Optimized O'Neill/Glaser Model for Human Population of Space and its Impact on Survival Probabilities

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Abstract. Two contemporary issues foretell a shift from our historical Earth based industrial economy and habitation to a solar system based society. The first is the limits to Earth's carrying capacity, that is the maximum number of people that the Earth can support before a catastrophic impact to the health of the planet and human species occurs. The simple example of carrying capacity is that of a bacterial colony in a Petri dish with a limited amount of nutrient. The colony experiences exponential population growth until the carrying capacity is reached after which catastrophic depopulation often results. Estimates of the Earth's carrying capacity vary between 14 and 40 billion people. Although at current population growth rates we may have over a century before we reach Earth's carrying limit our influence on climate and resources on the planetary scale is becoming scientifically established. The second issue is the exponential growth of knowledge and technological power. The exponential growth of technology interacts with the exponential growth of population in a manner that is unique to a highly intelligent species. Thus, the predicted consequences (world famines etc.) of the limits to growth have been largely avoided due to technological advances. However, at the mid twentieth century a critical coincidence occurred in these two trends – humanity obtained the technological ability to extinguish life on the planetary scale (by nuclear, chemical, biological means) and attained the ability to expand human life beyond Earth. This paper examines an optimized O'Neill/Glaser model (O'Neill 1975; Curreri 2007; Detweiler and Curreri 2008) for the economic human population of space. Critical to this model is the utilization of extraterrestrial resources, solar power and spaced based labor. A simple statistical analysis is then performed which predicts the robustness of a single planet based technological society versus that of multiple world (independent habitats) society.

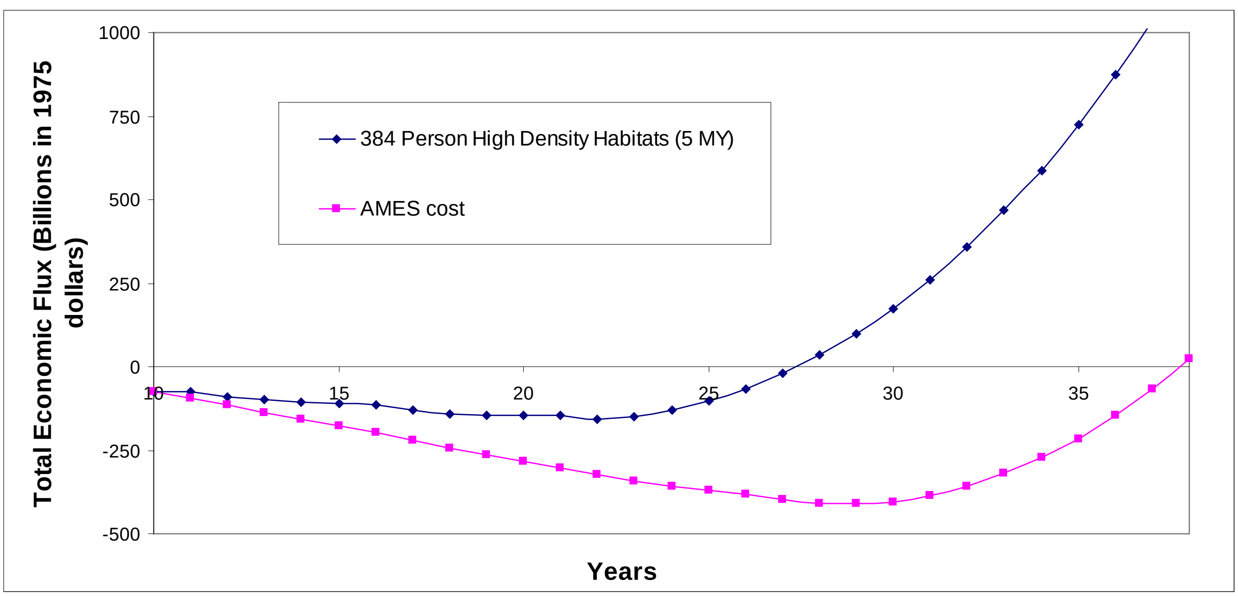

Figure 1. Net Present Value Curve for Space Solar Power and Habitat development showing classical O'Neill, Glaser Model (NASA Ames 1975) and model with optimized habitat size

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ABSTRACT

Two contemporary issues foretell a shift from our historical Earth based industrial economy and habitation to a solar system based society. The first is the limits to Earth's carrying capacity, that is the maximum number of people that the Earth can support before a catastrophic impact to the health of the planet and human species occurs. Estimates of the Earth's carrying capacity vary between 14 and 40 billion people. Although at current population growth rates we may have over a century before we reach Earth's carrying limit our influence on climate and resources on the planetary scale is becoming scientifically established. The second issue is the exponential growth of knowledge and technological power. The exponential growth of technology interacts with the exponential growth of population in a manner that is unique to a highly intelligent species. Thus, the predicted consequences (world famines etc.) of the limits to growth have been largely avoided due to technological advances. However, at the mid twentieth century a critical coincidence occurred in these two trends – humanity obtained the technological ability to extinguish life on the planetary scale (by nuclear, chemical, biological means) and attained the ability to expand human life beyond Earth. This paper examines an optimized O'Neill-Glaser model (O'Neill 1975; Curreri 2007; Detweiler and Curreri 2008) for the economic human population of space. Critical to this model is the utilization of extraterrestrial resources, solar power and spaced based labor. A simple statistical analysis is then performed which predicts the robustness of a single planet based technological society versus that of multiple world (independent habitats) society. The model predicts that the human extinction probability is high in this generation unless humans expand into multiple independent habitats in space.

INTRODUCTION

In the middle of the twentieth century a profound coincidence occurred. Humanity gained the technical power to effectively destroy all intelligent life on our planet as was graphically illustrated by the building of large arsenals of hydrogen bombs. For the first time in our history, a few people have had the ability to unleash global nuclear destruction - the ability to effectively end history.

Why have recent generations been at the brink of self induced extinction when so many generations before were robust? The answer is simply that our technological power has grown large in comparison to the size our single habitat – the Earth.

Concurrently we gained the technological power for people to leave the planet, as was illustrated by landing men on the moon. It was quickly realized (O'Neill, 1975) that by utilizing extraterrestrial materials and energy that we also had the ability to colonize space. NASA studies (Johnson and Holbrow, 1977) confirmed that it was technically possible to build large vista space habitats in free space, essentially anywhere in the solar system (out to the asteroid belt if only solar power were used) with up to about 4 million people in each. In O'Neill's habitat model the space citizens would live on the inside surfaces of radiation shielded spheres, cylinders, or torus's which would be rotated to provide Earth normal gravity. The prohibitive Earth launch costs for these massive structures could be off set by using lunar and asteroid materials. Construction of (Glaser, 1974) space solar power satellites by the space colonists would make the project economically viable. Economic break even for the O'Neill-Glaser model was calculated to be about 35 years after which very large profits would be incurred. The result would have been a solar powered Earth and millions of people living in space by the beginning of the twenty first century.

In this paper a simple model is suggested to analyze the risk of self induced extinction with continued growth in technological power for single and multiple habitat.

THE "RED BUTTON" SCENARIO

Let us begin with a thought experiment that we will call the "Red Button" scenario. Suppose that each person on Earth is given at 12 midnight GMT a "Red Button" which if pressed would essentially destroy all human life on Earth. How much longer would we last? The answer is almost certainly about 30 milliseconds after midnight which approximates the response time of the human thumb. With six billion people, we know that someone, probably quite a few people would push the button immediately.

What makes this thought experiment pertinent is that since 1950's there have been a number of people who have had the "Red Button" capability. How safe are we? To answer this question we must understand two things, the growth with time of technological power and the human propensity for self annihilation.

HUMAN PROPENSITY FOR SELF EXTINCTION

During the 1950's there were perhaps 10 people (about 5 in the U.S. and 5 in the U.S.S.R.) who had the power to initiate the global destruction of human society. What was our probability of self extinction? One (perhaps conservative) estimate of the human propensity for self extinction is the murder-suicide rate.

The human murder-suicide rate (Eliason, 2009) has remained relatively constant from 0.2 to 0.3 per 100,000 people per year. This would be about 15 thousand per year for a population of 6 billion or a probability of $2.5*10^{-6}$. With these assumptions we can estimate the probability of human self extinction during the 1950's. Where (for a single habitat) the probability of self extinction, P_0 is

$$P_0 = P_R \; N_C \qquad (1)$$

P_R is the probability that someone would initiate self extinction ("push the red button") and N_C is the number of people that have the capability to initiate extinction. So P_0 in the 1950's would be estimated as $2.5*10^{-5}$. Because of the relatively low propensity for murder-suicide our chances for survival in the mid 1950's were good. However, the number of people with apocalyptic capability has grown substantially during the last 60 years. Thus, in order to understand our self-extinction risks, we must understand the growth of N_C with time.

EXPONENTIAL GROWTH OF TECHNOLOGY AND N_C WITH TIME

The current number of people who possess the capability to initiate human extinction, N_C, is not easy to determine directly. There are now at least 10 nations that have nuclear weapons (FAS, 2008), stock piles have existed of biological weapons capable of destroying all humans 10,000 times over (John Hopkins, 2002), genetic engineering is becoming cheep and easy enough for a graduate student to do in a garage (Boutin, 2006) with unknown hazards, nano technologies and artificial intelligence are expected to have the potential for globally lethal events. Certainly, a serious comprehensive study of N_C with time is warranted, since the consequence of ignorance is to risk extinction.

With the above uncertainties stated, it is worthwhile to make a reasonable estimate for the trend of N_C. There is an impressive body of data (Kurzweil, 2005) that documents the exponential growth of knowledge and technology over the past centuries. Not only has the technological power increased exponentially but the costs of the technologies have tended to decrease exponentially with time. The growth N_C would be expected to follow the growth of technology in general. Thus, we can assume that N_C increases proportionately with the growth of technology. Following Kurzweil's model for technology growth, N_C as a function of time, t, would be

$$N_C = N_{C0}\, e^{(C\,t)} \qquad (2)$$

where N_{C0} is N_C at time zero and C is a constant. If we assume N_{C0} to be 10 at t = 1950, we could determine a value for C if with an estimate of N_C at 2010. Since a direct count of N_C is not available, we will make an indirect estimate. The increase in technological availability should be proportional to the increase in wealth and inversely proportional to the decrease in cost of the technology. For simplicity we will use nuclear weapon development and gross world product, GWP. Since 1945 the GWP has increased by a factor of 10 (Berkeley, 1998). Development of the first nuclear bomb in 1945 (The Manhattan Project) cost 20 billion (1996 dollars) (Brookings Institution, 2009). Development of the Pakistan nuclear bomb in 1998 was estimated to cost about $150 million. Thus the development cost of a nuclear weapon has decreased by about 100 times. Thus, a rough guess based on the increase in world wealth and the decrease in the costs of destructive technology for of the present value of N_C is 1000.

If we use $N_C = 10$ for 1950 and $N_C = 1000$ for 2010 in equation (2) we determine a value for C of 0.77. This allows us to calculate a projection for N_C versus time. P_0 can then be calculated by equation (1) assuming P_R to be equal to the murder-suicide probability. The result is given in Figure 1. What should be noted from this exercise is the increase in extinction probability over time, P_0, due to the exponential growth of technological power. In the given scenario P_0 was 1 in 100,000 in 1950, 1 in 500 today (2009), but will become 1 in 10 in 2060 and approach 1 in 2090. There are many assumptions in this calculation but the trend that N_C should increase in proportion to the exponential growth of knowledge and technological power is reasonable. If these calculations hold then the children born today would be the last humans to enjoy a full life span before self induced extinction becomes all but inevitable. The above analysis assumes that humanity remains a one planet society. Next we shall examine the effect on extinction probability if humanity adapts to multiple independent habitats beyond the Earth.

MULTIPLE INDEPENDENT HABITATS AND SUVIVAL PROBABILITIES

Next we will examine the survival probabilities of a “Red Button” capable society with multiple independent habitats. Let us define the subset of those who could produce an extinction event, N_C, which actually would push the “Red Button,” as N_R. If $N_R \geq 1$ we have extinction of a one habitat society. Next let us define N_H as the number of independent habitats that humans inhabit. In this context, independent means that the habitat has sufficient separation in space with other habitats that for the current technological level, a self extinction event in one habitat will not significantly affect the survival probability of another independent habitat.

Because of human nature (Eliason, 2009) we cannot reliably predict who is or will become a subset of N_R. (But by the analysis in Figure 1 it is very likely that the condition $N_R>1$ will occur within one human lifespan from the present.) So for the analysis we assume that N_R is randomly distributed among N_H. Now we can analyze the probability of self extinction, P_0, as a function of N_R and N_H. This analysis is similar to that for portfolio diversification (Miller, 2009) or for fault tolerant computing (Curreri, 2009).

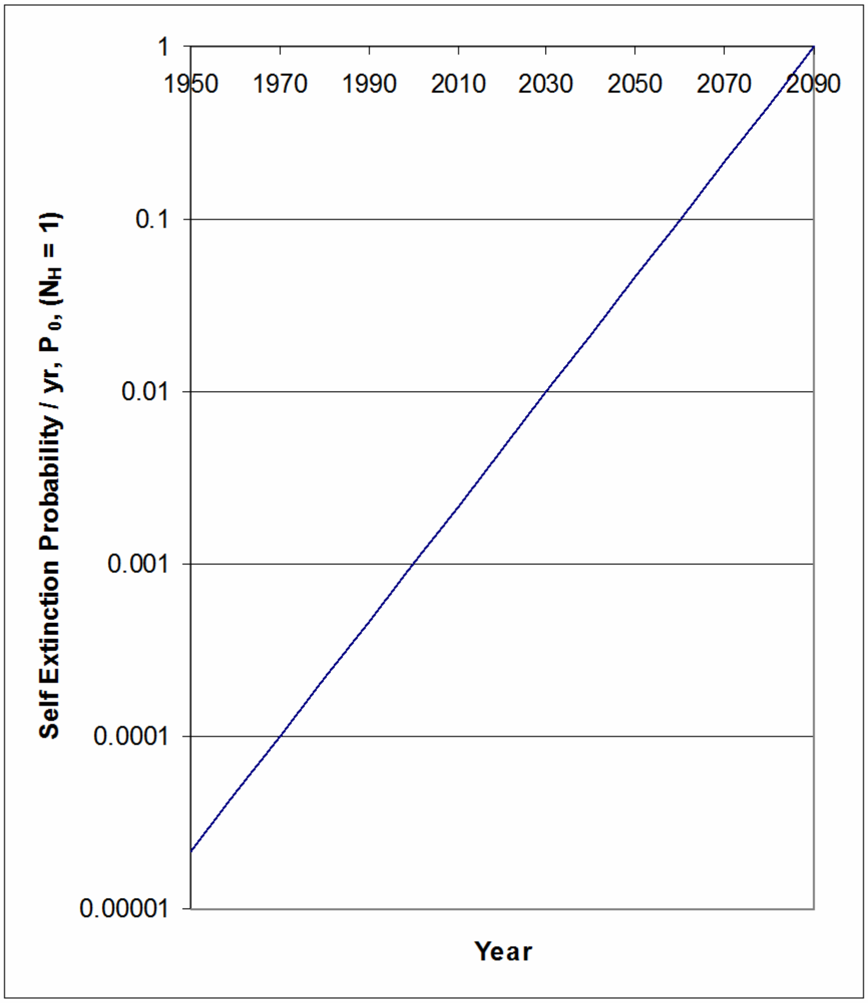

Figure 1. Calculation of Self Extinction Probability versus time for a single habitat if $N_C = 10$ in 1950 and $N_C = 1000$ in 2010.

An everyday analogy of this probability calculation is given as follows. Consider that a deck of cards represents an independent habitat, N_H, and the Aces are extinction events, N_R. The probability that we have an Ace in the deck (extinction) is 100%. If we cut the cards into two piles the probability of extinction, P_0, is less than 100 % since all the Aces could be in one pile. If we make 5 piles then the probability that each pile has one of the 4 Aces is zero ($P_0 = 0$). Let us apply this method with the assumption that humanity can establish habitats beyond Earth ($N_H > 1$).

The standard formula for the number of combinations of n and k where order is not important is

$$nCk = \frac{n!}{k!(n-k)!} \qquad (3)$$

Examining the probability for extinction, P_0, as a function of N_R and N_H we obtain

$$P_0 = \frac{(N_R - 1)C(N_H - 1)}{(N_H + N_R - 1)C\, N_R} \tag{4}$$

Let us explore the case where $N_R = N_H$ then

$$P_0 = \frac{1}{(N_H + N_R - 1)C\, N_R} \tag{5}$$

The extinction probability when $N_H = N_R$ for 1 to 10 habitats is given in Figure 2. Figure 2 shows that in the near future, N_R exceeds 1 the probability of human extinction can be greatly reduced with a small number of independent habitats. With one habitat by definition the probability of extinction is one, but with just two additional (Moon and Mars for example) the probability drops to one in ten per year. For five, nine, and ten habitats the probability of extinction per year drops to one in 100, 1,000 and 10,000 respectively.

The probability of extinction, however, tells only part of the story since it does not give information regarding surviving population. Multi habitat civilization design will need to consider the probability rate for outcomes of partial population loss. Equation 6 is the general formula for calculating the probabilities for all outcomes.

$$P_{(N_H, N_R)} = \sum_{K=1}^{K=(N_H V N_R)\min} \frac{(N_H C K)((N_R - 1)C(K-1))}{(N_H + N_R - 1)C\, N_R} \tag{6}$$

Equation 6 states that the probabilities for a N_H, N_R pair are given by the sum for k = 1 to the value of N_H or N_R whichever is lower acting on the ratio of the combinations to the right. The results for pairs of N_H and N_R from 1 to 6 are given in Table 1.

As an example of how to read the table, the cell for N_H and $N_R = 2$ would read that the probability outcome (for that time step) for zero population is one out of three, and the probability for survival of one half the initial habitats is 2 out of three. From study of Table 1 it is apparent the complexity of the possible outcomes increases as N_R and N_H become greater. It is evident that

If $N_R \geq N_H$ then $P_0 > 0$.
If $N_R < N_H$ then $P_0 = 0$.

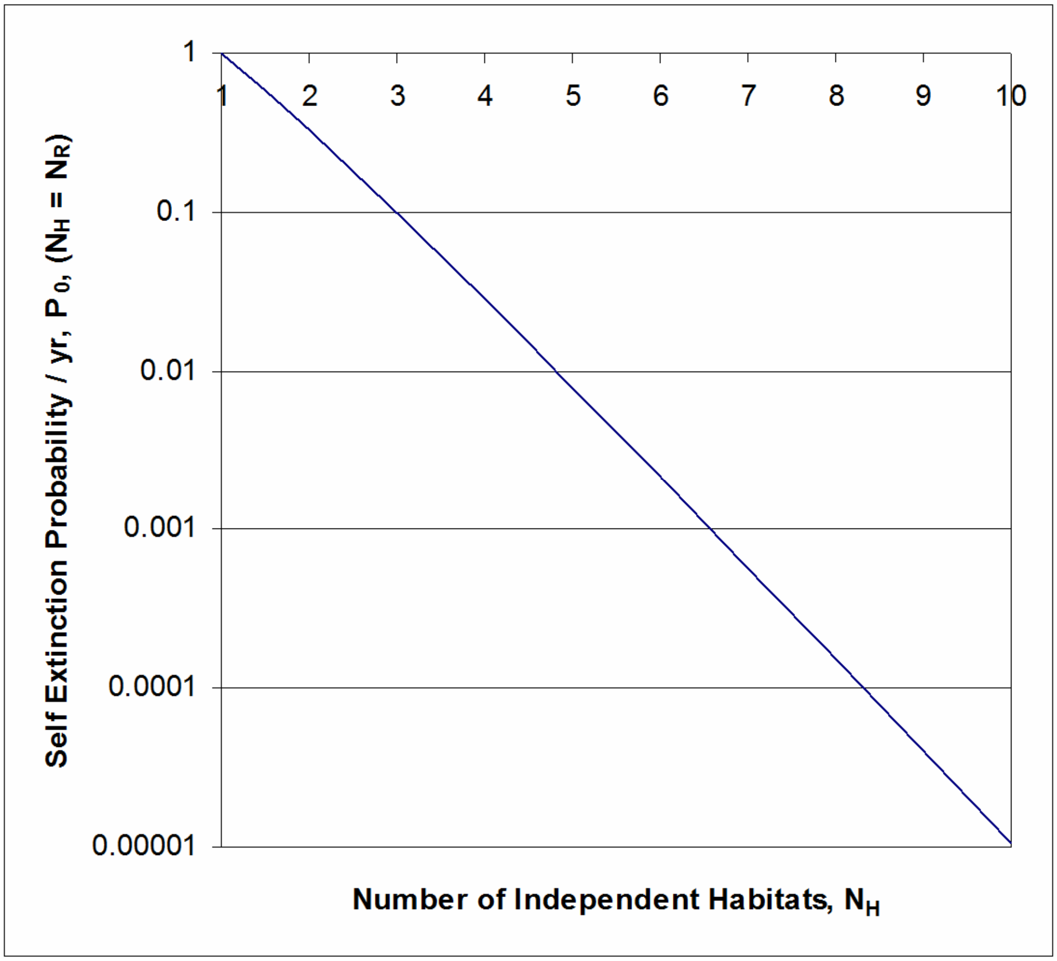

Figure 2. Self Extinction Probability for 1 to 10 Habitats when $N_H = N_R$.

THE "RED BUTTON" SCENARIO FOR MULTIPLE HABITATS

Now let us examine the "Red Button" scenario for an advanced society with multiple independent habitats. Let us assume as we did in the initial thought experiment that all humanity has the technical ability to destroy all life in its habitat. Because of the difficulties in calculating factorials of large numbers, an optimized tool was used (Shipway, 2008) which enabled the calculation for a human population, N_P, of 1 Billion. If we assume each of the billion people has the technical capacity to destroy their habitat then $N_C = N_P$. N_R then equals N_C

Table 1. Probability Matrix for N_H, and N_R values of 1 to 6.

	$N_R=1$	$N_R=2$	$N_R=3$	$N_R=4$	$N_R=5$	$N_R=6$
$N_H=1$	$P_0=1$	$P_0=1$	$P_0=1$	$P_0=1$	$P_0=1$	$P_0=1$
$N_H=2$	$P_{1/2}=1$	$P_0=1/3$; $P_{1/2}=2/3$	$P_0=2/4$; $P_{1/2}=2/4$	$P_0=3/5$; $P_{1/2}=2/5$	$P_0=4/6$; $P_{1/2}=2/6$	$P_0=5/7$; $P_{1/4}=2/7$
$N_H=3$	$P_{2/3}=1$	$P_{1/3}=3/6$; $P_{2/3}=3/6$	$P_0=1/10$; $P_{1/3}=6/10$; $P_{2/3}=3/10$	$P_0=3/15$; $P_{1/3}=9/15$; $P_{2/3}=3/15$	$P_0=6/21$; $P_{1/3}=12/21$; $P_{2/3}=3/21$	$P_0=10/28$; $P_{1/3}=15/28$; $P_{2/3}=3/28$
$N_H=4$	$P_{3/4}=1$	$P_{2/4}=6/10$; $P_{3/4}=4/10$	$P_{1/4}=4/20$; $P_{2/4}=12/20$; $P_{3/4}=4/20$	$P_0=1/35$; $P_{1/4}=12/35$; $P_{2/4}=18/35$; $P_{3/4}=4/35$	$P_0=4/56$; $P_{1/4}=24/56$; $P_{2/4}=24/56$; $P_{3/4}=4/56$	$P_0=10/84$; $P_{1/4}=40/84$; $P_{2/4}=30/84$; $P_{3/4}=4/84$
$N_H=5$	$P_{4/5}=1$	$P_{4/5}=5/15$; $P_{5/5}=10/15$	$P_{2/5}=10/35$; $P_{3/5}=20/35$; $P_{4/5}=5/35$	$P_{1/5}=5/70$; $P_{2/5}=30/70$; $P_{3/5}=30/70$; $P_{4/5}=5/70$	$P_0=1/126$; $P_{1/5}=20/126$; $P_{2/5}=60/126$; $P_{3/5}=40/126$; $P_{4/5}=5/126$	$P_0=5/210$; $P_{1/5}=50/210$; $P_{2/5}=100/210$; $P_{3/5}=50/210$; $P_{4/5}=5/210$
$N_H=6$	$P_{5/6}=1$	$P_{4/6}=15/21$; $P_{5/6}=6/21$	$P_{3/6}=20/56$; $P_{4/6}=30/56$; $P_{5/6}=6/56$	$P_{2/6}=15/126$; $P_{3/6}=60/126$; $P_{4/6}=45/126$; $P_{5/6}=6/126$	$P_{1/6}=6/252$; $P_{2/6}=60/252$; $P_{3/6}=120/252$; $P_{4/6}=60/252$; $P_{5/6}=6/252$	$P_0=1/462$; $P_{1/6}=30/462$; $P_{2/6}=150/462$; $P_{3/6}=200/462$; $P_{4/6}=75/462$; $P_{5/6}=6/462$

times the murder-suicide rate which gives $N_R = 2{,}334$. We now can utilize Equation 4 to calculate extinction probability, P_0, versus the number of habitats, N_H, for $N_R = 2{,}334$. The results shown in Figure 3 are surprising and not at all intuitive. For a human population of 1 billion, all with habitat destroying technology, if they were dispersed in 50 or less habitats their extinction within a decade is highly probable, yet with 150 habitats the chances of self extinction per year are one in half a million. The value of P_0 for 200 habitats approaches one in half a billion per year.

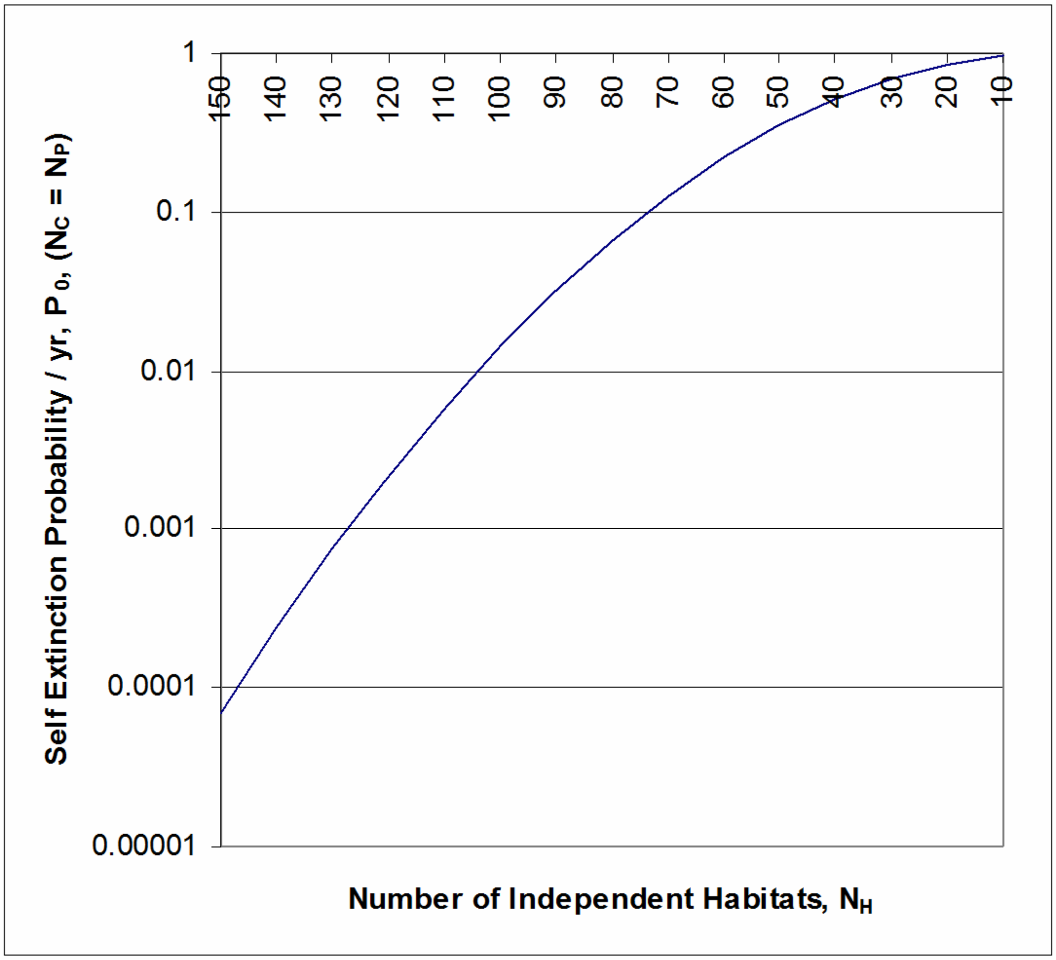

Figure 3. The "Red Button" scenario with multiple habitats (1 billion people).

A PRACTICAL PATH TO A MULTI HABITAT FUTURE

As reviewed in the introduction the O'Neill-Glaser model for space settlements and space solar power provided a technically and financially viable method for settling large numbers of people in space. However, the high investment cost and long time to financial break was a barrier to its implementation. One problem was O'Neill's vision of very large habitats with large vista internal open air views. Recently the O'Neill-Glaser model was recalculated (Detweiler and Curreri, 2008) to find the financially optimum habitat size. For simplicity only the habitat size was changed and the financial costs of money and energy updated, while keeping the original 1975 technological assumptions. In order to make the model financially viable the workers must live in space, space resources must be utilized and the community must build Space Solar Power Satellites, SSPS. Figure 4 gives a net present value plot showing the original calculations (Johnson and Holbrow, 1977) building 10,000 person torus habitats compared to calculations for the habitat size that optimizes costs. It can be seen that starting the program with smaller habitats (64 – 2000 persons) results in peak costs that are reduced by about 75 percent and one third reduction in time for financial break even (year 25 for the optimized model).

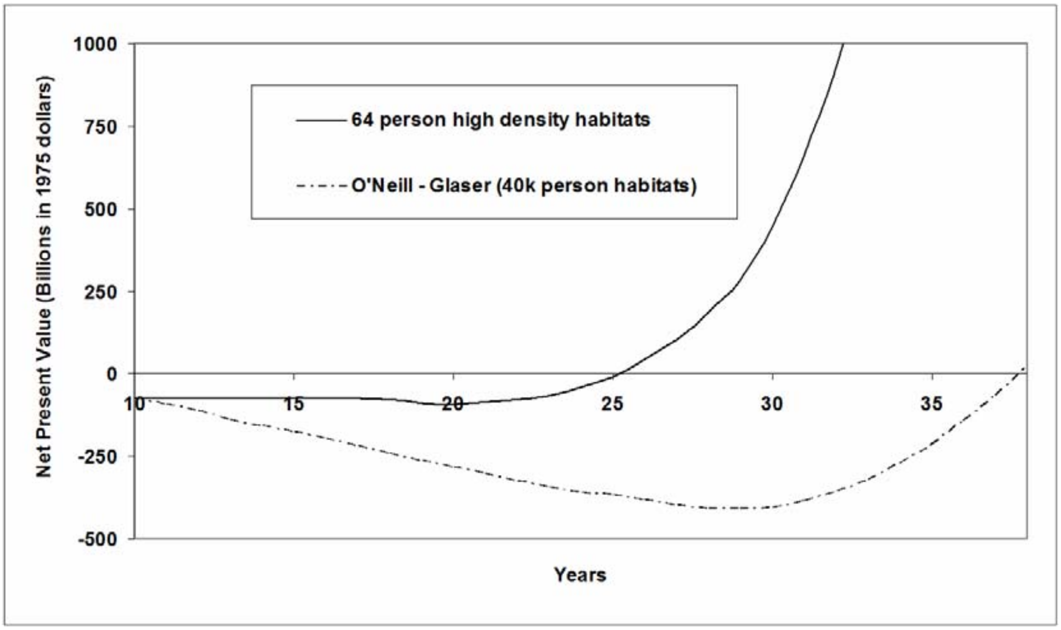

Figure 4. O'Neill-Glaser model finances for 10,000 and 64 person habitats.

In the O'Neill-Glaser model human habitation is built only in the amount required to produce sufficient Space Solar Power Satellites to meet world demand for new energy and the replacement of retired power plants. After financial break even (year 25 in the optimized model) the profits can be invested in increasing space real estate. The calculated result was that about 1 million people could be living in space by year 30. Also, it was found that the financial model after year 25 became less sensitive to habitat size, enabling a transition from building small habitats to the large million person habitats that O'Neill envisioned. Figure 5 gives these data in terms of number of habitats created, N_H. These data show that by year 30 about 300 habitats that can hold two thousand people or about 10 habitats that can hold ten thousand people could be produced. Thus, if we compare these projections for N_H with the projections for P_0 in Figures 2 and 3 we see that the model offers a path to survivability over the range of possible growth in N_C. Conservatively, if we assume fast technological growth we could build enough two thousand person habitats to be robust even as N_R approaches N_C (Figure 3). If we assume slower technological growth (Figure 2) then we could build 10 thousand person habitats. However, the O'Neill-Glaser model assumes that the first 10 years are needed to set up infrastructure on the moon and in space. Even the optimized model predicts 15 years are required before the first three habitats are built, and 20 years to build the first 10 habitats. Thus, the trends given in Figure 1 predict that we only have a decade or two to begin an independent habitat creation program before the risks of our extinction become high.

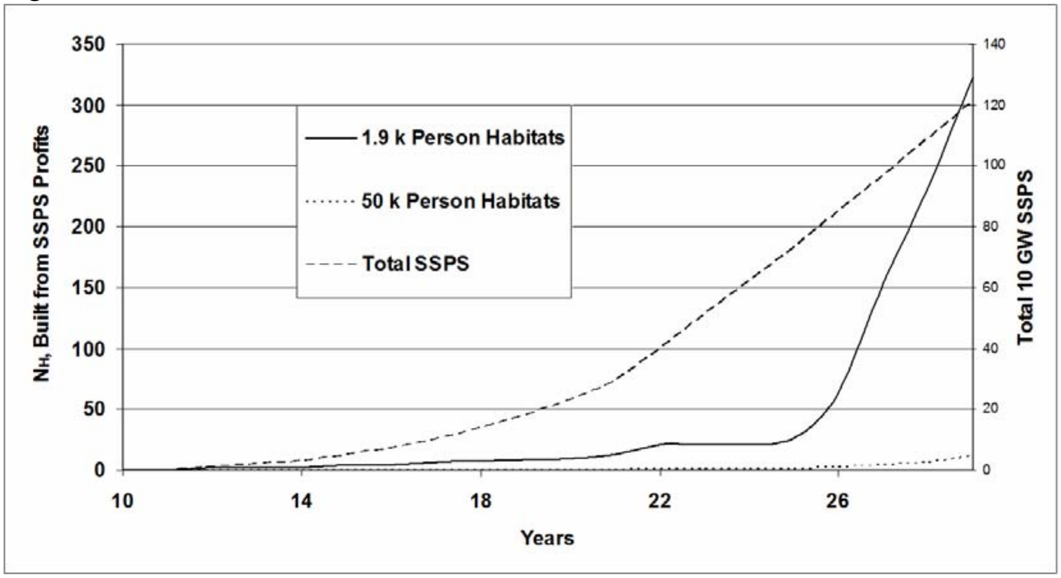

Figure 5. Number of habitats versus time (optimized O'Neill-Glaser Model).

DISCUSSION

Problems with some non-multi habitat strategies for survival. This paper presents a method to continue the free development of knowledge with the concomitant exponential growth of technology and economy while remaining robust against self extinction by expansion in space and creation of multiple independent habitats.

Recently there has been an increasing awareness of the dangers of technological growth. Some authors (Joy, 2000) have advocated repression of the pursuit of some knowledge and some fields of science. But this is a linear reaction to an exponentially growing problem. More and more repression of knowledge and thought would have to be applied. This would result in a loss or technological solutions for the problems associated with exponentially growing population. It could quickly result in Malthusian famines and a new intellectual dark age.

Another approach is the repression of "dangerous" people. But as stated previously (Eliason, 2009) the murder-suicide tendency can not be screened for without a large rate of false positives. With the exponential growth of technology a higher and higher percentage of people would have to be sequestered leading to a global police state and a new dark age.

Fermi paradox and the existence of extraterrestrial civilizations. The Drake equation, which relates the number of stars in the galaxy to factors that could support intelligent life usually predicts thousands of civilizations in our galaxy.

Some of these should be 1000 of years advanced beyond our technologies and so many believe that we should be able to detect their presence. Yet Fermi famously stated “Where are they?” The arguments in this paper propose that there is a short critical window in which an advanced society must leave their planet and become a multiple habitat society or face extinction. If such a term were added to the Drake equation (Mankins, 2009) it might explain the Fermi paradox.

Protection of habitat one, the Earth. The Earth is obviously a habitat that has our unique genetic and cultural heritage as well as vast beauty. A multiple habitat strategy can achieve robustness against self extinction but special means are required to protect the Earth. O’Neill postulated that as industry and population is relocated into space much of the burden can be lifted from Earth (O’Neill, 1974). From the analysis given in this paper such a strategy seems even more imperative.

Dedication. This paper is dedicated to Klaus Heiss, High Frontier Foundation, who encouraged the author to formalize the concepts in this paper.

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