic Risks (GCRs)

When we talk about reducing global catastrophic risks (GCR), we are concerned with the total GCR (including both natural and anthropogenic GCRs). Anthropogenic GCRs are by far more important than natural GCRs. However, there is no way to estimate anthropogenic GCRs objectively because human behaviors are involved, and the uncertainty is substantial. Nor can one estimate anthropogenic GCRs via frequency-like historical data because the extinction of the human species has never happened; thus, both the numerate and probability will be zero using this frequency-like method.

Thus, subjective estimates of the probabilities of the total GCR (including both natural and anthropogenic GCRs) may be our only reference and may also serve as a good guide. Some researchers in relation to human extinction-related decisions or evaluations have generated estimates or made statements about the total extinction risks, and even though these are subjective probabilities, they are of interest. We thus estimate the corresponding probabilities of GCRs for these subjective estimates should they fit the current model. The purpose is to use them as expert viewpoints to shape the considerably plausible GCR (Table 4). For example, the probability of human extinction in the 21st century is 1/2 (Rees 2003). Then, we estimate the corresponding extinction risk of the current model so that the cumulative (truncated) probability for this century is equivalent to 0.5. We find the corresponding GCR level to be $10^{-2.105}$ per year. From Table 4, we can see that the magnitude of the estimated GCR level associated with these subjective statements ranges from Carpenter and Bishop's $10^{-1.832}$ to Leslie's $10^{-3.136}$, indicating that we estimated most, if not all, of the reasonable extinction risk ranges, and we list them in Table 2. According to the famous Fermi Paradox, the apparent size and age of the universe suggest that many technologically advanced extraterrestrial civilizations ought to exist. However, this hypothesis seems inconsistent with the lack of observational evidence to support it.

Table 4. Subjective estimates of probabilities of global catastrophic risks (GCRs) and their corresponding extinction risks per year in the current model.

Persons or Studies	Timeframe	Probability of Extinction	Corresponding Total GCR in Current Model *
Carpenter and Bishop (2009)	Extinct-by-2080 scenario	Not available	$10^{-1.832}$
Stated by virologist Frank Fenner **	Extinct within the next 100 years	100% will become extinct, perhaps within 100 years	$\leq 10^{-1.944}$
Stated by cosmologist and astrophysicist Sir Martin Rees	21st century	1/2	$10^{-2.105}$
Stated by Nick Bostrom	21st century	$\geq 1/4$	$\geq 10^{-2.486}$
The “Stern Review” for the U.K. Treasury (Stern 2006)	21st century	Almost 10%	$10^{-2.922}$
Tonn and MacGregor (2009)	Extinct-by-3000 scenario	Not available	$10^{-2.948}$
John Leslie (Leslie 1996)	The next five centuries	30%	$10^{-3.136}$

* Per year. ** Frank Fenner led the fight against smallpox, which is the only virus that the human species has eliminated. Note: There may be more experts that have subjective probabilities of the total GCR. The list here is not exhaustive.

One of the many possible explanations for the Fermi Paradox is that extinction among highly technological civilizations is close to 100%. However, the time horizon is extremely long, and it is measured in billions of years. Thus, we believe it brings no further restriction

to the possible range of extinction risks, which implies that the associated level of extinction risks that we estimate ranges from 10^{-2} to 10^{-9} , following our earlier assumptions. In addition, former U.S. President Kennedy stated that the probability of a nuclear holocaust was between $1/2$ and $1/3$. However, the timeframe of this statement was not clear, and thus it is not feasible to calculate its corresponding PGCR in the current model.

In 2010, the famous theoretical physicist Stephen Hawking said that it would be difficult enough to avoid disaster on planet Earth in the next hundred years, and that humans should be safe if we can avoid disaster for the next two centuries and colonize other planets. The calculation of the corresponding PGCR in the current model is not feasible either. However, indirectly we know that it is smaller than $10^{-1.944}$ because the probability of extinction risks associated with Hawking's statement is smaller than that associated with Fenner's statement.

We take Rees as an example to explain how these probabilities are calculated. Rees (2003) states that the chance that humans will be extinct by the end of the 21st century is $1/2$. The magnitude of R that makes the probability of Equation (4) equivalent to 0.5 is as follows:

$$E_1 = \left(\sum_{i=1}^T ((1-R)^{i-1} \times R) \right) / \theta \quad (4)$$

where T is the remaining year from year 1. If we calculated it from year 2025, then T is 75, and if we calculated it from year 2003, then T is 97. Note, even if $T = 1.6$ million, the numerator of E_1 is very close to but still not equivalent to unity. Thus, the probability must be adjusted via the truncation factor $\theta = \left(\sum_{i=1}^{1.6 \text{ million}} ((1-R)^{i-1} \times R) \right)$. The solution is $R = 10^{-2.105}$.

We estimated the results listed in Table 5 by using the PGCR levels obtained from incorporating the subjective estimates of experts into the current model (i.e., the last column of Table 4). Again, each column in Table 5 also has one peak at $10^{-3.136}$ in terms of the distribution formed by the numbers in that column. The range of columns in Table 5 is smaller than that of the counterparts in Table 3, as each column in both Tables 3 and 5 has only one peak. Then, we estimated the expected human life years saved and expected monetary benefits of reducing the PGCR by 50% from 2026 to 2125 (Table 6).

Table 5. Considerable plausible range of increase in expected human survival years and upper bound of monetary benefit.

Total Anthropogenic GCR (per Year)	Increase in Expected Human Survival Years Due to Reducing Total Anthropogenic GCR by 50% from 2026 to 2125
$10^{-1.832}$	35.24
$10^{-1.944}$	38.01
$10^{-2.105}$	39.54
$10^{-2.486}$	46.09
$10^{-2.922}$	48.51
$10^{-2.948}$	48.60
$10^{-3.136}$	49.08

We demonstrate that within a considerably plausible range of GCR levels (i.e., between $10^{-1.832}$ and $10^{-3.136}$ per year), the benefits of reducing the total GCR by half for this century are substantial and fairly stable. The increase in human survival years is between 35.24 and 49.08 years, and the life years saved is between 296 and 412 billion. Finally, the corresponding expected monetary benefit is between USD 1315 and 1831 trillion. Assuming that a person can live 70~100 years, the benefit is as huge as 4 billion lives. By dividing

the benefits by 100 years to serve as a reference for the effort that should be expended to reduce the PGCR in each year, the annual benefit is equivalent to 18.8% to 26.2% of the global income measured based on the world's gross national product. In addition, we also estimate figures associated with a wider range (and not depending on the subjective estimates of experts) of PGCR levels.

Table 6. Considerably plausible ranges of human life years saved and monetary benefits.

PGCR (per Year)	Expected Human Life Years Saved by Reducing GCR by 50% from 2026 to 2125 (Billion Life Years)	Expected Monetary Benefit of Reducing Total Anthropogenic GCR by 50% from 2026 to 2125 (USD Trillion)
$10^{-1.832}$	296.08	3582.36
$10^{-1.944}$	319.30	3863.28
$10^{-2.105}$	332.20	4019.38
$10^{-2.486}$	387.15	4684.27
$10^{-2.922}$	407.55	4931.03
$10^{-2.948}$	408.26	4939.67
$10^{-3.136}$	412.33	4988.86

We demonstrate that within a considerably plausible range of the global catastrophic risk (GCR) levels ($10^{-1.832} \sim 10^{-3.136}$ per year), the benefits of reducing the total risks by half for the next 100 years are substantial and fairly stable. The human species survival years increase 35.24~49.08 years, and the life years saved is 296~412 billion. The monetary benefits are USD 3582~4988 trillion. In contrast, [Jones \(2025\)](#) found that investing at least 1% of the GDP annually to reduce AI risks is reasonable, even without considering the value of future generations. Our findings are consistent with those of [Jones \(2025\)](#), as we evaluated a wider range of GCR projects and assigned greater weight to future generations by assuming a preference for intergenerational altruism.

Please note that most of the calculations in the tables in this article (except Tables 5 and 6) did not depend on the accuracy of the subjective statements of experts, as these statements acted as a frame so that we could focus on certain narrower PGCR ranges ($10^{-1.832} \sim 10^{-3.136}$ per year). However, we did calculate the estimates for a much wider PGCR range ($10^{-2} \sim 10^{-9}$ per year), and readers can look at the results of this larger range in lieu of the opinions of the selected experts.

5. Sensitivity Analysis

In Section 4, we present the numerical calculations based on the baseline model. After the calculations, we performed a sensitivity analysis to obtain robust results by relaxing fixed assumptions regarding the horizon length, effort magnitude, population growth, GDP growth, discounting, mitigation period, and magnitude of natural GCRs. The results are in line with our expectations.

5.1. Sensitivity Analysis of Horizon Length

We tested the effects of the horizon length in this study. We assumed 1.6 million years as the horizon length for the human species, as that is the horizon length of our closet relative species, *Homo erectus*. In addition, we chose 0.37 million years as one alternative terminal, as that is the horizon length of a relative of the human species, Neanderthal. We also chose 50 thousand years as an alternative terminal, as that is the horizon length of late *Homo sapiens*. Finally, we choose 10 thousand years as an alternative terminal, as most literate cultures fall within this scale (several thousand to 10 thousand years).

We determined the expected human survival years that correspond to Equation (2) but under different horizon lengths (Table 7). The expected human survival years when it is business as usual increase monotonically as the horizon length increases under all PGCR levels. We also determined the expected human survival years when year 1~year 100 PGCR is halved, that is, corresponding to Equation (3) but under different horizon lengths (Table 8).

Table 7. Expected human survival years when it is business as usual (Equation (2)).

Total PGCR (per Year)	Horizon Length			
	10 Thousand	50 Thousand	0.37 Million	1.6 Million
10^{-2}	100.00	100.00	100.00	100.00
10^{-3}	999.55	1000.00	1000.00	1000.00
10^{-4}	4180.69	9,660.90	10,000.00	10,000.00
10^{-5}	4917.18	22,925.79	90,620.58	99,999.82
10^{-6}	4992.17	24,792.18	173,618.11	595,247.84
10^{-7}	4999.67	24,979.67	183,859.69	778,676.26
10^{-8}	5000.42	24,998.42	184,886.42	797,867.18
10^{-9}	5000.49	25,000.29	184,989.09	799,787.17

Table 8. Expected human survival years when year 1~year 100 PGCR is halved (Equation (3)).

Total PGCR (per Year)	Horizon Length			
	10 Thousand	50 Thousand	0.37 Million	1.6 Million
10^{-2}	139.24	139.24	139.24	139.24
10^{-3}	1048.29	1048.76	1048.76	1048.76
10^{-4}	4213.54	9709.41	10,049.87	10,049.87
10^{-5}	4942.88	22,954.88	90,667.02	100,049.81
10^{-6}	5017.12	24,817.57	173,646.17	595,285.13
10^{-7}	5024.55	25,004.68	183,885.00	778,702.59
10^{-8}	5025.29	25,023.40	184,911.44	797,892.31
10^{-9}	5025.37	25,025.27	185,014.09	799,812.18

Table 9 presents the expected human survival years when year 1~year 100 PGCR is halved, which can be calculated by subtracting the results in Table 7 from the corresponding cells in Table 8. Because both Tables 7 and 8 have similar patterns, the numbers in Table 9 are indeed stable. The subconclusion is that the expected human survival years when year 1~year 100 PGCR is halved is robust to the horizon length.

5.2. Sensitivity Analysis of Effort Magnitude

In the baseline model, we assumed that humans would put effort into reducing the total PGCR by 50% from 2026 to 2125. Then, we tested the effort magnitude. We calculated the increase in the expected human survival years due to reductions in the PGCR of 75%, 50%, and 25% (Table 10). Expected human survival years are sensitive to the effort magnitude. In other words, it does matter if we work harder to reduce the PGCR.

Table 9. Expected human survival years when year 1~year 100 PGCR is halved.

Total GCR (per Year)	Horizon Length			
	10 Thousand	50 Thousand	0.37 Million	1.6 Million
10^{-2}	39.24	39.24	39.24	39.24
10^{-3}	48.74	48.76	48.76	48.76
10^{-4}	32.85	48.50	49.87	49.87
10^{-5}	25.70	29.10	46.45	49.99
10^{-6}	24.96	25.39	28.07	37.29
10^{-7}	24.88	25.02	25.30	26.33
10^{-8}	24.88	24.98	25.03	25.13
10^{-9}	24.87	24.98	25.00	25.01

Note: Inside table: Increase in Expected Human Survival Years due to Reducing Total PGCR by 50% from 2026 to 2125.

Table 10. Sensitivity analysis of effort magnitude.

Total PGCR (per Year)	75% PGCR Reduction	50% PGCR Reduction	25% PGCR Reduction
	(Baseline)		
10^{-2}	66.24	39.24	17.53
10^{-3}	74.06	48.76	24.08
10^{-4}	74.91	49.87	24.91
10^{-5}	74.99	49.99	24.99
10^{-6}	55.94	37.29	18.64
10^{-7}	39.50	26.33	13.17
10^{-8}	37.70	25.13	12.57
10^{-9}	37.52	25.01	12.51

Note: Inside table: Increase in Expected Human Survival Years due to Reducing Total PGCR by 50% from 2026 to 2125.

5.3. Sensitivity Analysis of Population Growth

We assumed a zero population growth rate in our baseline model, based on our planet's limited carrying capacity due to ecological restrictions and resource endowments. However, this carrying capacity may increase in the future due to technology innovations or even space colonization. Thus, we tested the effects of the population growth rate. We used 8.2 billion as the current population. We chose 1% and 2% to serve as the low and moderate growth rates, respectively, as the current global population growth rate is 0.85%, and the historical high is 2.09%. We also chose 8% as a high population growth rate. However, due to the very long horizon length (1.6 million years), any population growth rate larger than 0.1% will explode (i.e., the expected life years go to infinity).

Thus, we tested a smaller population growth rate instead. The expected life years saved under different population growth rates are presented in Table 11. The expected life years saved monotonically increase as the population growth rate increases, consistent with our expectation. With a stable yearly population growth rate as large as 10^{-6} , the expected life years saved increase significantly, and with a stable yearly population growth rate 10^{-5} , the expected life years saved increase dramatically.

Table 11. The expected life years saved under different population growth rates by reducing PGCR by 50% from 2026 to 2125 (billion life years).

PGCR (per Year)	Yearly Population Growth Rate					
	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	0
10^{-2}	325.18	324.33	324.25	324.24	324.24	324.24
10^{-3}	408.73	401.05	400.29	400.21	400.21	400.21
10^{-4}	505.42	417.35	409.83	409.09	409.02	409.01
10^{-5}	52,488.02	506.09	418.23	410.72	409.98	409.90
10^{-6}	191,032,762.53	823.91	335.25	308.58	306.05	305.78
10^{-7}	215,016,470.75	661.53	240.05	218.20	216.14	215.92
10^{-8}	213,659,379.13	638.71	229.42	208.30	206.31	206.09
10^{-9}	213,484,396.06	636.38	228.35	207.30	205.32	205.10

5.4. Sensitivity Analysis of Global Real GDP per Capita Growth Rate

In the baseline model, we assume a fixed money value per life year using the global real GDP per capita. Here, we test the sensitivity against the global real GDP per capita growth rate.

According to the International Monetary Fund (IMF), the World GDP (GWP) was USD 106.2 trillion in 2023, and it is projected to be USD 113.8 trillion in 2025. The global real GDP was USD 92.6 trillion in 2023, and it is projected to be USD 117.17 trillion in 2025 at the current price. According to the IMF World Economic Outlook October 2025, the annual real GDP growth rate is 3.2%. The global GDP per capita is projected to be USD 13,138.33 (IMF). This is the most up-to-date projection and thus the one we use in this article. According to the World Bank Group, the recent annual global GDP per capita growth rate has been fluctuating considerably, and the average was around 1.9% in 2024. However, due to the very long horizon length (1.6 million years), any growth rate larger than 0.01% will explode (i.e., the expected money value saved goes to infinity).

Thus, we tested a smaller growth rate instead. The expected monetary benefits under different real GDP per capita growth rates are presented in Table 12. The expected monetary benefits saved monotonically increase as the GWP per capita growth rate increases, consistent with our expectation. With a stable yearly GWP per capita growth rate as large as 10^{-6} , the expected life years saved increase significantly, and with a stable yearly GWP per capita growth rate of 10^{-5} , the expected monetary benefits saved increase dramatically.

Table 12. Sensitivity analysis of expected monetary benefits against global real GDP per capita growth rate.

PGCR (per Year)	Expected Monetary Benefit of Reducing GCR by 50% from 2026 to 2125 (USD Trillion)					
	10^{-5}	10^{-6}	10^{-7}	10^{-9}	0	-10^{-9}
10^{-2}	4272.38	4261.20	4260.08	4259.96	4259.96	4259.96
10^{-3}	5370.05	5269.09	5259.15	5258.06	5258.04	5258.03
10^{-4}	6640.38	5483.32	5384.49	5373.78	5373.67	5373.56
10^{-5}	689,604.89	6649.22	5494.80	5386.48	5385.40	5384.32
10^{-6}	509,851,474.48	10,824.76	4404.63	4021.04	4017.38	4013.71
10^{-7}	2,824,957,350.17	8691.41	3153.87	2839.77	2836.79	2833.80
10^{-8}	2,807,127,431.59	8391.53	3014.14	2710.52	2707.64	2704.75
10^{-9}	2,804,828,440.27	8360.94	3000.13	2697.59	2694.71	2691.84

Note: Inside table: the expected monetary benefit of reducing GCRs by 50% from 2026 to 2125 (USD trillion).

5.5. Sensitivity Analysis of Discounting

In the baseline model, we do not discount the monetary benefit. Here, we test the sensitivity against the discounting rate. We wished to test low discounting rates, such as 1% and 2%, as well as a high discounting rate, 7%. However, due to the very long horizon length (1.6 million years), terminal condition, and truncation adjustment, any discounting rate larger than 0.0001% would have generated nonreasonable results (i.e., the expected money value saved would have been negative) for some PGCR levels. Thus, we tested a smaller discounting rate instead, echoing the work of Jones (2024), where he tested near-zero social discounting so as to put more weight on future generations. The expected monetary benefits under different discounting rates are presented in Table 13. The expected monetary benefits saved monotonically decrease as the discounting rate increases, consistent with our expectation. With a stable yearly discounting rate as large as 10^{-6} , the expected life years saved increase significantly, and with a stable yearly discounting rate of 10^{-5} , the expected life years saved increase dramatically for smaller PGCR levels, such as 10^{-6} , 10^{-7} , 10^{-8} , and 10^{-9} . A negative discount rate implies that future well-being is valued more highly than present well-being, a concept discussed in intergenerational equity debates. Thus, we tested the negative-discounting assumption too. The results associated with a discounting rate of -10^{-9} are similar to their zero-discounting counterparts, or 10^{-9} counterparts.

Table 13. Sensitivity Analysis of Discounting.

PGCR (per Year)	Discounting Rate					
	10^{-5}	10^{-6}	10^{-7}	10^{-9}	0	-10^{-9}
10^{-2}	4247.57	4258.72	4259.83	4259.96	4259.96	4259.96
10^{-3}	5149.35	5247.03	5256.94	5258.03	5258.04	5258.06
10^{-4}	4436.44	5267.27	5362.89	5373.56	5373.67	5373.78
10^{-5}	1344.34	4450.29	5279.24	5384.32	5385.40	5386.48
10^{-6}	69.55	1751.97	3670.16	4013.71	4017.38	4021.04
10^{-7}	23.97	1069.27	2555.29	2833.80	2836.79	2839.77
10^{-8}	21.17	1006.38	2435.77	2704.75	2707.64	2710.52
10^{-9}	20.90	1000.18	2423.83	2691.84	2694.71	2697.59

5.6. Sensitivity Analysis of Mitigation Period

In the baseline model, the mitigation period is 100 years. Here, we test the sensitivity against the mitigation period (Table 14). We chose 50, 200, and 400 years, as the coming centuries are crucial for human existence, where “200 years” echoes the work of Jones (2024). The expected monetary benefits under different mitigation periods are presented in Table 14. Under all PGCR levels, the expected monetary benefits saved monotonically increase as the mitigation period increases, consistent with our expectation, and demonstrating that the more effort we make, the better our welfare.

5.7. Sensitivity Analysis of Natural GCRs

An important study (Tegmark and Bostrom 2005) states that all natural GCRs are not larger than $1/(1.1 \times 10^9)$ (i.e., about 10^{-9}). For an issue as significant as this, relying on a single study is somewhat risky. Thus, we tested our results against different natural GCR levels. We chose three levels, 10^{-6} , 10^{-7} , and 10^{-8} , because we believe that this range bounds the natural GCR from above. The expected monetary benefits under different natural GCRs are presented in Table 15. The expected monetary benefits saved monotonically

ically increase as the natural GCR increases under all PGCR levels, consistent with our expectation.

Table 14. Sensitivity Analysis of Mitigation Period.

PGCR (per Year)	50 Years	100 Years	200 Years	400 Years
10^{-2}	2397.59	4259.96	6832.29	9328.54
10^{-3}	2661.92	5258.04	10,259.35	19,541.32
10^{-4}	2690.20	5373.67	10,720.54	21,334.40
10^{-5}	2693.04	5385.40	10,768.11	21,525.45
10^{-6}	2008.74	4017.38	8034.38	16,067.27
10^{-7}	1418.42	2836.79	5673.39	11,346.03
10^{-8}	1353.84	2707.64	5415.10	10,829.53
10^{-9}	1347.38	2694.71	5389.25	10,777.83

Inside table: The expected monetary benefit (USD trillion) of reducing the GCR by 50%. Note: For each calculation, reducing the GCR by 50% starts from 2026.

Table 15. Sensitivity Analysis of Natural GCRs.

PGCR (per Year)	Natural GCR Level (per Year)		
	10^{-6}	10^{-7}	10^{-8}
10^{-2}	4259.86	4259.95	4259.96
10^{-3}	5257.92	5258.03	5258.04
10^{-4}	5373.54	5373.66	5373.67
10^{-5}	5385.28	5385.39	5385.40
10^{-6}	4851.71	4126.47	4028.54
10^{-7}	4126.47	2979.57	2851.11
10^{-8}	4028.54	2851.11	2722.00
10^{-9}	4018.50	2838.22	2709.07

Inside table: The expected monetary benefit of reducing the total GCR by 50% from 2026 to 2125 (USD trillion).

The main findings from the sensitivity analysis are as follows:

1. The expected human survival years are sensitive to the mitigation effort but robust to the horizon length.
2. The higher the population growth rate, the larger the expected life years saved.
3. The expected monetary benefits are positively related to the GWP per capita growth rate, mitigation period, and magnitude of natural GCRs but are negatively related to the discounting rate.

Most of these numerical findings are in line with our expectations prior to conducting the calculation. However, the robustness of the expected human survival years to the horizon length does surprise us.

6. Discussion and Conclusions

The point of this paper is not to provide a clear answer to the question of the benefits of reducing all non-natural GCRs. Instead, a simple probability model is used to study how the answer to this question varies depending on how we set up the problem. We also made many assumptions to facilitate the calculations.

Our findings suggest that investing more resources and effort to reduce the risk of GCRs could improve the well-being of present and future generations under many situations. One key sensitivity is whether our efforts to reduce the global catastrophic risks (GCRs) (assuming effective) would pay off. The answer is yes. The expected human survival years are sensitive to the effort magnitude. In other words, it does matter if we work harder to reduce the global catastrophic risks (GCRs). Another key question

is whether our analysis changes when the horizon length varies. The answer is that the benefits are robust to horizon length ranges from 10 thousand years to 1.6 million years.

Population is, of course, crucial to this topic. The current global population growth rate is 0.85%, while the historical high is 2.09%. However, due to the very long horizon length (1.6 million years) in the analysis, any population growth rate larger than 0.1% would have exploded (i.e., the expected life years would have gone to infinity). Thus, we tested a much smaller population growth rate instead, and we found that the expected life years saved from the mitigation are sensitive to the population growth rate. In other words, the benefits monotonically increase as the population growth rate increases.

The global real GDP per capita growth rate also plays an important role in calculating the benefits. According to the IMF, the global GDP per capita is projected to be USD 13,138.33 (IMF). This is the most up-to-date projection and is thus the one we use in this article. We wished to test some growth rates around the 2024 annual GDP per capita growth rate, 1.9%. However, due to the very long horizon length (1.6 million years) again, any growth rate larger than 0.01% would have exploded. Thus, we once more tested a smaller growth rate. We found the expected monetary benefit saved monotonically increased as the growth rate increased.

A long-debated issue in GCR/ER is discounting. Some experts believe we should not perform discounting, some believe that a low discounting rate should be used, while others believe that we should still perform discounting in very-long-term analyses. We found that the expected monetary benefit saved monotonically decreased as the discounting rate increased. Originally, we wished to test all three discounting rates: zero, very low, and regular. However, due to the very long horizon length (1.6 million years), terminal condition, and truncation adjustment, any discounting rate larger than 0.0001% would have generated nonreasonable results (i.e., the expected money value saved would have been negative) for some PGCR levels. Thus, we tested a smaller discounting rate instead, echoing the work of [Jones \(2024\)](#), where he tested the near-zero social discounting so as to put more weight on future generations. With a stable yearly growth rate as large as 10^{-6} , the expected life years saved increase significantly. With a stable yearly growth rate of 10^{-5} , the expected life years saved increase dramatically for smaller PGCR levels, such as 10^{-6} , 10^{-7} , 10^{-8} , and 10^{-9} .

The analytical framework used in this article provides examples of and insights into the benefits of reducing GCRs. This research is preliminary and based on existing indicators. Researchers may disagree with the assumptions underlying the variable values used, as well as the variables themselves, and readers are encouraged to apply their own assumptions to the model and explore the results.

Limitations and Future Research Directions

In this study, we relied on assumptions, simulations, and specialist opinions. First of all, we assumed that the estimate made by [Tegmark and Bostrom \(2005\)](#) is correct. [Tegmark and Bostrom \(2005\)](#)'s estimate bound the natural risks from above as $1/(1.1 \times 10^9)$. If [Tegmark and Bostrom \(2005\)](#) are correct, then the aggregate probability of non-dominant risks is indeed negligible compared to the anthropogenic risks within the chosen range. Many of our analyses rely on this assumption, while some results can stand alone.

In addition, future studies may adopt utility/social welfare functions, such as [Jones \(2024\)](#) and [Jones \(2025\)](#), to establish a better economic foundation in their models. Further, researchers may merge utility mathematic equations into the probability model of this article to increase the calculation speed so that more thorough Monte Carlo-type analyses can be performed in a more time-efficient manner. Incorporating an investment efficiency parameter into the model could be fruitful as well. [Jones \(2024\)](#) shows that the benefits

based on the value of the statistical life year can be twice as large as benefit estimates based on the GWP per capita for US cases. The benefit estimates in our article are based on the global gross domestic product (GWP per capita). Future studies may also consider using the value of the statistical life year. Moreover, the link between the calculated “benefits” and actual, cost-effective policy interventions can be made in future studies. Our analysis can be applied either with or without space colonization and with low or moderate population increases. However, our analysis does not apply to space colonization with significantly high population increases. Furthermore, the non-constant annual hazard rate for aggregated GCRs can be tested. In addition, we attached zero weight to post-human species throughout this study, and future studies may relax this assumption. Nonetheless, our model calculates expected survival conditional on extinction within the horizon. Future research may compute unconditional expectations to better explore the properties of the finite limiting values as R approaches zero. Finally, further research through multiple values, variables, and even model structures will help us better understand the important global disaster risk (GCR) issue, gather sufficient resources, develop reasonable response methods, and ultimately reduce the global disaster risk (GCR).

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Abbreviations and Definitions

Abbreviation	Terminology	Definition
GCRs	Global catastrophic risks	The most significant risks that threaten the survival of the human species.
NGCRs	Natural GCRs	GCRs that are broadly unrelated to human activity; they are also known as * exogenous risks.
AGCRs	Anthropogenic GCRs	GCRs that are caused or closely linked to human activity; they are also known as endogenous risks. It is a sub-set of PGCR. **
PGCRs	Partial AGCRs	GCRs caused by anthropogenic factors or partially anthropogenic factors; they are a larger set than AGCRs.
LAA	Loose-approximation assumption	A heuristic for reconciling disparate probability estimates. ***
MG	Magnitude gap	One risk is 10^{-5} per year, the second risk is 10^{-10} . Then, there is an MG, and the second risk is minor.
ERs	Existential risks	Also refer to the largest risks to the survival of the human species.
GWP	Gross world product	Similar to the GDP but at the global level.
EGCRs	Extreme global climate risks	Extreme climate risk scenarios, often caused by climate change, which could cause the extinction of the human species.
APRs	Anthropogenic pandemic risks	Extreme pandemic risk scenarios caused by anthropogenic pathogens that could cause the extinction of the human species.

*, ** ÓhÉigearthaigh (2025). *** Details can be found in the text.

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