# Sensitivity of expected civilization longevity models

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## ABSTRACT

In this paper, we analyse the parameter sensitivities of the Sandberg and Rare Earth civilization longevity models. The Sandberg model relies on the Drake equation, while the Rare Earth model assumes that the Earth is a very unique planet because of rare sequence of events causing its evolution. In addition to the sensitivity of the parameters, we also analyse the importance of those parameters.

## KEYWORDS

Human extinction, Drake equation, Civilization collapse, Rare Earth hypothesis, distributions

## 1 INTRODUCTION

After years of dealing with Fermi's question: "Where is everybody?", we still do not seem to have a good answer. After scanning more than 10 million stars [11], we have not found a single extraterrestrial life.

We know that it is inevitable that human civilization will one day die out, but what is the expected longevity and how is it related to the absence of observed civilizations? One way is to design human longevity models that use a variety of parameters to answer this question. However, it is not clear which models heavily rely on the values of parameters. In this paper we study the sensitivity of the models to the parameters and we also try to determine which parameters have the greatest impact.

In our previous papers [6, 14] we approached the topic of the extinction of human civilization and introduced the Drake equation [1]. In the first paper [6] we presented Sandberg's [8] interpretation of the Drake equation and analysed it. In the second paper [14], we presented possible causes of human extinction and used the Drake equation to estimate the longevity of human civilization. In the last paper [4], we presented four different models with some modifications of the Drake equation and considered their prospects for the time we have left. We concluded that we are most likely to survive at most 10 000 years.

In this paper, we focused mainly on two of the models from the previous paper [4]. The first model we analysed is based on Sandberg [8] and the second one represents the "rare Earth" hypothesis [12]. For both models we analysed the difference between using log-uniform and log-normal distributions of the parameters. In addition, we analysed which parameters most affect the results in each model. All in all, we dove into the structure of the models and tried to improve the accuracy of the results.


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## 2 RELATED WORK

Some publications suggest there are 600 to 40 000 technological civilizations in our galaxy [10], while others think there should be about 36 of them, assuming an average lifespan of 100 years [13]. However, given our ability to detect intelligent life [3] and their radio signals [2], and the fact that we have not detected anything yet, a large number of civilizations is unlikely.

In our previous paper [4], we analyzed 4 different models of the modified Drake equation to determine longevity of human civilization. From the accessible data, we concluded that the human technological civilization will most likely survive at most 10 000 years. Note that the analysis is not able to conclude anything about biological aspects of humans. Another research induces that the yearly probability for extinction is most likely less than 1 in 87 000 using four different models [9]. In [5] they explain that humanity will eventually have to move to avoid the death of our Sun.

In this paper we focused on how the parameters of the Drake equation and the choice of the various attributes in two models affect the probability of longevity of human technological civilization.

## 3 ESTIMATING THE LONGEVITY OF HUMAN CIVILIZATION WITH SANDBERG AND RARE EARTH MODEL

### 3.1 SANDBERG MODEL

The Sandberg model [8] is based on Drake equation:

$$N = R_* f_p n_e f_l f_i f_c L \tag{1}$$

- $R_*$ being the rate of star formation per year,
- $f_p$ the fraction of stars with planets,
- $n_e$ the number of Earth-like (or otherwise habitable) planets per a star that has planets,
- $f_l$ the fraction of habitable planets with actual life,
- $f_i$ the fraction of life-bearing planets that develop intelligence,
- $f_c$ the fraction of intelligent civilizations that are detectable,
- $L$ the average longevity of such civilizations.

**Table 1: Probability densities for the parameters in equation** (1)

| Parameter | Distribution |
|---|---|
| $R_*$ | log-uniform from from 1 to 100 |
| $f_p$ | log-uniform from 0.1 to 1 |
| $n_e$ | log-uniform from 0.1 to 1 |
| $f_l$ | log-normal rate, described in paper [9] |
| $f_i$ | log-uniform from 0.001 to 1 |
| $f_c$ | log-uniform from 0.01 to 1 |
| $N$ | point values: 1 to 10 000 |

From the equation we can compute $N$, which is the number of detectable civilizations, or longevity $L$:

$$L = \frac{N}{R_* f_p n_e f_l f_i f_c} \tag{2}$$

with parameters, i.e. probability densities and limits from Table 1. As Sandberg suggests, all distributions used in this model were log-uniform.

## 3.2 RARE EARTH MODEL

The Rare Earth model is based on the "rare Earth" theory that assumes that Earth is a very unique planet evolved under rare circumstances. This theory introduces equation:

$$N = N^* n_g f_p f_{pm} f_i f_c f_l f_m f_j f_{me} \tag{3}$$

We combined equation (3) with Drake's equation and used probability distributions from Tables 1 and 2. This instantly rules out the need of the $f_p$ (the fraction of stars with planets) parameter. Furthermore, product $f_l * f_i * f_c$ from Drake is equal to $f_i * f_c * f_l$ from Rare Earth, which gives us the final equation:

$$L = \frac{N^* n_g f_{pm} f_m f_j f_{me}}{R_* n_e} \tag{4}$$

and some new parameters:

- $N^*$ is the number of stars in the Milky Way galaxy (between 250 and 500 billion),
- $n_g$
- $f_{pm}$ is the fraction of planets that are metal-rich (between 1 and 10 percent),
- $f_m$ is the fraction of planets with a large moon (between 0.3 and 3 percent),
- $f_j$ is the fraction of solar systems with Jupiter-size planets (between 5 and 10 percent),
- $f_{me}$ is the fraction of planets with a critically low number of extinction events (between 1 and 10 percent).

In the Rare Earth model we also used log-uniform distribution, in order to compare it to the Sandberg model results.

# 4 EXPERIMENTS

## 4.1 Issues with log-uniform distribution

In analysing the two models, we focused primarily on how different distributions affect the results. Due to the shape of log-uniform distribution (see Figure 2), the part of the graph that is very close to zero has a significant impact on the final result. Since we have a logarithmic scale, the part from zero to one on the logarithmic scale corresponds to the range from zero to one percent, while the part from one to two percents corresponds to the range between one and one hundred percent, even though they appear to have the same weight on the logarithmic scale. The high values near zero therefore make it very sensitive to changes in parameter ranges and can even cause numerical errors when multiplications occur or at least strongly influence the final result.

For this reason, distributions whose values are close to zero at the boundaries of the parameter range are more stable with respect to changes in the parameters. We compared the stability of the log-uniform distribution with the log-normal distribution by slightly changing the lower bound of some parameters and observing the corresponding change in the distribution. The results in Figures 1 and 2, and later 3 and 4 indicate that the change of log-uniform distribution is much larger than that of log-normal distribution. Therefore, the log-normal distribution is much less dependent on the choice of the parameter range.

**Table 2: Probability densities for the parameters in equation** (4)

| Parameter | Distribution |
|---|---|
| $N^*$ | log-uniform from 10.7 to 12.7 |
| $n_g$ | log-uniform from -1.3 to -0.8 |
| $f_{pm}$ | log-uniform from -3 to -0.7 |
| $f_m$ | log-uniform from -2.5 to -1.5 |
| $f_j$ | log-uniform from -1 to 0 |
| $f_{me}$ | log-uniform from -2.5 to -1.5 |

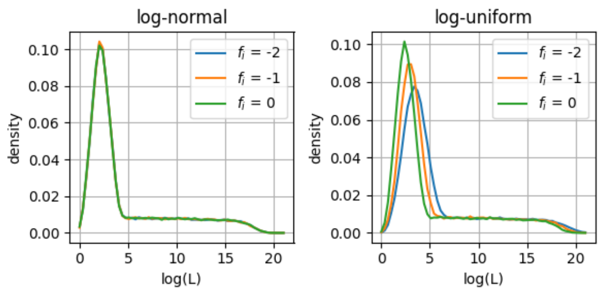


**Figure 1: Change of probability distribution with respect to change of lower range limit of parameter $f_i$.**

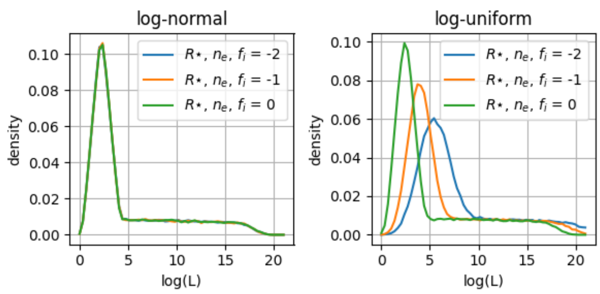


**Figure 2: Change of probability distribution with respect to change of lower range limit of parameters $R*$, $n_e$ and $f_i$.**

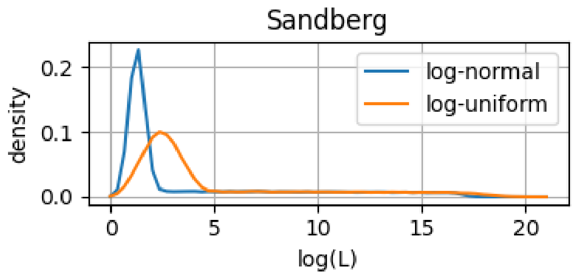


**Figure 3: Difference between log-uniform and log-normal distribution in the Sandberg model.**

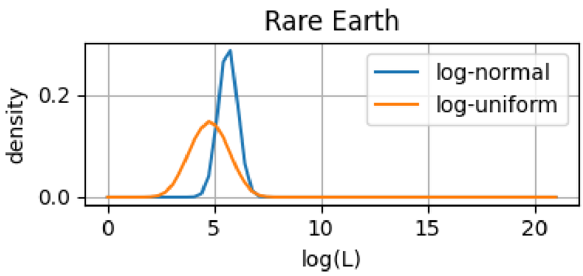


**Figure 4: Difference between log-uniform and log-normal distribution in the Rare Earth model.**

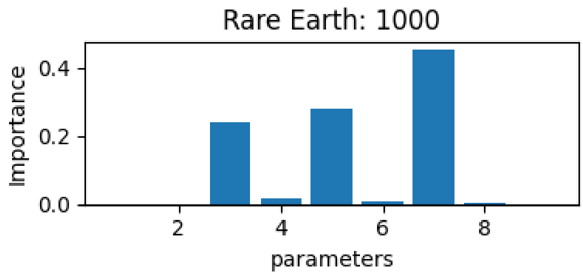


**Figure 5: Importance of parameters in Rare Earth model for estimating probability of surviving 1000 years.**

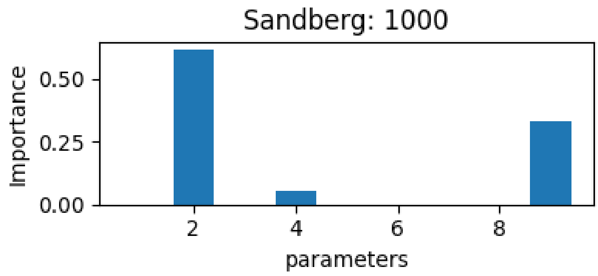


**Figure 6: Importance of parameters in Sandberg model for estimating probability of surviving 1000 years.**

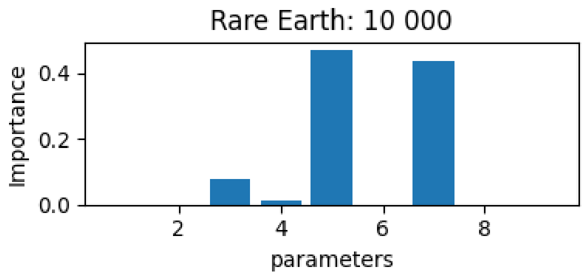


**Figure 7: Importance of parameters in Rare Earth model for estimating probability of surviving 10 000 years.**

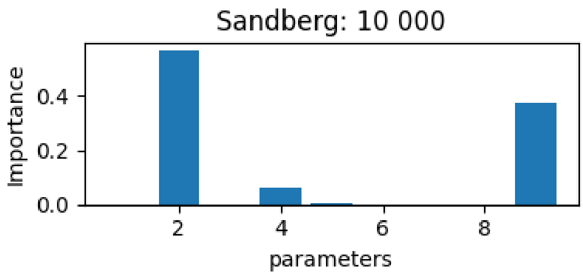


**Figure 8: Importance of parameters in Sandberg model for estimating probability of surviving 10 000 years.**

## 4.2 Parameter importance

In order to analyse the stability/sensitivity of the two models, we studied which parameters have the greatest impact on the final result. For this purpose, a dataset with different values and distributions for the parameters was created for the two models. Then, three subsets were taken, each containing only the subset with rows for which the probability that we survive at least L years is above 90%. The L options chosen were: 1000, 10 000, 100 000. The importance of the features in each of the subsets was then calculated using the Gini importance method implemented in the Python's scikit-learn decision tree regressor algorithm [7]. The feature importance scores are shown in Figures 5 to 10.

We found that in the Sandberg model, parameters 2 and 9 play the most important role, as you can see in Figures 6, 8 and 10, which show the importance of the parameters in calculating the probability that we survive 1000, 10 000 and 100 000 years.

In the model Rare Earth, on the other hand, parameters 5 and 7 are crucial for the prediction. This can be seen from Figures 5, 7 and 9, which show the importance scores of the parameters when calculating the same probabilities with the model Rare Earth.

# 5 DISCUSSION AND CONCLUSION

This research took two promising models from our earlier study [4] and analysed stability and sensitivity of the models and parameters. We analysed the stability of the log-uniform distribution compared to the log-normal distribution. To determine the difference between the two, Figures 1 and 2 are visually informative: changing the parameter range significantly affects the log-normal distribution, while the log-normal distribution is insensitive to these changes. Therefore, the log-normal distribution provides more reliable results, while the log-uniform distribution may cause some numerical curiosities. It seems reasonable to use distributions that rely mainly on the central values rather than the marginal values.

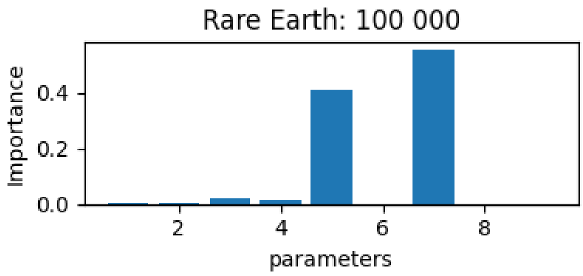


**Figure 9: Importance of parameters in Rare Earth model for estimating probability of surviving 100 000 years.**

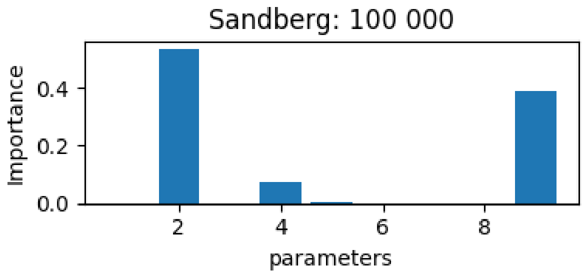


**Figure 10: Importance of parameters in Sandberg model for estimating probability of surviving 100 000 years.**

From Figures 3 and 4 we can observe that the Rare Earth model is considerably more optimistic than the Sandberg model. If we assume that Earth is very unique in our galaxy, we have the highest probability of living around 1 000 000 years. On the other hand, universe observations do not support well the uniqueness of our planet in terms of the large amount of suns with their planets. Further galaxy observations should provide more information which model fits the reality better.

From Figures 5 to 10, we can interpret that parameters 2, 5, 7, and 9 play the most important role in predicting the extinction of humanity. This seems novel compared to previous studies, and enables further discussion and studies regarding the causes and consequences of it. Whatever the case, while parameters seem to have numerically equal role and weight, studies of numerical relevance of the parameters of the equations (2) or (4) indicate significant differences.

Parameter 9 represents the choice of the distribution of the parameters. This is consistent with the distribution studies in this paper indicating that the probability curve for the longevity of human civilization strongly influences the obtained results.

Finally, while models do perform differently given different values of parameters, some patterns seem to emerge quite consistently if the parameters are set reasonably.

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