Cost-Benefit Analysis of Space Exploration: Some Ethical Considerations

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**Abstract**

Humanity faces many important decisions about space exploration. An important but controversial decision making paradigm is cost-benefit analysis (CBA). This paper discusses some ethical considerations in CBA that are important to decision making about space exploration, including: how we define costs and benefits; space exploration's non-market value; the standing of future humans and of extraterrestrials; and the role of discounting in evaluating long-term space exploration projects.

## 1. Introduction

Humanity faces many important decisions about space exploration. Should we send humans to the moon, to Mars, and/or beyond? Should we develop self-sufficient space colonies, such as through terraforming? Should we preserve extraterrestrial planets in their native form? These are just a few of the important space exploration decisions society faces.

In studying how we go about answering questions such as these, it is helpful to distinguish between an *ethical framework* and a *decision making paradigm*. An ethical framework is an underlying view of what is fundamentally right and wrong which can be used to evaluate specific decisions. A decision making paradigm is a procedure for making decisions given both an ethical framework and the requirements of a decision making scenario, such as limited time and information. Different ethical frameworks can – and indeed often do – share the same decision making paradigm in certain scenarios.

Cost-benefit analysis (CBA) is a very prominent decision making paradigm. Many government agencies around the world are often asked to justify their programs via CBA. For example, CBA justification is required of all agencies of the Executive Branch of the USA, including NASA [1–2]. CBA also has strong support from some sectors of the academic community, including economics and risk analysis. Finally, private businesses also employ a form of CBA in much of their decision making.

Despite its prominence, CBA remains highly controversial. Many outright reject CBA on ethical grounds; others accept CBA itself but object to the way in which it is commonly implemented, also on ethical grounds. (See [3] for discussion.) Even within the common approach to CBA implementation, there exists great flexibility in how to conduct and interpret the analysis; again, different ethical frameworks will yield different implementations. How – if at all – CBA is implemented has substantial implications for space exploration decision making and thus is the focus of this paper.

This paper discusses some ethical considerations in CBA as they pertain to space exploration. Section 2 provides some background information on the CBA paradigm, including a discussion of how costs and benefits are defined. Section 3 discusses non-market valuation, which is the process of valuing costs and benefits that cannot be priced through market transactions. Section 4 discusses the issue of standing, the issue of whose costs and benefits are relevant to CBA. Section 5 discusses discounting, the process for comparing costs and benefits that occur at different points in time. Section 6 concludes.

## 2. The CBA Paradigm

In the cost-benefit analysis decision making paradigm, the outcomes of possible decisions are analyzed in terms of their costs and benefits. For a given possible decision, if the benefits are larger than the costs, then that decision is said to *pass* the CBA; if the costs are larger than the benefits, then the decision is said to *fail* the CBA.

In general, as the benefits of a decision increase and the costs decrease, the decision becomes more likely to be recommended. If the underlying ethical framework consists exclusively of the costs and benefits being measured, then decisions are recommended if and only if they pass CBA. However, if the underlying ethical framework contains other factors, then it is possible for a decision to pass a CBA yet not be recommended, or to fail a CBA and be recommended. For example, the Clinton administration also considered the distribution of costs and benefits and thus would recommend programs that failed CBA if they involved substantial wealth redistribution from rich to poor [4].

The CBA paradigm itself is flexible regarding how costs and benefits are defined. Indeed, costs and benefits can be and often are defined in many ways: there can be monetary costs and benefits, human costs and benefits, environmental costs and benefits, and so on. For example, space exploration is known to hold a "physical" cost representing the physiological harm of space travel [5]. Furthermore, how these costs and benefits are measured is also flexible. Indeed, how to measure costs and benefits is often the subject of much inquiry, such as how to measure the cost associated with the loss of human life [6].

Despite the considerable flexibility allowed by the CBA paradigm, CBA is commonly implemented with costs and benefits being measured in units of money [7]. This is the case, for example, in recent discussions of space policy appearing in this journal [8–9].[1] Thus, while remaining open to the broader range of possible versions of CBA, this paper will pay particular attention to the commonly-used CBA based on units of money. I will refer to the broader range of possible CBAs as CBA *broadly understood* and to the common CBA as *money-based* CBA.

[1] Note that [8–9] are not CBAs but discussions of challenges in estimating the costs of space programs. However, both assume that costs are to be measured in units of money.

It should be noted that the flexibility of CBA is not unlimited. In particular, CBA, even when broadly construed, still falls within the realm of consequentialist ethics [7]. This means that only the consequences of decisions are taken into consideration. Questions of fundamental rights are ignored. Thus, where questions of rights come up in space exploration, such as in questions of whether we have the right to perturb extraterrestrial planets from their native condition [10–11], CBA may be of limited or negligible relevance.

While CBA may not help us handle rights violations, CBA can help us decide what to do given recognition of inviolable rights. Here, the rights are imposed as a constraint on available options. CBA is then conducted to compare those options that meet the constraint. For example, there could be a constraint forbidding us from perturbing extraterrestrial planets. CBA can help us assess what to do from among those options in which the planets are not perturbed. Such analysis is often called *cost-effectiveness analysis* because the analysis seeks the most "cost-effective" means of meeting the constraint. Cost-effectiveness analysis is used heavily in health policy, where the aim is to minimize monetary costs (maximize monetary benefits) given a constraint of some level of health care provision, or alternatively to maximize health benefits given a constraint of some level of monetary expenditure [12–13].

## 3. Non-market valuation

The common approach to CBA defines costs and benefits in terms of their values in market transactions, measured in units of money. However, many phenomena that we value are not exchanged in markets. This includes such things as ecosystem services such as clean air and water [14], the existence of ecosystems even in the absence of any human use thereof [15], and our own lives [6]. In order to include these values in CBA, it is common practice to conduct *non-market valuation* [16]. Non-market valuation is thus, in a sense, a means of quantifying seemingly qualitative values. As this section shows, non-market valuation can play an important role in CBA of space exploration. Thus, whether or not we should include non-market valuation is an important consideration.

Whether to include non-market valuations in CBA is a matter of controversy, both for money-based CBA and for CBA broadly understood. Some people object to measuring the values of such things as ecosystem services and human lives in monetary units [17]. This objection can sometimes be resolved by conducting CBA in non-monetary units, including units of ecosystem services or units of human lives. However, other times, the objection stems from a rejection of consequentialist ethics in at least some circumstances. For example, those who argue that it is fundamentally wrong to cause loss of human life (even to save a greater number of human lives) would reject any CBA involving loss of human life. However, they might accept a cost-effectiveness analysis in which the causation of loss of human life was a constraint. Alternatively, they might accept a CBA as information that can be part of the decision making process while requiring other information as well.

One of the biggest benefits of space exploration is the insights we gain about our place in the universe. These insights come from discoveries such as cosmic microwave background radiation (c.f. [18–20]), which provides strong evidence for the Big Bang model for the formation of the universe, as well as from the information sent back from spacecraft (including spacecraft both with and without humans on board), and studies related to the distribution of life in the universe. While some of this benefit can be measured in market terms, such as through sales of books like *A Brief History of Time* [21] and *Pale Blue Dot* [22], quite a lot of this benefit goes uncaptured by markets. I am unaware of any efforts to estimate this benefit, although I suspect that the benefit is often large enough to justify estimation studies, especially if project decisions may be influenced by such estimates. Such estimates may compensate at least in part for the perceived excessive cost of space exploration programs [8–9] which often makes these programs seem difficult to justify [23–24].

Another non-market benefit of space exploration is reduction in the risk of the extinction of humanity and other Earth-originating life. Without space colonization, the survival of humanity and other Earth-originating life becomes extremely difficult- perhaps impossible- over the very long-term. This is because the Sun, like all stars, changes in its composition and radiative output over time. The Sun is gradually converting hydrogen into helium, thereby getting warmer. In approximately 500 million to one billion years, this warming is projected to render Earth uninhabitable to life as we know it [25–26]. Humanity, if it still exists on Earth then, could conceivably develop technology by then to survive on Earth despite these radical conditions. Such technology may descend from present proposals to "geoengineer" the planet in response to anthropogenic climate change [27–28].[2] However, the Sun later- approximately seven billion years later- loses mass that spreads into Earth's orbit, causing Earth to slow, be pulled into the Sun, and evaporate. The only way life could survive on Earth may be if Earth, by sheer coincidence (the odds are on the order of one in $10^5$ to one in $10^6$ [29]) happens to be pulled out of the solar system by a star system that passes by. This process *might* enable life to survive on Earth much longer, although the chance of this is quite remote.

While space colonization would provide a hedge against these very long-term astrological threats, it would also provide a hedge against the more immediate threats that face humanity and other species. These threats include nuclear warfare, pandemics, anthropogenic climate change, and disruptive technology [30]. Because these threats would generally only affect life on Earth and not life elsewhere,[3] self-sufficient space

[2] The term "geoengineering" is commonly understood to refer to "the intentional large-scale manipulation of the environment, particularly manipulation that is intended to reduce undesired anthropogenic climate change" [27, p.245]. Contemporary geoengineering proposals include injecting aerosols into the upper atmosphere or stratosphere, placing radiation shields between Earth and the Sun, and fertilizing oceans with iron to stimulate photosynthesis [27].

[3] A possible exception is the threat of runaway artificial intelligence [31], which may have the capacity to seek and destroy space colonies. This possibility places the artificial intelligence threat in an even more severe class than those threats that would only affect life on Earth.

colonies would survive these catastrophes, enabling life to persist in the universe. For this reason, space colonization has been advocated as a means of ensuring long-term human survival [32–33]. Space exploration projects can help increase the probability of long-term human survival in other ways as well: technology developed for space exploration is central to proposals to avoid threats from large comet and asteroid impacts [34–35]. However, given the goal of increasing the probability of long-term human survival by a certain amount, there may be more cost-effective options than space colonization (with costs defined in terms of money, effort, or related measures). More cost-effective options may include isolated refuges on Earth to help humans survive a catastrophe [36] and materials to assist survivors, such as a how-to manual for civilization [37] or a seed bank [38]. Further analysis is necessary to determine the most cost-effective means of increasing the probability of long-term human survival.

A related question also relevant to space exploration is how to make tradeoffs between increases in survival probability and other benefits. This question treats survival not as a constraint for cost-effectiveness analysis but as a benefit that can be compared with other benefits. Such comparisons require a measure of the value of human survival. However, the value of survival lacks a precise figure. In traditional money-based CBA, it is not unreasonable to assign humanity's survival an infinite value, or a value that is sufficiently large that it dominates everything else in CBA as if it were infinite. In *Catastrophe: Risk and Response* [39], United States Court of Appeals judge Richard Posner gave human survival a value of $600 trillion; Posner described this as a crude underestimate intended to show that even with such an underestimate, extensive effort to avoid human extinction passes CBA. Thus, following the common approach to non-market valuation, any reasonable estimate for the value of human survival suggests that this may be an important factor in space exploration CBA.

It is of note that the priority of reducing human extinction risk persists in forms of CBA which value nature in an *ecocentric* fashion, i.e. independently of any consideration of human interests. The basic reason is that without humanity leading long-term survival efforts (which would most likely include space colonization), the rest of Earth life would perish due to the astrological processes described above. This point is elaborated by futurist Bruce Tonn, who argues on ecocentric grounds for reorienting society to focus on avoiding human extinction through both immediate avoidance of catastrophe and long-term space colonization [40]. Tonn dubs this process of surviving beyond Earth's eventual demise "transcending oblivion" [41]. There is thus some convergence in the recommendations of the common anthropocentric, money-based CBA and the ecocentric CBA described here. This convergence is due to the fact that (in all likelihood) only humans are capable of colonizing space, and thus human survival is necessary for Earth life to transcend oblivion.

## 4. Standing

Standing concerns whose costs and benefits to count in CBA. Though often overlooked in CBA design, whom to give standing to can be a crucial concern [42]. For example, a

CBA that gives standing only to the contemporary residents of one region may recommend far less environmental protection than a CBA that gives standing to everyone in the world over a long time period. Standing is also an important factor in space exploration.

One important question for CBA of space exploration is whether to give standing to extraterrestrials. This can include both any sentient extraterrestrials that humans might encounter as well as any non-sentient extraterrestrial life and the non-living extraterrestrial environment (planetary rocks, atmospheric gasses, etc.). By granting standing to extraterrestrials, concern for them can be integrated into CBA beyond the concern that humans have for them. Implementing this concern may be more readily implemented if the CBA is not the common money-based form, because extraterrestrials, like non-humans on Earth, do not use money and thus cannot easily have their interests monetized.[4] For example, following an ethical framework that values both human welfare and intact extraterrestrial planets, it is possible to develop a framework for deciding when the costs to a planet of terraforming outweigh the benefits to humanity of increased resources and living space. Precisely how to develop such a framework may be an ambiguous and ambitious task, but it would not be inconsistent with the principles of CBA, broadly understood.

It should be emphasized that the traditional money-based CBA can (and often does) place value on non-human phenomena and thus could be used to value extraterrestrials. As discussed above, this valuation includes both aspects of non-human phenomena that humans value because we use them ("use value") and aspects that we value simply because they exist ("existence value") [15]. However, these valuations remain anthropocentric in the sense that the non-human phenomena aspects are considered to hold value only to the extent that they are valued by humans. Giving standing to these phenomena would ensure that they are valued regardless of what opinions any humans have on the matter. This approach is advocated by ecocentric ethicists, although these ethicists commonly also value human interests as well [43]. Of course, some anthropocentrism is inevitable, as long as the CBA (or other analysis) is conducted by humans [44], but this fact does not preclude us from giving standing to non-humans in such a way that their interests more fully than is done through anthropocentric evaluation techniques such as money-based CBA.

A space exploration scenario in which the standing question may be particularly important or even crucial is the event of conflict or possible conflict between humanity and an extraterrestrial civilization. Here, whether to give the civilization standing in CBA could prove highly controversial. It could easily result that a CBA would suggest that humanity should forfeit the conflict, sacrificing itself to the extraterrestrials in order to increase the total amount of benefit in the universe. This situation resembles the famous utility monster developed by philosopher Robert Nozick [45] as an argument against utilitarianism, the ethical framework that advocates conducting CBA in units of

[4] This would not be the case if humans encountered an extraterrestrial civilization which used a form of money which was comparable to human money. In this case, money-based CBA could be conducted using an exchange rate between human money and extraterrestrial money.

utility, which here means wellbeing or quality of life. Under utilitarianism, one would recommend sacrificing humanity if the extraterrestrials would experience more utility than the humans would. While this clearly is a defensible position, it is almost certain to be highly controversial.

The question of giving standing to extraterrestrials also resembles some more familiar questions of giving standing to 'others'. For example, in CBA of global issues such as climate change, foreigners often have less standing than citizens of the same country, and sometimes have no standing at all (c.f. [46]). Ethicist Peter Singer, a supporter of utilitarianism, famously argues that humans should try to help all other humans equally, regardless of where they are around the world [47] and that non-human animals should have equal standing as humans [48]. Singer has also commented on extraterrestrials, writing "If we were to meet intelligent, sympathetic extraterrestrials, would we deny them basic rights because they are not members of our own species? At a minimum, we should recognize basic rights in all beings who show intelligence and awareness (including some level of self-awareness) and who have emotional and social needs" [49]. Personally, I am sympathetic to Singer's views, although I understand why his work is controversial [50].

If both humans and extraterrestrials are given standing, the question arises of how to compare their respective lives. If a tradeoff must be made between human lives and extraterrestrial lives, then how should the tradeoff be made? A CBA approach using non-market valuations of human and extraterrestrial lives can help make this tradeoff. Here, how this to make this tradeoff corresponds to how much human lives should be valued relative to extraterrestrial lives. Similar issues exist within human populations. For example, should the lives of the poor [51] or the elderly [52] be valued less than the lives of the rich or the young? Arguments have been made in favor of valuing all human lives equally in CBA [53]. However, the question of whether we should value extraterrestrial lives equally to human lives may more closely parallel the question of whether we should value human lives equally to non-human lives on Earth. As money-based CBA generally does not grant non-humans standing, it does not value non-human lives (except to the extent that they are valued by humans, as discussed above). Thus, if extraterrestrials are granted standing, then valuing their lives would require adjustment to common CBA practice.

Another important question for CBA of space exploration is whether to give standing to future humans. This question is important because of the very long time scales involved in space exploration. For example, the terraforming of Mars could take tens to hundreds of thousands of years [54]. If future humans have no standing, then the benefits of terraforming Mars would not be included in the CBA and the terraforming is unlikely to be recommended. These issues of temporal distribution are discussed in greater detail in the Section 5, on discounting.

## 5. Discounting

Discounting generally refers to the process of comparing the values of costs and benefits that occur in different points in time. The discounting concept is often weakly understood and haphazardly implemented [55]. However, how discounting is implemented is an important part of CBAs of decisions which cause future costs and benefits. The longer-term the decision, the more important discounting becomes. As space exploration involves some very long-term decisions, discounting is very important to space exploration CBA.

Discounting is commonly discussed in terms of the *discount rate*, i.e. the rate at which costs and benefits lose value over time. If a benefit of size B occurs at N years in the future, then, with an annual discount rate D, the benefit has the same value as a benefit of size B*exp(-D*N) that occurs now. The lower the discount rate, the more important future costs and benefits are.

The most common approach to discounting under money-based CBA is to match the discount rate to market interest rates. Within this approach, there is still some flexibility in choosing discount rates, depending on whether one uses the interest rates from bonds, stocks, or other financial instruments [56]. Furthermore, given uncertainty about future economic performance, it is often recommended that *certainty equivalent* discount rates are used. Certainty-equivalent rates decline over time, making future costs and benefits more important than they are when uncertainty is not factored in [57].

Another common approach to discounting, called the *prescriptive approach*, matches the discount rate to whatever is optimal according to the ethical framework (prescription) in effect [58]. The prescriptive approach is commonly implemented using the utilitarianism ethical framework. This leads to lower discount rates than the market interest rate approach, which in this context is called the *descriptive approach*. There exists much debate over these two approaches to discounting [59].

As noted above, space exploration decisions are often very long-term. Because of this, how discounting is handled in CBA will figure prominently in what space exploration decisions are recommended. Lower discount rates will yield CBAs more favorable to space exploration. However, where space exploration can reduce the risk of human extinction, even a high discount rate may yield recommendations in favor of space exploration [60]. Humanity's survival is simply worth that much, under the common assumptions about value.

## 6. Conclusions

CBA is a prominent decision making paradigm that can be used to guide space exploration decision making. While CBA is commonly expressed in units of money, CBA broadly understood offers considerable flexibility in how it is expressed. Both within and beyond the common expression of CBA, several ethical issues arise. How these issues are addressed can significantly affect space exploration decision making. However, where space exploration reduces the risk of human extinction, it will likely be recommended under a wide range of possible versions of CBA.

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