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THE WAIT CALCULATION: THE BROADER CONSEQUENCES OF THE MINIMUM TIME FROM NOW TO INTERSTELLAR DESTINATIONS AND ITS SIGNIFICANCE TO THE SPACE ECONOMY

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This paper summarises the wait calculation [1] of interstellar voyagers which finds the minimum time to destination given exponential growth in the rate of travel available to a civilisation. The minimum time obliges stellar system colonisers to consider departure times a significant risk factor in their voyages since a departure then to a destination will beat a departure made at any other time before or after. Generalised conclusions will be drawn about the significant impact that departures to interstellar destinations before, at, or after the minimum time will have on the economic potential of missions and on the inevitability of competition between them. There will be no international law operating in interstellar space and an ability to escape predatory actions *en route,* or at the destination, can only be done by precise calculations of departure times. Social and economic forces affecting the factors in the growth equation are discussed with reference to the probability of accelerating growth reaching the technological Singularity and strengthening the growth incentive trap. Islamic banking practices are discussed as a credible alternative to compounding interest bearing paper for funding the space economy in the long term and for supporting stakeholder investment in such long term mission development. The paper considers the essential free productivity of the Earth's biosphere and the capital accumulations made possible by land productivity are essential components to a viable long term space economy and that research into re-creating the costless productivity of the biosphere at a destination will determine both the mission's ultimate success and provide means of returns for stakeholders during the long build up. Conclusions of these arguments suggest that the Icarus project should ignore a robotic interstellar mission concept and develop a manned colonising mission from now.

Keywords: Wait calculation, interstellar departures, space economy, biosphere, Icarus, investment

1. INTRODUCTION

During the market-led capital investment of private enterprise rather than of governments in the growing space economy there are two fundamental problems that occur which must be solved by the pioneers of space colonisation. The first is the recognition that Earth-based economies are founded on the free productivity of the biosphere, and the second is that current social and economic structures are unlikely to support the long periods of time required to fund, construct and send out colonising missions and to sustain themselves while they wait for the pay off. Long voyage times call into question the ability of even compounded capital to fund exploration of the stars (over the long term the value of currencies are attacked by inflation and relative devaluations), and interstellar voyages last periods of time in which Earth-based societies can pass through many upheavals and reversals. The purported trend towards the Singularity does not remove the incentive traps to future growth or solve any of the above-mentioned difficulties, rather it is likely to create them. Technology does not arise in a vacuum, and social forces antagonistic to the principal engine to growth also develop in parallel with it. Compounded economic growth may be braked in the future by a philosophical rejection of leveraged returns on mere money instruments, stalling any trend towards Singularity (although aiding very long term projects like interstellar travel). The existence of the minimum time to an interstellar destination given long term average growth rates in the velocity of travel will stimulate the return of human societies to competing groups since the investment return in space travel cannot be assured to any but the first arrivals. It can be seen that the understanding and monitoring of economic and scientific growth and its impact upon times of departures and arrivals at a destination will need to be mastered by all civilisations expanding into space.

2. A SUMMARY OF THE WAIT CALCULATION

Following from my paper of 2006 [1], it can be seen that under the standard picture of steady technological growth, voyages to other planetary systems invoke an incentive trap. Once voyagers leave, their technological level will remain static and their resources will steadily diminish, so they will have few if any opportunities to improve their travel velocity. Since voyagers will have the reasonable fear that continuing growth will produce higher travel velocities that they will be unable to compete with, they will know that later departures will overtake theirs on the way to the destination. If this is true for any departure time in the future, there is little incentive for voyagers to leave when it seems that they will never get to the destination first for any departure date.

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By considering, that, in energy terms, the power required to produce a given rate of travel is proportional to the square of the velocity, the velocity of travel available after any time t will be proportional to the root of power production. Hence, a doubling of the velocity of travel requires a quadrupling of available power, where r = annual growth increment and $v \,\alpha\, W^{1/2.}$

$$v_t = v_0 (1 + r)^{t/2} \tag{1}$$

so total time to destination d in light years from now, and v_0 in units of c

$$T = t + (d / v_0) / (1+r)^{t/2} \tag{2}$$

By plotting total time to destination against waiting time (Fig. 1) we can see that by relating average compounded growth in the rate of velocity of travel to the future mission departure time and travel time to destination, there is a minimum in the total time to destination which is the optimum time to leave such that departures before that time will be overtaken and departures after that time will not catch the mission up.

2.1 The Minimum Wait Time

M.G. Millis [2] considered how to calculate the actual fraction of power generated by humankind available for spaceflight but for the purposes of calculating the minimum we only need the long term average rate of change.

The world energy consumption rose at an annual rate of 1.4% between 1990–2002, and it is expected to rise to about 2% between 2002 and 2025 [3]. In the long term, rising demand, declining resources, the slow rise in nuclear capacity and the lack of progress with fusion generation all contribute to difficulties in maintaining such a growth rate on Earth, so a long term annual rise in 1.4% is reasonable base figure.

So, taking $r = 0.014$ as the actual long term annual increment in the power available for travel, and taking $v_0 = c/20000$, Fig. 1 shows the minimum time to various destinations (in light years).

The minimum time to Bernard's Star (6 light years distant) under these requirements for growth (Fig. 1.) is 1111 yrs and requires a wait from now of ~967 years, and where the voyage lasts 144 years (at a velocity of ~1/24 the speed of light).

A modest increase in the annual growth rate in power available to 2% gives us a minimum journey to Barnard's Star of 100 years after a wait of 716 years making the total time to destination of 816 years (Fig. 1). A faster growth rate shortens the waiting time but does not avoid the minimum in the curve; it only makes it sharper, exacerbating how the small differences of waiting convert into longer journeys. As shown earlier [1], relativistic effects on velocity ($v > c/10$) do not affect the minimum for any reasonable destination and certainly not for any of the first and nearest destinations for any civilisation in the galaxy.

Consider the Icarus project [4], a robotic mission, developed from the original BIS Daedalus project [5], with a declared goal of a mission time of 100 years. How this may be done is not yet known, but if the Icarus project turns out to be the plan in use, then its specified 100 years journey time, using equation (1), at the mean growth rate of $r = 0.014$, requires a wait of 1019 years from now for the growth in velocity to reach Barnard's Star at that speed. But the plot shows that a departure at the minimum time of 967 years, 52 years earlier, although a 144 year voyage, would already have arrived and have had 8 years of enjoyment at the destination before Icarus' arrival. Waiting until Icarus could travel 6 light years to Barnard's Star in 100 years (at $r = 0.014$) is actually a waste of effort. Barnard's Star is relatively close and the minimum is fairly flat 50 years either side of the minimum. A mission that left 20 years earlier than the minimum might arrive just 5 years later than the departure at the minimum. But the moment growth rates rise and destinations are sought beyond 10 light years, this flatness is considerably reduced (Fig. 2). The implications of this are profound.

2.2 The Waiting Calculation and the Race to Leave

Figure 1 shows that before the minimum, the incentive trap is

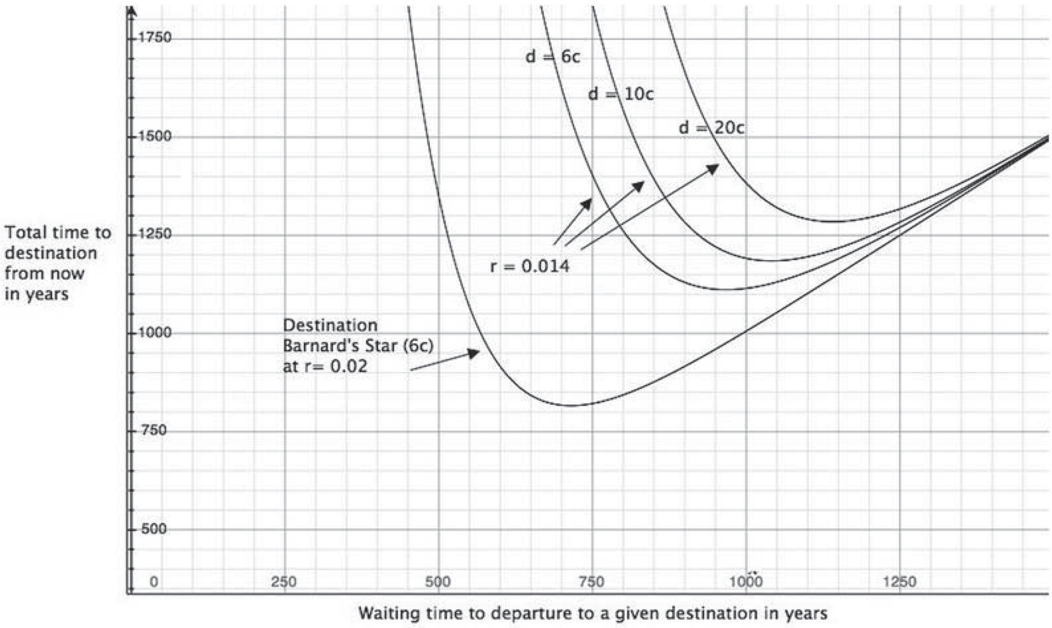

Fig. 1 Minimum time to given destinations at given growth rate.

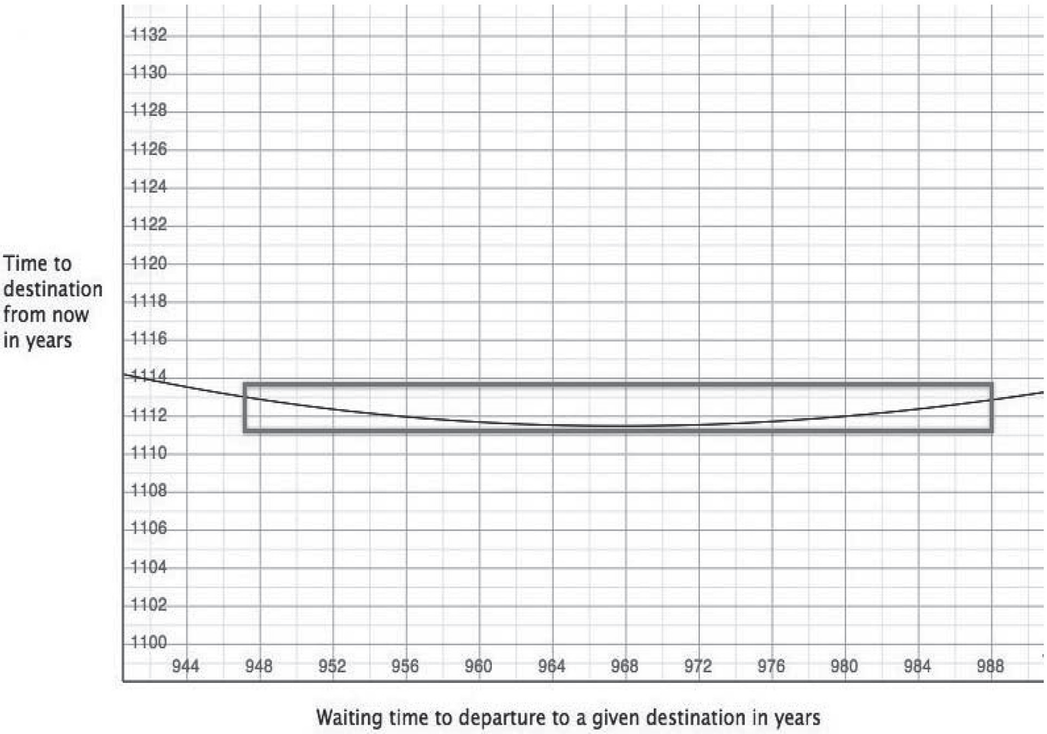

Fig. 2 Minimum time to Barnard's star at 1.4% average growth.

in play, where potential travellers to a destination know that a future departure will beat them. Once the minimum has passed, the inceptive trap ceases: those who plan later journeys will know that they will arrive later, even though the journeys are faster. At slow rates of growth, however, separate departures within a generation (say 40 years) produce differences in arrival times of at best 2 or 3 years, see Fig. 2. Higher growth rates will sharpen this minimum (Fig. 1), increasing the differences in arrival times either side of it.

A criticism of this magnified portion of the curve is that it is too idealised and that where a new technique is implemented, the velocity increase is more than the average. While this may be true in some instances, such advances are followed by long periods of gradual improvements in the underlying technology giving rise to velocity growth under the long term average over a long period of time until the next major technique shift gives another above average increment in the velocity. The actual shape of the curve at this level of magnification will be stepwise and will affect the precise timing of departures, but is not crucial to the argument. Technological advances are well understood through published papers and patents, trial projects and so on before they are implemented and influencing the decision-making process as if the smooth average (Fig. 2) did exist.

Civilisations are not obliged to launch at the minimum, but waiting until the minimum is the most efficient way to explore, and will produce the quickest return on the investment. Given the vast resources required for such projects, however, and the risks of debilitating the launching economy to pursue them, the probability is low that a single voyage made by any civilisation would leave at a time far from the minimum.

2.3 Departure Options

There are three departure options to consider: before the minimum, at the minimum and after the minimum.

1) Leaving earlier than the minimum

   A departure lies on the section of the curve (Fig. 1) where voyage time initially falls steeply over time.

a) Leaving earlier may be a reasonable gamble, if there is a probability that mission velocity increases may flatten (for example, coming up against resource limits), or that there are grave dangers threatening the stability or survival of the civilisation. Should there, however, be any suspicion that the long term rate of growth has an upward trend (say when the hints of a new technology are realised), then leaving earlier will separate the voyagers even more distinctly from the later voyagers.

b) In a political environment where the launching society is unified and is investing for the whole (the 'One-Earth' philosophy), the opposite motivations to a) are required. The first colonisers will be more willing to depart early if the civilisation has the capability to make several launches. It could use knowledge of the minimum to spread arrival times to encourage separate groups of colonisers to leave on the basis that others would either be there first to welcome them or be following close behind bringing with them the future technologies. Voyagers will need to be confident in the consistency of the society and the high likelihood that the multiple launch plan will go ahead.

c) As can be seen from Fig. 1 a departure made long before the minimum would arrive at Barnard's star the same time as a departures made long after. It certainly could be argued that by setting out so early, and assuming that the voyagers could survive such lengthy trips, the mission at arrival would be precipitated directly into the highly advanced society of later human civilization. Humans may well need to take that risk when faced by solar or galactic events which threaten the survival of humankind as a whole. Although such a threat would also reduce the likelihood of any follow up missions that could arrive earlier. Such a voyage would be of the Ark type: putting out a repository of humankind with all the technology required to survive a journey of perhaps more than a thousand years in the hope that it will continue human civilisation elsewhere.

i) Outcomes to launches earlier than the minimum.

a) **Unsupported planetfall:** Arriving at the destination having been passed by no one and finding no colonizers already landed would be a very bad sign. It would suggest a significant social failure or catastrophe in the launching civilization. The voyagers would reason that they will be alone for quite some considerable time, and will not be able to depend upon the future technologies that would have come with the other missions.

b) **Overtaken and ignored:** Being ignored by overtaking ships might point to psychological, physiological, cultural or systemic lesions in the launching civilisation:

i) **Psychological lesions:** Some likely psychological states such as fear of the stranger, fear of the past, may have a strong influence on overtaking voyagers. The launching premises may have changed from benign hope to desperate need. The launching society may have broken up into more (even more) competitive groups. It would suggest a problematical landing for those who had been passed by and ignored. It would confirm the fear that the future generations who are arriving at the destination earlier, (having had an easier/shorter trip), may squander all the fruits of the landfall before the original voyagers arrive.

ii) **Cultural lesions:** Historically, humans tend to eradicate earlier or more primitive cultures. If the first voyagers leave too early, they could arrive too late. Rather than end up as brave colleagues to the pioneer party (who left later but landed first), they may be an awkward presence in a world that has advanced too far beyond them. They will be historical curiosities to the earlier arrivals, hardly 'modern' from the first colonisers point of view. They would have little or no training in the advanced culture, little to contribute, and little scope for being assimilated. They would probably be a burden, and may even be, because of their world-view or even spiritual outlook developed in an earlier epoch, a political thorn in the side of the colony's authorities.

iii) **Physiological lesions:** There is another and perhaps more overriding reason why missions ignore the voyagers they pass – quarantine. This will be a factor in the voyagers' preference to leave at the minimum so as not to risk contact with diseased populations on the way. Virulent variants of old diseases and even entirely new ones could easily emerge in either or both populations of voyagers through contact and create risks for both parties.

While the likelihood of infection being spread on meeting could be reduced by putting the voyagers in hibernation, hibernation does not prevent incipient diseases from breaking out after revival of the mixing populations each of whom may well have distinct immunological profiles. Voyagers will be out of contact with the originating biosphere reservoir of disease for humans and they will travel with a genetic bank and possess genetic treatments for almost any human health eventuality and the immune system and genetic profile of every human voyager will be well understood. What cannot be anticipated is either the rapidity with which a dangerous adaption produced in contact with strange environments may spread in the small close knit group after landfall or the unpredictable alien diseases which will undoubtedly be present at any landfall. While it is not yet known how human hibernation could be managed there is an evident risk to maintaining very slow metabolisms for long periods of time. The suppressed immune system of hibernating bodies may not be able to control the slow build up of almost dormant viruses present in the bodies at departure nor to cope with mutations in them occurring during the long trip, and which would spread on revival.

iv) **Systemic lesions:** Interstellar missions will undoubtedly be led by artificial intelligence systems. These, too, will also be prone to system errors similar to organic viruses and to unpredictable psychoses or emotional instabilities. Kubrick and Clarke's psychotic computer HAL in their film 2001 depicts a very real likelihood of such contamination [6]. The nature of the guiding artificial intelligence and its connection with communication and computing networks before launch introduces the fear of contamination by computing disease through accident or sabotage, and similar fears may restrict later contact between other missions.

c) **Merging with overtaking missions:** Overtaking ships incorporate the earlier launches into the community flotilla. This would be the ideal 'One World' situation but the probabilities of this happening appear low.

It is unlikely to be possible to match older and newer mission velocities. The older missions would have been sent at their maximum speed and with the propellant stores appropriate for their mission. Higher velocity missions are unlikely to want to slow down and match the slower velocities of the earlier missions even if they had the propellant to do so. Velocity differences between missions can be significant. A mission travelling at 1/15 the speed of light (Barnard's Star in 90 years) would be closing on a mission up ahead travelling at 1/20th the speed of light (Barnard's Star in 120 years) at 5.10^6 $m.sec^{-1}$!

This will be a costly manoeuvre to perform and it will also contradict the intentions of the later voyagers who chose their departure time because it produced a quicker trip. On the other hand, if the intention is to join forces at the destination, then a mid-voyage exchange might be useful to upgrade the older mission with the latest technologies and strategic plans, and certainly, quick transfers (the above closing speed crosses the Earth-Moon divide in under 80 seconds) between the ships at time of closest approach might be theoretically feasible, although the question of radiation produced by any drive system currently under discussion [7] may make contact or exchange too dangerous to perform. Certainly the widening wake of radiation of the earlier mission is likely to cut across some part of the following mission's course, given the diminishing parallax of the two tracks, which may cause following missions to give as wide a berth as possible to the earlier mission.

Should an overtaking mission have the technology and resources to slow down and make contact with a mission ahead then another option will present itself – that of piracy. A natural consequence of competing colonising groups. The threat of piracy will also drive departures to find most precisely when the minimum time to destination is likely to occur.

2) Leaving after the minimum where voyage times tend to rise linearly

Colonising voyages, as opposed to robotic scientific exploration, will bring with them the seeds of their continuing growth after landfall. These seeds will be in the form of artificial intelligence-directed automatic production facilities and terraforming capabilities. These 'seeds' will be sown all around the target solar system and set to work mining and refining the raw materials for growth and creating biospheres for human habitation. However the rate and efficiency of these factories will have been set at time of departure. Later arrivals may have improved autonomous production facilities with faster growth rates and higher efficiencies with which they may compete and outperform the original colonisers' systems.The latest arrivals to the settled systems, with more advanced technologies, will tend to dominate the established colony or even ignore it.

Indeed, many might consider that deliberately timing their departure to be after the minimum so as to prey upon the earlier efforts of the first colonisers – the piratical approach - is tactically strong. The new arrivals, launched with more advanced technologies, may have higher power requirements and resource use, and exploiting the resources of the sitting colony may be part of their colonising strategy. Plans of later missions to exploit the colony as a staging post to other destinations may not be well received. This will be a difficult calculation to make since it will have to be made before launch, and two specific factors increase the risks to the new arrivals of trying to exploit the established colony and which are likely to direct separate missions initially towards slow integration rather than to either separate development or domination of the colony.

a) **Quarantine:** The risk of contamination through any contact, physical or through communication networks is a real threat which may not have any solution other than isolation until the risks have been understood.

b) **Debility:** The debilitating effects of the long journey may be too much for the new arrivals to take advantage of the established colony who have had the opportunity to restore the losses of their journey. Further, the first colony will have had the pick of sites, and if it comes to a contest, they will possess the 'high ground'. Later missions, unwilling to integrate, will have less favourable sites to develop and will need more in reserve to do so.

Later arrivals may have particular and more efficient technologies at their disposal, but the efficiencies of launches may preclude loading a mission with surplus resources. The practice of loading missions with surpluses to maintain their independence at the destination leads to escalating mission loading, where future missions need to carry yet more resources to maintain their strength or to ensure their survival at the destination, which is unlikely to find favour with investors. An alternative to loading missions with surpluses is simple piracy: the capture and use of the resources of ships up ahead. The extra speed and technological capability of following ships may make piracy the most efficient use of their launch window which makes the minimum time calculation necessary to escape such a threat during the voyage.

It should be noted that if a voyage has already left at the minimum then waiting for news to be transmitted the interstellar distances will tend to delay subsequent departures. There is no guarantee, however, that the news transmitted is the truth, unless the artificial intelligence systems are programmed to be true at whatever cost to the voyagers or to the launching civilisation.

3) Leaving at the minimum where voyage times are relatively flat over time

As time goes on, and with one destination in mind, successive generations will have less and less time to wait for the minimum, as the minimum point becomes more precisely established. With slow rates of growth, the curve is relatively shallow, so, among competing groups, the minimum may become a time crowded with departures all intending to arrive within a few months or years of each other. The power requirements alone of such a trip possible suggest, however, that only single voyages could be made at any one time.

Making a landfall after a voyage of such high velocities is not a simple matter. The orientation of the target solar system (whether one arrives perpendicular to its plane or in the plane makes a great difference to braking energy required by the capture manoeuvres) and the distribution of the planetary bodies in it may well require years of manoeuvring before a landfall could be made. In this situation, where arrival times are so close, the few months difference between competing missions may be all that is needed to cement the advantages of priority.

Among competing colonising groups the first to sow the seeds of terraforming and industrial production will have an advantage over the later arrivals even if the advantage is measured in months.

3. THE WAIT EQUATION VARIABLES

The timings indicated by the wait calculation depend upon the values of a two variables, the long term average growth rate in power production and the exponent of the equation.

1) The average rate of growth and the Singularity

Technological advances and capital investment, contribute to the expansion of an economy, but there is also the countercurrent of negative social factors as well as unforeseen errors, fraud and mis-management that will reduce investment, damage essential scientific activity and the slow the exponential nature of the growth over time. The average long term growth rate will be the result of all influences. Supporters of the Singularity hypothesis, a term first coined by John von Neumann, and furthered by Vinge, Kurzweil [8] and others do not accept the confluence of all forces on growth. They describe a point at which exponential growth delivers a capability of a different order to human development. Normal exponential growth breaks down (a tenuous analogy is drawn with the singularity inside a black hole where normal space-time is no longer maintained) and a different kind of synergistic growth takes over. The Singularity suggests an interpenetration of fields of discovery to create a more fertile knowledge base that produces ever more rapid advances in all areas of science and technology.

Points of singularity, however, are not observed in the natural world, where the behaviour of any biological system is modulated by the interaction with and dependency on the systems in which it is embedded. Cycles of expansion and decline are the normal state of affairs at every trophic level from microbes to elephants. In fact, it is easier to argue from this observation that points of technological Singularity (distinct from steady exponential growth) become even more unlikely the more our systems interpenetrate and develop increasing numbers of feedback loops.

Supporters of the Singularity hypothesis believe, however, that growth will rapidly produce the systems needed to manage such interplanetary missions, in particular, superconscious minds, mastery of genetics and longevity. Artificial Intelligence, in particular will arrive early enough to help design interstellar ships. A survey of workers in the field suggest that human level intelligence can be created by 2045 [9]. Longevity – perhaps a vastly increased longevity – may be the capacity most likely to encourage departures on long interstellar journeys, whether or not made in hibernation, for any length of voyage. Even so, voyagers would need to be very confident that the launching society would last long enough and 'keep the faith' to launch further ships at later dates.

Kurzweil observes that rates of growth are themselves susceptible to exponential. He hypothesises a law of accelerating returns [8]. For example, by plotting the log of the cost of computational power over time, Kurzweil notes the hint of a gradual rising curve rather than a straight line which he claims suggests an exponential rise in the exponent of the rate of growth which he assumes across all fields of endeavour. This particular plot with a linear axis of time spans only 100 years,however, which seems insufficient to extrapolate the range of 1500 years shown in Fig.1.

In the expression (1), the rate of growth of power production is represented by r, which can be considered as a composite figure, the sum of a series, which can be found by inspection and adjusted yearly through observation. It is unlikely that r summed over all contributing growth curves could be subject to a consistent increase over time of anything more than a very small amount for the obvious reason that a compounded rise would exhaust productivity far too rapidly to be sustainable. Its actual value will become better known as time goes on. The minimum in the curve remains.

But, by assuming r is subject to a slight compounded rise on average over time of say 0.05% then inserting $r = r_0\ (1.0005)^t$ into equation (1), for a trip to Barnard's star where $r_0 = 0.014$, the minimum comes at ~741 years of waiting (cf. 716 yrs with constant average $r = 0.02$) and giving total time to destination of ~812 yrs and a trip time of 71 years. see Fig. 3.

2) Factors affecting the exponent of the equation

The exponent in the expression $t/2$, is derived from the ideal physical relationship between velocity and the power that produces it. In practice, achievable velocities are likely to be less than the ideal, so the plotted curves produce by the equations incorporate shortest journey times for the average rate of growth rather than the most likely times.

Taking the journey to Barnard's Star, using equation (1) ($r = 1.4\%$) with a slightly reduced exponent of $7t/16$, gives a minimum occurring after ~1078 years, up from 967 years, and with total time to destination of ~1248 yrs where voyage time is 170 yrs.

By using an exponent of $7t/16$, and the exponential rise in r, for the same voyage, we have a minimum at ~806 years of waiting and giving a voyage of 80 yrs giving only a slightly longer voyage to that indicated by the ideal exponent of $t/2$, yet still further strengthening the case that such data will be crucial to the future of planning interstellar missions.

We can see that with these long term growth rates, Relativity concerns (where $v > c/10$ and travel times to Barnard's Star are <60 years) appear quite rapidly after the minimum, at 752 years of waiting, making further demands on power production and clarifying that the probability of the Singularity altering velocities significantly may be unlikely.

Table 1 summarises the various cases discussed above.

3) Factors affecting the cultural environment of growth

Kurzweil plots many disparate graphs of growth in disparate fields [8] but he does not consider the integrated long term overall expansion of the society which must necessarily include changes in the social attitude to these technological advances.

Before the Christian era practical sophisticated technologies could be found in almost every sphere of life including cooking, surgery, theatre and gambling. The Antikythera mechanism, a complex geared calendar from the 1st century BCE [10] is only one example of advances produced during these early centuries. James and Thorpe's catalogue of ancient inventions [11], most lost in later centuries, makes sober reading. Many inventions showed intelligence, ingenuity and penetrating insight even while dubious theorising and superstition ran alongside. This loss of knowledge base occurred at various moments all over the world. Central American cultures developed sophisticated mathematics and architectural technologies and yet these did not prevent cultural collapse or make them robust enough to cope with climate change or invasion.

Quite what the mechanisms by which a practical knowledge base fails to cohere into science or is lost to culture are not yet known in detail. It is certain that there are persistent counter currents to science regardless of warfare and economic cycles formed principally of

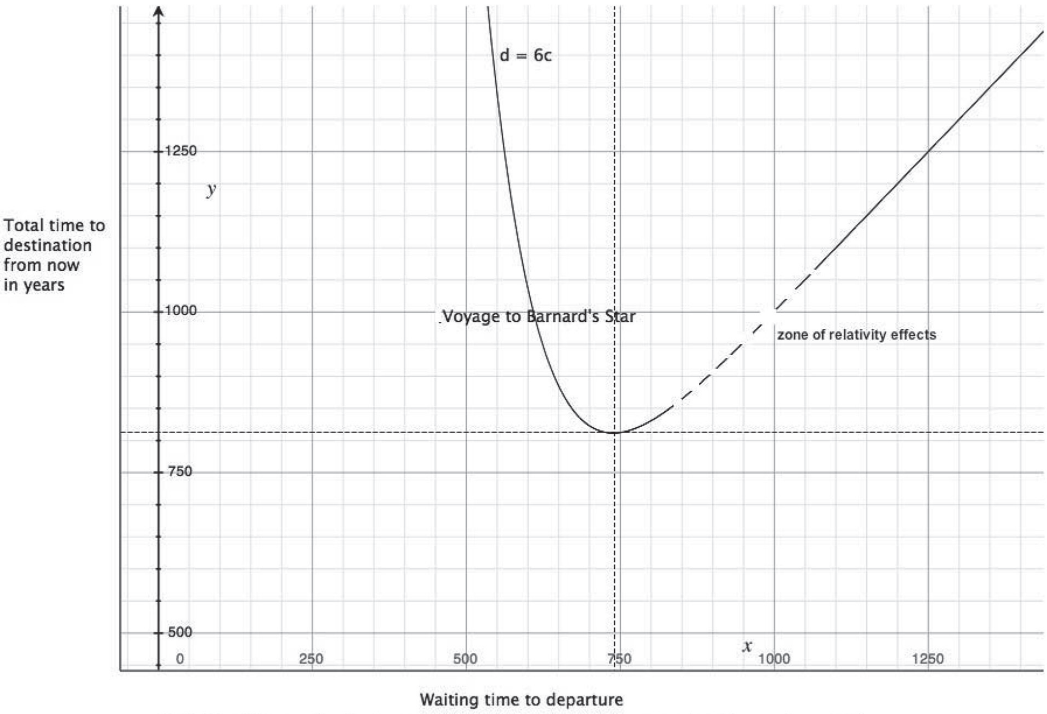

Fig. 3 Total time to destination against waiting time to departure using increasing growth rate.

TABLE 1: *?.*

Total time to Barnard's Star (6c)	*r*	Exponent, x	Time to minimum, years	Voyage time, years
$T = t + d/(1+r)^x$	1.40%	*t/2*	967	144
	1.40%	*7.t/16*	~1078	170
	$0.014(1.0005)^t$	*t/2*	~741	71
	$0.014(1.0005)^t$	7.t/16	~806	80 (Fig. 3)

two components: political and religious philosophies which cast doubt on the human and spiritual values of technological progress, and a growing problem with the scientific method itself. These influences contribute and will continue to contribute to a braking of the technological engine to economic growth.

a) **Political and religious philosophies:** Recently, a report produced by the National Intelligence Council in 2008, noted the trend towards a more complex international economical and political system was not necessarily going to be positive.

   “...The trend toward greater diffusion of authority and power that has been occurring for a couple decades is likely to accelerate because of the emergence of new global players, the worsening institutional deficit, potential expansion of regional blocs, and enhanced strength of nonstate actors and networks. The multiplicity of actors on the international scene could add strength— in terms of filling gaps left by ageing post-World War II institutions—or further fragment the international system and incapacitate international cooperation. The diversity in type of actor raises the likelihood of fragmentation occurring over the next two decades, particularly given the wide array of transnational challenges facing the international community. Intrinsic to the growing complexity of the overlapping roles of states, institutions, and nonstate actors is the proliferation of political identities, which is leading to establishment of new networks and rediscovered communities. No one political identity is likely to be dominant in most societies by 2025. Religion-based networks may be quintessential issue networks and overall may play a more powerful role on many transnational issues such as the environment and inequalities than secular groupings...” [12].

Trends running against non-partisan learning and science sufficiently strong to subdue progress have been observed frequently in Earth’s history. The story of The Library of Alexandria, in Egypt is well known [13, 14]. More mysterious is how completely it was forgotten. While it is difficult to pin down the date of the most significant destruction of the library (there were several), it was finished as a centre of learning by the end of the 4th century AD. Theon, the father of Hypatia, the last director of the library, was the last recorded scholar appointed to the Mouseion in AD380, and there is not even a mention of the library in the following centuries [14], so completely was its influence eclipsed by the rise of Christianity.

The later flowering of university based learning and research in Moorish Cordoba, Spain, between the 8th and 11th centuries AD, was paralleled by a tolerance of other religious cultures. At its height in the 10th century, Cordoba was probably the most prosperous city in Europe and a principal cultural centre of the Islamic world that also gave voice to Jewish and Christian scholars as well as furthering the translations of Greek texts and mathematical discoveries all originating in India [15]. The collapse of the 'Caliphate of Cordoba' in AD1031 came with the invasion of a stricter Islamic movements from North Africa [14, 16]. While some centres resisted the changes, and complicated alliances were made with some Christian kingdoms, nevertheless the tolerant synergy of the University-style centres of learning came to an end, and the Medieval Dark Ages in Europe began, marked, in particular by the power of the Catholic Church who presided for centuries over as moribund a technology as learning.

While it is often said that Christian monasteries maintained learning throughout the Dark Ages, it is not the case. In fact, as the catholic historian Joseph McCabe has clearly showed [17], Christianity actively fostered ignorance,. It destroyed the remains of the Greek culture wherever it could be found and considered most books of the ancient world pagan and evil, including those of mathematics. Schools were closed throughout the remains of the Roman Empire (who had advanced public schooling) and by the end of the 5th century AD 90-95% of Europe was illiterate including its ruling class and many of its religious figures [13]. It quashed research and resisted change right through the Renaissance until the rise of philanthropy in the 18th century. Thomas MacCaulay, the English historian (1800-1859), also observed the Catholic Church's denigration of education and intellectual enquiry and wrote,

'...during the last three centuries to stunt the growth of the human mind was her chief object. Throughout Christendom, whatever advance had been made in knowledge, in freedom, in wealth, and in the arts of life, had been made in spite of her, and has everywhere been in inverse proportions to her power. The loveliest and most fertile provinces of Europe have, under her rule, been sunk in poverty, in political servitude and in intellectual torpor' [18].

Rather than expand learning, Medieval monasteries worked illiterate monks to merely illuminate and copy religious texts endlessly, while pagan works were destroyed. One of the reasons we have examples of some ancient plays and works of philosophy at all is because of a shortage of parchment. Old books were re-used, scraped and overwritten leaving behind traces of the originals which can be read today. The militant arm of the Church ruthlessly wiped out heretical communities and destroyed their works before their influence could spread.

Even as the Middle Ages came to an end, the Catholic Spanish conquest of the New World brought destruction to the 'pagan' works of the Mayas, Aztecs, Incas, and the indigenous island peoples of the Caribbean. The principal reason we know anything at all about the science and culture of the central American civilisations is that Diego de Landa, the San Franciscan Friar who was one of the most zealous destroyers of this 'paganism' later began to collect and translate the Mayan works in order to better communicate the word of god to the heathen (he gave his name to a transliteration system that has now been superseded) [19]. A hundred years on and long after the world had been circumnavigated, with world trade booming, and a handful of years before the Royal Society was formed in Protestant England (AD1660), the fear of science and paganism led the Church to threaten Galileo with torture and hold under house arrest until he died (AD1642) for promoting not just the heliocentric solar system but the plurality of worlds.

The strength of philosophical attitudes destroying or channelling science did not occur only in the West. Chinese culture had already suffered two episodes of the burning of books with heretical ideas, first with Emperor Shih Huang Di (259-210BC) and the later with Kublai Khan (AD1215-1294), when the Emperors of the Ming Dynasty opted for isolation from the West. The trading fleets of the Chinese Emperor were, at the end of the 14th century very technically advanced. They built enormous junks with as many as nine masts which, using their batten system of sails, could beat against the wind [20]. They voyaged and traded certainly to Africa [21], while some sources believe they traversed the Pacific Ocean [22] and even circumnavigated the globe [23]. Yet the entire fleet was recalled in the 1433, the large ships burnt and ship building was reduced to producing keel-less junks for river and in-shore waters only.

While it is hard to imagine a world without science in the 21st century CE, history suggests there are weaknesses in the scientific method whereby science fails to find a permanent or at least convincing place in human's cultural and psychological evolution. We may be seeing a possible reason why arising today.

b) **Abuse of the scientific method:** More important than a distaste with science and the progress it fuels is the well documented but less understood observation that scientific results are getting hard to replicate[24]. As more science is done, evidence becomes more elusive or is too contradictory. Theories simultaneously multiply, and deciding which reflects the best path for further research becomes more difficult. The number of choices of theory dilutes available funds, and confuses critical analysis. As Kuhn observed in his study of science [25] all paradigms have their anomalies. The inexorable trend in modern science is to take anomalies and create fresh paradigms rather than solve the problems they indicate. Michael Mabe using *Ulrich's Periodicals Directory* showed that refereed academic journals grow by 3.36% a year [26], outperforming world population growth. While the growth in numbers of scientific papers published is often cited as an example of unstoppable exponential growth, fewer articles are cited. Only 40.6% (in 2009) of articles published in top science and social science journals were cited between 2002 and 2006 [27]. So, the amount of work done in science does not necessarily equate to the progress made.

The contribution of science to the growth rate in the long term is sensitive not only to cultural philosophies but to the ways and means available of laying off the cost of research and development within the culture's economic structure. Financial practices in the market economy become intricately bound up with technological progress and scientific research.

c) **Failure of economic systems:** In the years since the 2008 banking crisis, governments are having trouble trying to stimulate or fund both the accelerating requirements of industry and the welfare commitments to their citizens. Since the crisis onset,

> "Public debt (money owed to all creditors) as a percent of GDP in OECD countries as a whole went from hovering around 70% throughout the 1990s to more than 90% in 2009 and is projected to grow to almost 100% of GDP by 2011, possibly rising even higher in the following years. It could already be higher, as potential costs of ageing populations may not be entirely reflected in the budget projections of some countries...
>
> ...A new study from the World Competitiveness Center of Swiss business school IMD suggests that the largest "old" industrialized nations will suffer a "debt curse" lasting decades – in the worst case lasting until 2084. The IMD defines "bearable" public debt as being 60% or less of GDP and estimates the "time horizons" in which the nations will revert to bearable public debt, assuming they gradually reduce their budget deficits to reach equilibrium by 2015 and devote 1% of their GDP to repayment of debt. It also assumes that as of 2015 each nation resumes a GDP growth rate equivalent to its average rate from 2000 to 2009" [28].

During the US government's recent negotiations with Congress to raise its debt ceiling, few could have missed the news that Apple Corporation, one of the highest capitalised corporations in the US, held more cash than the US government (August 2011). This may well mark a long term trend in governance around the world where less money is levied from citizens and corporations and less work is done by government on their behalf, as the wealth of individual corporations begins to surpass that available to governments for investment. The trend has been established for Governments to transfer cash to banks to pay paper debts and has brought into question their abilities to fund directly research and development, citizen welfare and improvements in productivity, and, in the OECD, to shift their emphasis to simply managing debt instruments.

Modern western banking practices, and in particular fractional reserve banking used to support what has been termed the American Business Model (minimal state intervention, free markets, low taxation, self-interested materialism) [29] might be considered as having failed at a key moment in capitalist growth. The recent widespread techniques of leveraging interest bearing capital into further interest bearing bonds, useful for seeding exponential growth has turned out to be too circular to be sustainable and has highlighted the question of whether higher expansion can also support citizen welfare *and/or* investment in research and development. This question is very pertinent to the latent braking of long term growth inherent in the Earth's economy over and above the expansion-recession cycles. As an illustration, China, now the world's second largest economy, grew from 1978 at an annual rate of 10% to become the world's second largest economy in 2012 without providing pensions for the rural 57% of its population [30], and its income per capita is still less than the world average. Its high mortality rate lies 126th in world rankings (from low to high) [31]. There is now an attempt to put a pension plan in place. Earth's greatest economy, the United States, provides little state health care, almost no public transport, invests little on the nation's superstructure, has no national rail network, no national communication systems; and has reduced spending in public education. Worker's wages have stagnated for forty years and the well-publicised gap between the rich and poor has grown like never before. Life expectancy has not increased in the US since the 1950s and lies 50th in world rankings [32]. High rates of expansion are likely to bring with them dissatisfied populations, higher risks of political instability and a search for alternatives means of investment which will impact negatively on the long term growth rate.

4. FUNDING INTERSTELLAR MISSIONS

One such alternative means of investment may already exist in Islamic banking practices. Islamic banking does not permit straightforward collection of interest on loans and prefers partnerships where bank or funder share in the profits of the enterprise with the entrepreneur [33]. As Mohammed Nejatullah Siddiqi put it,

> "...By far the most impressive argument in favour of Islamic finance has been that it integrates the financial sector with the real sector. The debt propelled conventional system fails to do so. In the Islamic financial system there is an existing or potential real asset corresponding to every financial asset..." [34].

In other words, banking funds are not available to multiply paper debt inhibiting the formation of economic bubbles which push investment in high risk but high return ventures. Wider introduction of such practices would impede the possible accelerating returns on growth suggested by the supporters of the Singularity. There are other techniques used. For example, murabahah or cost-plus financing, where the bank purchases a resource at the request of the entrepreneur and sells it on to the entrepreneur after a set time at an agreed higher price; there are bond-like instruments based on rents on property; there are sell and lease or buy back arrangements. These practices, however, have familiar difficulties such as fraudulent accounting of profit, delays in payment, moral hazard, although the end result is more stable financing [34].

When it comes to interstellar travel, the time to the return on the investment will be much longer than say the longest term government bond (30 years), perhaps hundreds of years, and it is not easy to see how the capital markets will respond to such lengthy periods before investment funds can either be redeemed or pay interest. Projects requiring large initial investments demanding a compounded return over hundreds of years are not feasible with our current investment instruments or accounting practices where costs can be discounted against future taxes. Islamic banking practices, however, do not manage or exploit risk in ventures very well. In the case of an interstellar mission, however, where funding is supplied for hundreds of years without a return, the concept of risk on the expenditure ceases to be meaningful. So stakeholder participation directly in the returns from any voyage might be the only way forward in the space economy. Such a stake could be treated as an asset with restricted pass-on rules in order to keep the stakeholders and their assigns within the compass of the activity in which they are invested.

An additional advantage to the wait calculation is that it gives both investors and in these voyages and the tax authorities a date to work towards from the point of view of concessions, write-offs contracts and other investment calculations.

If investment in the long term space economy is to succeed then all activities in the various research and development blocks must be organised in such a way as to spin off a continuous stream of benefits to society at large as the work proceeds so that costs in the present can be alleviated by some form of return and to provide for future inheritance of profits at much later dates. One of the most important areas of research that will provide intermediary benefits over time, impacting both on the Earth economy and on future space exploration will be in the study and maintenance of the productivity of the earth's biosphere.

5. REPLICATION OF THE BIOSPHERE UNDERLYING REASONS TO EXPLOIT THE MINIMUM TIME TO DESTINATION

As expansion beyond the solar system becomes likely, the minimum time to destination shown above is extremely important to competing industrial conglomerates if the future development of space is governed by market-led economic forces. Undoubtedly, the stable economic exploitation of our solar system resources and the colonising of other stellar systems by humans requires the productivity of planetary or near-planetary biospheres. Whoever can initiate or convert biospheres to produce a sustainable foundation to the human economy most quickly will win the higher returns.

Human economics and true seat of species unity here on Earth rely on the costless biological productivity of the Earth's biosphere and the passive store of mantle resources. Nearby regions of space may well have passive stores of elementary resources but contain few hospitable biospheres, if any, and the lack of them will drive a rather different economic model and require different philosophies and the social environments that foster them.

The natural productivity of the Earth is prodigious source of free capital. Costanza *et al*. in a 1997 paper calculated that,

> "For the entire biosphere, the value (most of which is outside the market) is estimated to be in the range of US$16-54 trillion ($10^{12}$) per year, with an average of US$33 trillion per year. Because of the nature of the uncertainties, this must be considered a minimum estimate. Global gross national product total is around US$18 trillion per year" [35].

(Compare with the world countries total GDP in 1999 of $30,211,993 [36].) Interestingly, Costanza estimates most of the total value ($21 trillion) comes from the oceans and the hydrological cycle which performs many environmental functions in addition to making life possible. The presence of significant bodies of water is an essential component to planetary body biosphere creation. None of this free value is available in spaceflight. Every single molecule of air used, of water drunk, of food eaten and every single quantum of energy enjoyed or adjusted will have a cost to it. Human beings themselves will be living breathing cost centres whose value will be endlessly re-calculated as operations demand.

It is not simply the 'free lunch' that the biosphere provides but its particular characteristics may also provide the essential catalyst for eliciting the range of behaviours we call the human personality [37], and without which intra-personal relations in space may lose their consistency and whose effect on community building will turn out to be yet another cost. (Tantalising indications to this problem have already surfaced even in brief LEO missions [38] as well as in longer missions aboard both Mir and the ISS [39] and where fifty years of testing is still an imperfect predictor of astronaut behaviour [40].)

While the value of Earth's biosphere on a galactic scale may be almost infinite if it is the single reservoir of the genetic material for life, Earth, too, is a spaceship, and its biosphere is not completely renewable. At the end of the 20th century it was calculated that 32% of its available energy flux comes from sustainable energy sources of sunlight, tidal momentum and deep heat, while 68% comes from non-renewable or only slowly renewed sources [41]. So the total value of the Earth's biosphere will inevitably decline as growth continues from this source, causing ineradicable economic pressures that will impact on spaceflight. We are already seeing extra costs imposed upon the world economies through loss of biodiversity or damage to ecosystems. A recent, two-year study for the United Nations Environment Programme [42], put the damage done to the natural world by human activity in 2008 at between $2tn and $4.5tn and which serves only to emphasise how crucial the biosphere productivity will be to the nascent colonies in other worlds. Since capital is tied fundamentally to the bio-productivity of land, the exponential growth in capital required to match the growth in technological advances will falter as productive land runs out. Already the quality of soil has been falling for many years, losing mineral and organic matter at an alarming rate [43] and which will impact all sectors of the economy. Off the Earth, without terraforming or the creation of planetary bodies suitable for self-sustainable life, the strain on capital to provide and sustain every single component of the economy may cripple not only the far off colonising missions but missions around our Solar System.

This constraint in turn affects the choice of interstellar destination since many exo-planets may not have sufficient light radiation in the required spectrum to sustain photosynthesis. For example, the efficiency of photosynthesis (energy to mass conversion) in crop plants on Earth ranges between only 2–8% [44]. While it can be expected that genetic and technological improvements may make normal photosynthesis function further from a sun than is possible now and with an extended range of radiation frequencies, it is unlikely to reduce the burden on the space economy beyond Mars.

As an indication of the difficulties ahead for expanding out into the solar system consider that data from the Biosphere II experiment seemed to indicate that each crew member needed about 25–30 *tonnes* of healthy plant material to sustain him or her [45]. The Biosphere II was a failure so there is data still missing from this calculation. Even though the ISS is large, it supports just 6 crew and needs to be re-supplied every 3 months or so with several tons of material.

Even here on Earth settling new lands proved to be not such a simple matter. Settlements on territories in the New World on Earth such as La Isabela, founded by Cristobal Colon on his second voyage, failed on many levels but principally though a lack of understanding of local ecology [46]. Early settlers did not come prepared for climate extremes like droughts and storms and did not seem to appreciate that local ecology might be very different to that of the places they had left. Recent evidence from Jamestown, the first permanent settlement in the north of the American continent, suggests that the local water table had levels of salts and arsenic to poison the settlers [47]. The Mayflower pilgrims, acting on exaggerated claims of fertility of the New England coastline, brought with them grain that could not flourish in the depleted soils of Massachusetts [48]. Had early settlers to new lands been able to bring their home ecological niches with them, human expansion over the globe might well have advanced civilisation far more rapidly than it has done.

Biosphere support for space colony economics is not only a question of human ecology. No matter what form of colonisation, be it through robotic and artificial intelligence systems or human means, the systems in place will need to exploit as much of the ‘free’ energy and local ecological support as they can to reduce the capital load on development. Since it is unlikely that we will know in sufficient detail the intricate characteristics of the local ecological systems, colonising missions will need to bring their own ecological niches with them or the means to rapidly re-construct them in place in order to make the missions viable for investors in the long term. Sending out self-aware artificial intelligence systems to run such missions does not escape the demands of an ecological-type support system, and an attempt to do so is likely to be a mistake, since consciousness does not exist in isolation and needs its own supporting social ‘ecology’ without which it will not function as a completely autonomous system. It is not yet clear whether the threshold from artificial intelligence systems to consciousness can be crossed without some form of biological underpinnings.

When humans venture into space they will lose the basic free means to sustain themselves, an open space in which to be and to express themselves, and a personality to express, all of which is given to them by Earth’s biosphere. The costs of replacing this productivity does not yet seem to be of concern in the planning for space activity, but its negative influence on the space economy will be seen the moment humans begin to maintain a permanent presence outside Earth.

6. THE ROLE OF DELAY IN THE SPACE ECONOMY

Travel time delay between population centres will not only fractionate society into autonomous or semi-autonomous groups, it will also require increasingly higher capital concentration. Gravitational and energetic boundaries will play the same role in differentiating groups and their development rates and prospects as Jared Diamond observed that oceanic, geographical and botanical barriers did to human groups on the surface of the Earth [49]. Earth’s gravitational well is an extremely expensive barrier to entrance into the space economy and requires capital far in excess of that normally required to compete in an Earth-based market. Far from unifying diverse cultures, practices and beliefs, space travel times will serve to intensify stakeholder interests over widespread unity.

As in the early days of international trade when each trading group possessed much the same transport technology, the key to investment return was arriving first to market. As has been observed in Earth economies in the past, delays between resource and market have stimulated competition rather than stifled it. Early users of telescopes were merchants looking for a few hours advantage in the markets by knowing which ship was approaching port before others. Such delays stimulated the race to set down the railways across the American continent, or ocean-going shipping and navigation technology, and the desire for a more global immediacy is currently leading humans to contemplate hypersonic passenger plane projects (such as that planned by the EADS foundation [50]) to reduce flight times across the globe down to around two hours. In a modern financial centre, sophisticated stock and currency trading programs make profits out of millisecond delays in market information.

Out in the solar system where likely delays of information transmission can be hours, leaving aside travel times of months and years, it is likely that these delays will provide economic opportunities further stimulating economic competition.

This situation is magnified when interstellar travel is considered. Interstellar travel requires the accumulation of capital and long delays before any returns can be realised. Further, it is argued in this paper that solving the problems of biosphere recreation for human voyagers will be crucial in producing the returns required by the stakeholders in any interstellar mission. Under these conditions it is inconceivable that the differences in times to destination revealed by the wait calculation will not be made use of by competing economic interests.

7. THE ‘ONE-EARTH’ PHILOSOPHY AND THE WAIT CALCULATION

Here and now, we see clearly the seeds of a competitive economic space environment, nourished by the extensive, but now reducing, past investment of governments, are already developing.[51]. The expansion of private enterprise is certainly in part assisted by the lack of consent to the notion that space is a property common to all mankind.

A romantic (or ´One Earth´ philosophy) view of space exploration is still held by many and can best be expressed by a recent document produced by the European Space Agency where politicians**,** technicians and entrepreneurs ponder what space exploration can offer Humankind:

> ‘...Further, the principal space treaty, the Outer Space Treaty of 1967, commits states to explore space ‘for the benefit and in the interest of all countries’. Thus, the US and other States party to the Treaty (there are ninety-eight) foresee win-win outcomes over time. The logics of win-lose and lose-lose are still present, but over time I expect non-zero-sum, win-win games to characterize the space age. Ultimate non-zero-sumness will arrive when humanity becomes a multiplanetary species and when we recognize ourselves as one people rather than conflictual subsets of our species...’
> Dr. Jonathan Fuller Galloway**,** *Professor Emeritus of International Relations Lake Forest College / International Institute of Space Law.*
>
> ‘...People who didn’t ‘get it’ are still fighting wars based on medieval fundamentalist paradigms about dominance – economic, religious, environmental. People who do ‘get it’ are fostering awareness of the inter-dependency of our lives, umbilically connected to our parent planet...’
> Mr Roy Gibson**,** *First Director General of the European Space Agency First Director General of the British National Space Centre.*
>
> ‘...(space exploration) is about BREAKING FREE. From petty man-made boundaries and distinctions of race, religion and colour.

> It is about CELEBRATION. Of the blur that separates fact from fiction.
> It is about 'that' PALE BLUE DOT. That beautiful, fragile spaceship we call home.
> It is about PEACE, LOVE, and CONNECTEDNESS...'
> Ms Susmita Mohanty, *Space Entrepreneur Moonfront (USA), Liquifer (Austria), Spaceships that Think (India)* [52]

Yet, while the *Outer Space Treaty* of 1967 demands that nations explore space for the 'benefit of all countries', no further treaties dealing with space as a common resource have been agreed upon. *The Bogota Declaration* of 1976 which stated that the arc of geosynchronous orbit directly over the territories of the countries through which the Earth's equator passes should be owned by those countries, while the portions over the sea should be common property, has been signed by the countries concerned but not ratified by the UN and it has no legal standing. *The Moon Treaty* of 1979 declaring the moon the legal property of all mankind has never been ratified. So there are few legal mechanisms in place to manage or modify the space activities and the goals of private enterprises or to support the 'One-Earth' sentiments expressed in the ESA document [52]. The field is open for private interest groups to begin to stake their claims on the material resources of the solar system. Indeed, Planetary Resources Inc., a company founded by 10 rich individuals in 2012 [53] is planning to do just that by mining of asteroids for commercial gain [54].

Future humankind, assuming it survives through the next centuries will comprise many billions of individuals widely spread throughout the solar system. The notion that this vast mass of beings will be united by a single culture and purpose seems fantastical. There is no historical evidence to suggest that humans could achieve this even if it could be shown that it desirable. The burden of economic necessity seems to preclude it. No social systems or structures are known that could possibly provide the necessary common ground over such a distended human group living under a multitude of time zones, environmental niches, social organisations, political philosophies and educational experiences.

Baxter considers that project Icarus or any other long-duration starship should be '...thought of as a vehicle of philosophy, of legacy for the future rather than short-term benefit for its builders' [55]. By observing the options revealed by the wait calculation we can see that such a philosophy is unlikely to carry sufficient weight in the centuries ahead and that those supporters of interstellar projects may need to adjust their attitudes towards more concrete goals in order to attract the financial investment needed.

8. RAMIFICATIONS FOR THE ICARUS PROJECT

There are three conclusions drawn from this discussion of the wait calculation that may impact upon the planning of the Icarus project [56].

1) Icarus' planned maximum journey time of 100 years is likely to require too long a wait. The travel time of a departure at the minimum for a given destination depends on the rate of growth. To make a voyage to a destination beyond Barnard's Star lasting 100 years or less requires higher long term growth rates, so using the 100 year voyage as the determinant is limiting, since future long term growth rates are still unknown.

   As shown in Fig 1. a destination of around 10 light years can best be reached by waiting around a little more than 1000 years then leave for a voyage time of around 200 years at a speed of *c/20,* at the steady long term growth rate of available power of 1.4% p.a. If the long term rate would rise to 2% growth, then the wait time to the minimum could be shortened to 770 years with a voyage time of 97 years. The intention should be to launch at the minimum for which ever destination is chosen.
2) To send Icarus out as a robotic mission is a waste of resources. Expenditure on the development will demand some return. It is not clear that a robotic mission will provide sufficient returns, or indeed any returns comparable to its cost. Robotic missions into deep space will have been sent beforehand and, coupled with experiences within the solar system, by the time Icarus is ready humans will probably know enough about how to travel through the first couple of light years of interstellar space not to need an information gathering exercise. Interstellar voyages are not voyages that can be rehearsed. Humans cannot afford to spend hundreds of years just finding out if they can make a craft to last a hundred year journey. Icarus should be a human colonising mission, and be developed as such from the start. Its destination will be the first human outpost in interstellar space and will have incomparable long term investment value as a stepping stone in the centuries ahead. Further, as has been argued, by the time it is ready Icarus is unlikely to be the only mission and a robotic mission is unlikely to compete well with a human mission at the destination. The founders of Icarus should treat their project now as if it was aiming for the best launch window, and that it will carry humans with the intention to colonise the destination.
3) Following from points 1 and 2, the development brief for the Icarus project should include biospheric research. This in turn will narrow the destination or exo-planet requirements to include scope for biosphere production.

9. CONCLUSION

While the minimum time to destination calculation uses a simplified notion of compound growth, it is considered that the culmination of forces for growth and the braking influences on this growth from social factors such as reduced faith in the scientific method, the rise of religion or alternative banking practices allows long term average growth rates to be useful in discussing not only the mission scenarios for various departure times for interstellar missions but how the Earth's economy might fund such a mission. By looking at the free productivity of the biosphere as an essential underpinning to Earth based economies it is argued that interstellar missions will need to have the capability to replicate such productivity at a destination, and thus, arrival priority will be crucial to the investment success of a mission. Research and development into biosphere production could produce on-going benefits and provide a means by which investments in the interstellar mission could be repaid in short time scales.

The hypothesis of the technological Singularity has been used to undermine the concept of steady exponential growth behind the wait calculation. Even if the state of the technological singularity does arrive, however, the major unacknowledged consequence for interstellar travel is that the incentive trap becomes ever more dominant. If it is the case that growth proceeds by ever increasing leaps and bounds then to leave on one of the first interstellar missions knowing full well that the mission would be made redundant by the inevitability of technological advances would be foolish. No investor would consider an option in such a voyage since arriving first at a destination is the only way that profits are likely to repay the investors. The wait calculation becomes ever more important. Even if travel at or around light velocities becomes possible, it is likely that all useful destinations from Earth will take >20 years to reach. If growth gradually improves upon these speeds, the incentive trap will still be in play and affect the arrival times of differential departures.

While it is true that at slow rates of growth and to near destinations, the minimum time curve is fairly flat around the minimum allowing departures to destinations of <10 light years made say 50 years either side of it to arrive within a decade of each other, when growth rates rise and destinations get further the curve sharpens. This is more significant than it seems if useful destinations are more remote than we expect and if predatory competition exists. There will be no international law operating in interstellar space and an ability to escape predatory actions *en route,* or at the destination, can only be done by precise calculations of departure times.

Using the wait calculation concept and by examining its implications, it becomes evident that even the Icarus mission will be made redundant before it leaves unless the mission profile is changed from a robotic one to a human colonising mission.

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