JBIS, Vol. 59, pp.xxx-xxx, 2006

INTERSTELLAR TRAVEL: THE WAIT CALCULATION AND THE INCENTIVE TRAP OF PROGRESS

ANDREW KENNEDY
The Chronolith Project, calle Goles 48, bajo A, Seville 41002, Spain.
Email: drewk@eresmas.com

This paper describes an incentive trap of growth that shows that civilisations may delay interstellar exploration as long as voyagers have the reasonable expectation that whenever they set out growth will continue to progress and find quicker means of travel, overtaking them to reach and colonise the destination before they do. This paper analyses the voyagers' wait calculation, using the example of a trip to Barnard's Star, and finds a surprising minimum to time to destination at a given rate of growth that affects the expansion of all civilisations. Using simple equations of growth, it can be shown that there is a time where the negative incentive to travel turns positive and where departures will beat departures made at all other times. Waiting for fear future technology will make a journey redundant is irrational since it can be shown that if growth rates alter then leaving earlier may be a better option. It considers that while growth is resilient and may follow surprising avenues, a future discovery producing a quantum leap in travel technology that justifies waiting is unlikely.

Keywords: Interstellar travel, incentive trap, the wait calculation, expansion of civilisation

1. INTRODUCTION TO GROWTH

1.1 Keeping the Momentum Going?

Analysts of growth are divided on whether growth will save human civilisation or destroy it. Fred Hoyle observed as long ago as 1964 [1] that if technological growth reaches a certain point and then fails recovery may be impossible.

> It has often been said, if the human species fails to make a go of it here on Earth, some other species will take over the running. In a sense of developing high intelligence, this is not correct. We have or will have, exhausted the necessary physical prerequisites so far as this planet is concerned. With coal gone, oil gone, high-grade metallic ores gone, no species however competent can make the long climb from primitive conditions to high-level technology. This is a one-shot affair. If we fail, this planetary system fails so far as intelligence is concerned. The same is true of other planetary systems. On each of them, there will be one chance, and one chance only.

Many modern economists, fearful of Hoyle's observation, tend to side with E.C. Prescott, co-Nobel prize winner for Economics in 2004 and a great proponent of growth who remarked that the greatest challenge facing the world was, '…keeping the momentum going' [2]. It is now fair to ask whether keeping the momentum of growth going will take humanity to the stars.

There are three major threats to the momentum of growth: economic collapse, disease and natural disasters. From current trends, all these fears have diminished, and it is quite probable that civilisation on Earth has already passed the danger points of collapse and is safe from permanently debilitating setbacks to its expansion.

Past prognosticators on the perils of growth have all been wrong. Paul Ehrlich, among many in the 1960s and 1970s, predicted civilisation's decline in the 21st century due to the explosive growth in world population [3]. The Club of Rome in 1972 predicted widespread trouble for the world economy by the year 2000 [4]. Many Commentators have written that resources, especially oil, are already failing and that world growth will inevitably decline from current levels. For example, Duncan believes that world oil production has already peaked [5,6] and Deffeyes believes it will peak between 2004–2008 [7].

If we expand our viewpoint a little from the purely local to the global, we can observe that global long-term growth is far more tenacious than is generally accepted. In spite of the dire warnings, most commentators accept that, at this point in our history, exponential growth continues to define the progress of almost any particular sphere of activity or field of learning. This is especially true of science itself where 80–90% of all scientists who have ever lived are alive now [8].

Fears of a world economic collapse have all but vanished [9]. Economic recessions last less and less time; they are measured in months and years rather than in decades [8]. The Kondratev cycles (40-50 years) of decline of the past centuries are no longer observed [8]. The average recession time (Juglar Cycle) from the last century lasted between 8–10 years [8]. The depression that followed the 20s boom was the last depression to last this length of time. Further recessions occurred in the 70s, 80s, and 90s and most recently during 2001–2002, but they are timed in months rather than years [8].

Disease is a possible source of decline, although the reaction of governments around the world to contain recent SARS and the theoretical threat from a mutated Avian flu outbreaks (in 2004–2005) shows that the impact of new diseases are most likely to be well contained. The likelihood is slim, in any event, that a disease pandemic would make much of a dent in the annual population increase of 93 million a year. Even AIDS, which attacks the sexually active portion of the population, may kill 3+ million a year [8] for a while – representing perhaps 0.05% of the World's population. Compared with 93 million mouths added to the world's population each year (at the turn of the millennium) this is not very significant.

Even a pandemic on the scale of the first wave of the Black Death in Europe braked growth very temporarily. The death rate in Europe was probably about a third [8, 10], and it is thought that its population did not rise to pre-1349 levels until 1600 [8]. Warfare came to a halt and trade was severely reduced. Yet a quick scan of history shows that a 150 years or so afterwards, America had been discovered, improved ship-building and navigation (using the recent Western version of the compass) made journeys to the Far East commonplace, ships had sailed around the world (in AD1521), and Europe was trading with China and India. The spread of credit-based banking and the invention of double entry bookkeeping had brought investment funds into play, and warfare had picked up again [11].

The years after the First World War are even more instructive. War action had killed off at least twenty million combatants, mainly adults, and civilians world-wide [8] followed by famine and deprivation in some areas, when an epidemic of flu appeared - possibly the most virulent pandemic ever seen – which killed off perhaps between 40-50 million (estimates vary) world-wide between 1918–1919 [12]. A large portion of these was among the 20-40 year age group, the largest group of contributors to growth. Yet populations everywhere boomed in the years afterwards, leading to the manic economic growth of the 1920s. India, for example, lost at least 12–13 million to the disease, but now is destined to become the most populous country on Earth [13].

To take another example, the on-set of climactic conditions that has been termed 'The Little Ice Age' began at the start of the 14th century with widespread famines (1315-1317) and then caused, a general 'economic contraction' [10]. In England, the cycle of wet summers raised the wheat price to 6 times its normal level and 'men ate horses and dogs and even, it was said, children' [14]. However, by 1318, England was planning a new invasion of Scotland. By 1330 with young Edward III on the throne and in the midst of continuous warfare with the nations of Britain and in France, nobles were accumulating expensive armour, rich furred robes, jewelled belts, tapestries and all the accoutrements of wealth. Castles were being turned from military installations into palaces, books were being collected and England's imports of spices, wine, silks and furs, rice and fruit stimulated the shipping industry [14]. The Bay of Biscay was sometimes referred to as the 'sea of the English' [14] from the multitude of English ships sailing its waters. Great churches were built or re-built in the new gothic style, and the cathedral of St. Paul's in London was finished. It was the biggest church in Europe with a 500-foot tower and spire [14].

Over a similar era in the New World, the Mayan and Toltec empires collapsed completely at the end of the 12th century AD. Yet the Aztec Empire rose in their place in the 15th century [10]. The Aztec capital, Tenochtitlán, at the time of the Spanish conquest, was by then one of the great cities on Earth with a population exceeding 140,000 people [8]. By contrast, in the same era, Seville, the Spanish city that led the conquest of the New World had at most 45,000 inhabitants [8].

Threats from worldwide natural catastrophes remain [10], and Hempsell has analysed the historical record and predicts the current chance of dying from one to be about 1 in 40 and increasing into this century [15]. But even in early urban history where the frequency and impact of natural catastrophes on a global scale may have been greater than previously thought [10], society still recovers and overall growth is sustained in the longer term.

In more recent times, events of the Second World War illustrate the tenacity of growth. The intense bombardment of Germany's heartland could be considered similar to a large natural disaster. Yet, Germany's industrial output hardly slowed until the last few weeks of the war. The tanks may have run out of petrol in the Ardennes counter-offensive, but Germany still managed to construct and put in the air the first jet aircraft, and bombed London with the first intercontinental ballistic missiles, having developed a plastics industry at the same time [8]. Japan, still a partly feudal society when it waged war in 1940, had its industrial base destroyed by 1945. 50 years on, before the stock market falls of the 1990s, it owned the most expensive real estate on the planet, and the Tokyo Stock Exchange had overtaken that of New York in the trading of securities [8].

It would seem that technological growth is getting harder and harder to slow down. Such growth will not only consume the Earth rapidly but also require the re-building of the Solar System into Dyson spheres, or something like them. Sagan and Shklovskii calculated in 1966 that, with an average annual growth rate of 1/3 of a percent, in 2,500 years energy demand will outstrip the total solar radiation falling on the Earth by a factor of 100,000 [16].

Though, as our argument suggests, and as many economists believe, as long as growth continues unabated, Human civilisation will find ways to circumvent this problem. This is a safe prediction, even if the precise sequence of steps cannot be predicted.

As far as space travel is concerned, however, growth presents a new problem.

2. THE INCENTIVE TRAP

Let us imagine that technological growth has provided an interstellar space ship to travel to Barnard's Star (6 light years distant). The voyagers are prepared to leave behind their birthplace forever to voyage far and long into space to visit, even colonise, a distant planet. This is the moment to pause and consider the following:

Civilisation is growing faster each day. Scientific progress will produce ever-faster means of travel. It may even solve the riddle of travel at light speeds or beyond. If that happens while the ship is still travelling, people setting out later will get to the destination ahead of it, making the first trip a wasted sacrifice.

It is clear that if the time to wait for the development of faster means of travel is far greater than the length of the journey, then the voyagers should go ahead and make the journey. But if the likely future travel time plus the length of wait is equal or less than the current journey time then they should definitely wait.

Is it possible to calculate precisely how long the voyagers should wait for any desired journey time?

2.1 A Growth Equation

Using a classic doubling equation to describe the effects growth would have on achievable velocity of travel:

$$\text{speed of travel, } v = v_0\, 2^{t/h} \qquad (1)$$

Where t is the waiting time interval, h is the time between doublings of speed.

Then, the waiting time can be found for making the journey in a time comfortable for the voyagers.

Re-arranging equation 1 gives:

$$t = h\,((\log v - \log v_0)/\log 2)$$

and here is an example:

Current technology say, enables the travellers to set off now to Barnard's Star, 6 light years distant, at a given velocity and reach it in 12,000 years ($v_0 = c/2000$).

Conceivable future technologies could make the journey quicker [17, 18, 19, 20, 21, 22]. As a bench mark, Project Daedalus, conceived by the BIS in the 1970s, was designed to achieve a speed of about 1/10 the speed of light, making the trip to Barnard's Star in about 50 years [23]. However, this journey was planned as a fly-by not a landing since carrying the extra propellant required for deceleration was unfeasible. We can consider that were decelerations to orbital velocity possible the journey time would take twice as long.

If technology growth is likely to double every 100 years the speed at which this journey could be made, then, using equation –1, it would seem that a voyager need only wait 690 years or so to make the journey in 100 years or less (i.e. at a speed of 6/100 speed of light). In other words, the star could be reached in well under a thousand years from now simply by waiting. Total time to destination is 690 years of wait + 100 years of travel = 790 years.

Aware of what growth could do to the available velocity of travel, could others wait longer and travel even more quickly?

Generalising equation —1 thus,

Let t_0 be the travel time to destination now.

And T be the time it takes at some later time after a time t of waiting.

$$1/T = (1 / t_0)\, 2^{t/h}$$
$$t_0 / T = 2^{t/h} \qquad (2)$$

The full time to destination $t + T$ must be less than or equal to t_0 otherwise there's no point waiting. By plotting total time to destination from now against the wait time (see fig.1), an important result is revealed.

For a doubling time of 100 years, the minimum time to destination is ~782 years achieved after ~637 years of waiting. Although the journey takes longer (145 years), those who left at this minimum would beat anyone who wanted to wait to make the journey in 100 years. A doubling time of 50 years brings the minimum time to destination to ~441 years after ~371 years of waiting and a shorter travel time of 70 years.

It should be noted that $v_0 = c/2000$, (150 km sec^{-1}) is an optimistic figure and assumes a current technological level that we may not quite yet possess. As an illustration, NASA's mission to Pluto, 'New Horizons', leaving in January 2006 is being launched by an Atlas V-551 at an injection speed of ~ 12 km sec^{-1} (48,000 km hr^{-1}), although the 'slingshot' maneuver around Jupiter could raise cruising speed by as much as 4 km sec^{-1} [24]. It is expected to pass Pluto at a speed of ~14 km sec^{-1}. Taking approximately this mission velocity as $v_0 = c/20{,}000$ as a lower base velocity, we find the waiting time to minimum has risen to ~969 years.

2.2 The Minimum Wait Time

Figure 1 shows that at a given growth rate there is a waiting time longer than which will not get the voyagers to the destination any quicker. A departure at this point beats any later departure since, even though growth will continue to produce faster velocities, the time of waiting is too long to make up with any faster velocity. After the minimum, the incentive trap ceases: those who leave later arrive later.

The Daedalus project requires, among other things, the mining of thousands of tons of ^{3}He from Jupiter's atmosphere [23]. We have no idea how this might be done right now, but if the Daedalus project turns out to be the plan in use, the travel to and going into orbit around Barnard's star in a voyage of a 100 years, and taking a velocity of travel doubling time, $h = 100$ years, the above calculation shows that we have to wait ~ 969 years before it will done, making the minimum time from now (where $v_0 = c/20{,}000$) to the Barnard Star destination ~ 1069 years.

Faster growth (for example using a doubling time of $h = 50$ years), while shortening the waiting time, does not avoid the minimum in the curve. It only makes it sharper, exacerbating how the small differences of waiting convert into longer journeys.

This equation does not guarantee that Project Daedalus or any scheme conceived now will come to fruition. Another scheme entirely novel may take its place. The equation does not favour any imaginative exercise in prediction. It merely describes an achievable velocity of travel produced by continuous growth. The implications of this will be discussed below.

2.3 Compound growth

Equation —1 has a fixed time interval and does not incorporate the acceleration inherent in compounded technological growth.

Let us use a simple compound equation

$$v = v_0\,(1 + r)^t \qquad (3)$$

Where r = is the % yearly growth increment,

Using this equation, we can easily model the rate of increase of the average speed of travel available to the ordinary citizen over the last century. At the end of the 19th century, car enthusiasts had taken internal combustion engine cars to 80 km/hr [8].

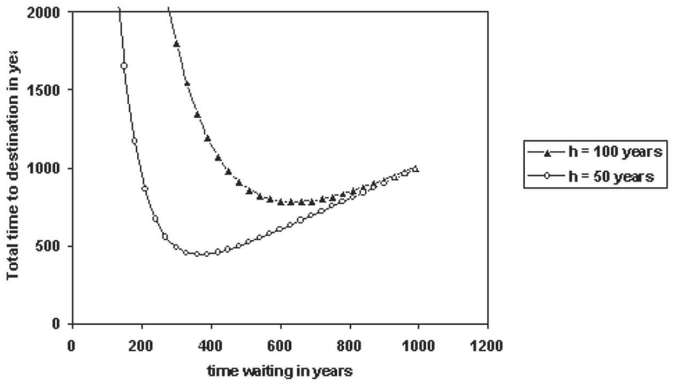

Fig. 1 A plot of total time to destination from now against travel time in years using $v_0 = c/2000$.

Taking r =0.01 we find speed has grown to ~135 km/hr in 1950. At the turn of this century, where $t = 100$ years, this equation produces an available speed of 225 km/hr, the cruising speed of an elite sports car.

We can see how long this same rate of growth would take to make the interstellar journey to Barnard's Star (6 light years) in 100 years or less using our current realistic base interstellar velocity as above of *c/20000*.

$$v = 6c / 100; \; v_0 = c/20000; \text{ where } c = \text{speed of light}$$

Eliminating *c* and re-arranging we have

$$t = (\log 6/100 - \log 1/20000)/\log (1.01)$$

which gives waiting time to minimum, $t = 712$ years (see Fig. 2).

For $v = c$ and $v_0 = c/20000$, this modest compounded growth if it continues in this simple fashion might produce travel at the speed of light in $t = 950$ years.

As above, we can generalise this equation thus:

$$t_0 / T = (1 + r)^t \tag{4}$$

where T = travel time after a time t of wait; *r* is the average % yearly rate of change. *r* may increase or decrease slightly from year to year, but in the long term, these differences will be absorbed into an average increment.

2.4 The Waiting Calculation

From this simple calculation, we can see that any civilisation may prefer to wait until growth produces a travel time that approaches the minimum since this will also be the minimum expended energy. Successive generations will have less and less time to wait for the minimum, but, given that the average long-term rate of growth does not change appreciably, any attainable velocity will lie on the same curve and the point in time where the minimum occurs does not change.

Future generations may approach this minimum point with heightened anticipation if they only have the capability to make a single launch, since leaving at any other time than the minimum is risky. Many of the trips to the more remote stars planned for the future, using the technological techniques that are expected to be available, will take place at velocities of around 0.02c [25] and may thus take thousands of years rather than hundreds. Consequently, there is the fear that leaving earlier than the minimum will mean that future generations will not only arrive at these destinations earlier, having had an easier trip, but may squander all the fruits of the landfall before the original voyagers arrive.

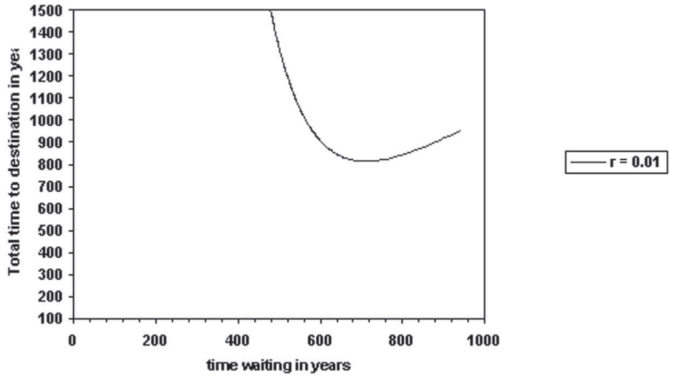

Fig. 2 Using the compounded growth equation and plotting total time to destination from now against the waiting time in years where $v_0 = c/20000$

If the civilisation has the capability to make several launches, then they could make use of the spread of arrival times to encourage individuals 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.

Civilisations are not obliged to launch at the minimum, but waiting until the minimum is the most efficient way to explore. Other than this, a departure time to choose may be simply a matter of psychology. Few will want to travel willingly into space unless they can participate in the landfall. One can readily imagine travellers giving up, say, 30 years of their life on a journey – even in hibernation - as long as they can be rewarded with the arrival. Longer travel times, although they imply a happier landfall (if later travellers have arrived first), may not be so attractive to the voyager.

In this respect, the **wait calculation** is crucial. Either side of the minimum, voyagers will arrive later than those who set off at the minimum. At the minimum wait time, growth will not catch the voyagers up during their journey. They will arrive to an unsettled destination, expecting others to follow, but not knowing if the vanguard of civilisation will appear on their horizon before much time has passed. If they leave before or after the minimum and find their destination still unsettled when they arrive, they will know that growth has slowed or stopped and that they will be alone for some time.

But there are other anxieties. Historically, humans tend to eradicate earlier or more primitive cultures. If the first voyagers, in order to make sure that there is a welcome committee, leave too early, they could arrive too late. Rather than end up as brave colleagues to the pioneer party, they would be an awkward presence in a world that has advanced far beyond their experience. They will be historical curiosities, hardly at the forefront of social change. They would have little or no training in the advanced culture, little to contribute, and little scope for being independent. They would probably be a burden, and may even be, because of a world-view developed in an earlier epoch, a thorn in the side of the authorities.

If we trust in the continued expansion of civilisation, the risks of being overtaken are real. All civilisations, including Earth, are caught in this **incentive trap of growth**. And it is an important consideration since it is perfectly possible that the colonisation of space will be a competitive venture between disparate cultural groups. In which case, getting the **waiting calculation** wrong may be fatal since, after the minimum has passed, those who leave later arrive later.

2.5 What Rate of Growth is Likely?

An increase in the velocity of interstellar travel of 1% per annum may be unrealistic since it leads so quickly to light speeds. The chances are very high that the Galaxy would be teeming with travellers if any civilisation could sustain this rate of growth. In fact, the appearance of the first interstellar traveller arriving on Earth would be a very bad sign, because we would know that the vast rates of growth that got the traveller here are poised to swamp humanity with further travellers within a very short period of time. It seems unlikely, therefore, that there have been isolated cases of contact with ETIs in the historical or even recent past since there has been no follow-up given this expansion rate of a civilisation. Interstellar travel does not, therefore, appear to be commonplace. There must be delaying factors to growth.

So what rate of velocity growth can be used? Let us consider that the rate of Human expansion is intimately tied to the use of resources. In this respect then, it should be more closely related to the integrated long-term return on investment rather than to any short-term usage of energy. However, more work will need to be done on establishing the precise long-term relationship between the energy resources used and power output available for interstellar travel, but to illustrate the argument we will take the recent simple annual percentage growth in energy consumption to represent the same rate of growth of power available to interstellar flight.

Consider that, in energy terms, the power required to produce a given rate of travel is proportional to the square of the velocity. Hence, a doubling of the velocity of travel requires a quadrupling of power. Thus the velocity growth rate will be proportional to the root of power production, $v \alpha p^{1/2}$.

The world energy consumption rose at an annual rate of 1.4% between 1990–2202, and it is expected to rise to about 2% between 2002 and 2025 [26].

So, taking r = 0.014 as the actual annual increment in the velocity of travel we have:

$$v = v_0 (1.014)^{t/2} \tag{5}$$

In which case, where $v_0 = 1 / 20000$, minimum time to Bernard’s Star under these requirements for growth requires a wait from now of ~966 years, a figure very little different to that produced by equation –1.

2.6 Relativity Effects

However, as human growth and expansion produces ever-higher travel speeds, eventually the constraints of Relativity enter the picture. But is this significant?

At relativistic speeds, the mass rises and hence the power required to accelerate a spaceship rises by a factor of

$$(1 - v^2 / c^2)^{1/2} \tag{6}$$

However, these relativistic effects are modest at speeds quite close to the speed of light. At 99% the speed of light, the mass has risen only by a factor of 7 or so.

In general, if the time to a particular power level and hence to a velocity level at a given velocity of travel is retarded by relativistic considerations, then we can summarise the situation for any particular trip using equations —5 and —6 like this:

where $v = n.c / T$ and $v_0 = n.c / t_0$

we have

$$t_0 / T. (1 - n^2 / T^2)^{1/2} = (1 + r)^{t/2}$$

$$t = (2.\log (t_0) - (2.\log T + \log (n^2 / T^2)) / \log (1 + r)$$

By plotting time to destination against this new waiting time in fig.3 we see that the relativity component does not change the basic curve derived from equation —5 Long before relativity effects are in evidence – say when $v > 0.8c$, giving a journey time of $(6/8) = 7.77$ years - the minimum time to destination (at $r = 0.014$) has already been reached, which, for the Barnard Star journey requires a wait of ~ 966 years (plus a journey time of 145 years) with a minimum time to destination of ~1111 years.

For near destinations and at these speeds (~4% the speed of light), there is no significant time-dilation to improve the experience, this journey can be made only with hibernation or with so-called ‘generation’ ships which contain a small group of people whose children or grandchildren will see the destination. With these figures, the effort put into reaching the velocities required by Project Daedalus (~c/10), or even faster concepts, will be not be worth it.

If the power growth rate ever slows then the minimum time to destination increases rapidly (see Fig. 4). A long term average power growth of 5% pa produces a minimum time to Barnard’s Star from now of ~327 years from now. But if the annualised rate slows as civilisation comes up against resource limits for example, then making any kind of useful interstellar journey becomes increasingly remote. A growth rate of ½ % pa. would produce a minimum time to destination of ~ 2287 years with a journey time of 400 years.

An important result of equation –7 is that, since achieved velocity grows with time, the minimum time to destination occurs at an increasing velocity for further destinations (Fig. 5). Thus, the incentive trap will always be present for far destinations unless these velocities can be achieved. At a given rate of growth, a journey planned with any velocity either side of the plotted line (Fig.5) will be subject to the incentive trap. This does not mean the journey cannot be made, rather it shows that the incentive trap will be an inevitable component of the decision whether or not to go.

3. CAN THE INCENTIVE TRAP BE AVOIDED?

3.1 Is the Disincentive to Travel Irrational?

The incentive trap occurs when interstellar voyagers have reason to believe that being overtaken poses a risk or implies a waste of effort. During the initial stages of growth, there is no incentive for voyagers to leave at any particular time since

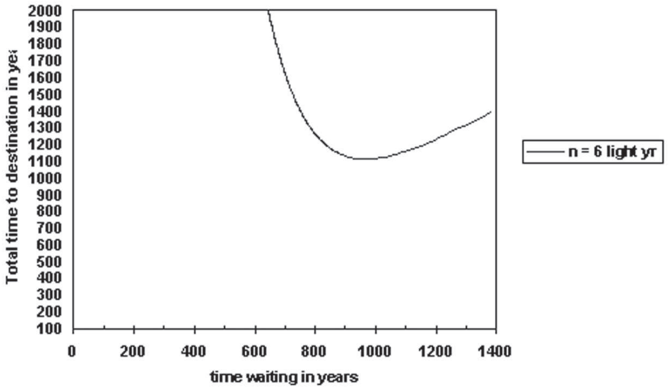

Fig. 3 Total time to destination from now against the waiting time in years where $v_0 = c/20000$ and $r = 0.014$.

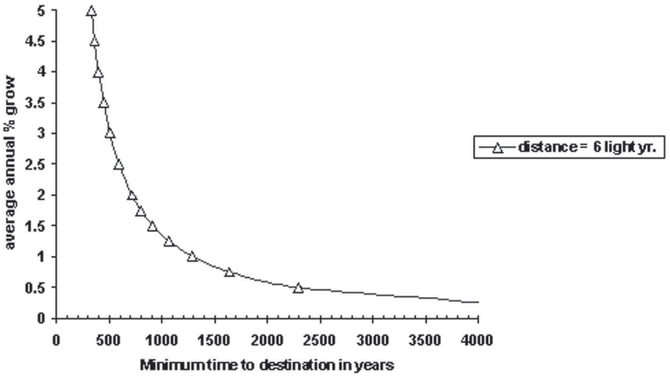

Fig. 4 Plotting average rates of growth in % annual increments against the minimum time to a destination of 6 light years where $v_0 = c/20000$.

technological development will overtake them if they do leave. This dis-incentive to travel continues until a minimum, when for a given rate and destination, waiting for growth to produce higher travel velocities will not allow voyagers to overtake an earlier launch.

The wait equation describes this minimum. This is the point at which the negative incentive to leave changes to a positive one; where the incentive to set out on the interstellar journey is the strongest.

In spite of this, there is a widespread belief that a departure at any time runs the risk of being undermined by sudden leaps in technology that could make the early voyage redundant regardless of the time it set out. In other words, there is never a strong incentive to leave. Vulpetti voices this typical expectation, '…While …a vehicle proceeds to nearby star(s), probably humankind's physical knowledge could exhibit some leap(s) inducing breakthrough(s) in space propulsion technology.' [25]. He recognises that this expectation could undermine the willingness to leave on an interstellar flight and even the willingness to invest in technologies designed for interstellar flight.

This fear, however, is irrational. It implies that the application of scientific breakthroughs is independent of interconnecting patterns of growth. This fear has two manifestations. Firstly, that a single remarkable technological breakthrough may happen at any time independent of any growth factor, and secondly, that overall growth itself may take sudden leaps upwards and alter the future beyond recognition.

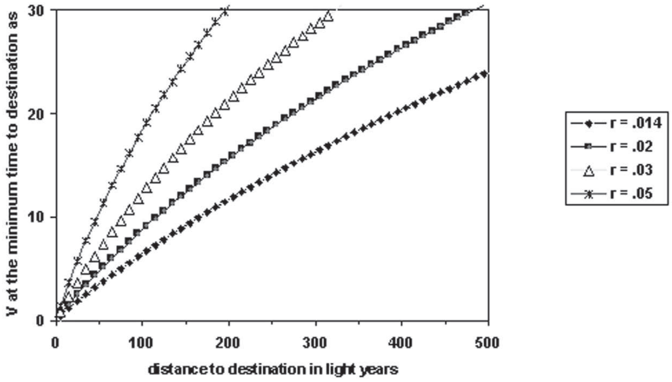

Fig. 5 Taking the velocity at the minimum time to destination for destinations between 5 and 500 light years for r = 0.014; 0.02;0.03;0.05, and where $v_0 = c/20000$

Both these fears are based on misconceptions of the nature of growth. In order to appreciate these misconceptions, it is worth dwelling on some random cultural and scientific illustrations.

3.2 Brief Reflections on the Nature of Growth

We have seen how overall growth is resilient, but its expression is unpredictable. At the mid-way point of the 16th century, England was in decline, riven by civil unrest, corruption and lack of finance [27]. Spain had destroyed the vast American nations of the Aztecs and Incas and had a monopoly on all trade with the Americas and its endless stream of gold and silver. Through marriage and the use of its crack mercenary troops, it controlled half of all Europe. Although the Cabots, sailing out of Bristol, England, had been the first Europeans to set foot on the North American mainland (1497), no permanent English colony would be set up in the Americas until the 17th century. In 1556, no one would have predicted that two hundred and twenty years later, the new American Nation would be speaking English and breaking away from its mother country of Britain.

Science continually produces rogue results and highly speculative theorisation, but these have to await the time in which sense can be made of them. Max Planck introduced the idea of energy quantum in 1900. Einstein independently solved the problem of the photoelectric effect with quanta in 1905 [9], and by 1926 the Quantum theory was in existence[9]. The best scientific minds of the century had applied themselves to developing the theory and yet it was not until almost 50 years later that the tricks of normalisation, discovered by Feynmann, Bethe and others, allowed actual physical values to be extracted from the theory. Entanglement in quantum physics has been around since at least 1935 [29] and is only now (70 years later) finding applications in quantum computing and cipher creation in which it can theoretically be employed, though it still cannot permit faster than light communication as we understand it now. More than 100 years after the conception of the quantum, a unified field theory still remains elusive.

There are leaps in knowledge certainly, but exploiting the leaps is never as obvious as it might first appear. The principle of nuclear fusion was understood in the 1930s when Hans Bethe saw that the fusion of hydrogen nuclei produced energy and was the source of the energy in stars. A fusion bomb was exploded in 1952 [9]. But although massively expensive work on projects designed to make fusion an energy source for this century have been proceeding for over 50 years, no one can even predict when fusion reactors will come on stream, such is the amount of work still to do.

Some great technological discoveries take years to fulfil their promise, if at all. In 1899, Belgian Camille Jenatzy reportedly drove his electric car, “La Jamais Contente” (‘Never Satisfied’) to a world land speed record of more than 100 km per hour. By 1900, more electric vehicles were registered in the U.S. than steam or gasoline vehicles [28]. Yet today the performance of electric cars is still a long way behind the internal combustion engine vehicles. The gradual improvements and slow accumulations of efficiencies and new technologies have benefited the internal combustion engine and not the battery.

New technologies follow known laws of power use and information spread and are obliged to connect with what already exists. Remarkable theoretical discoveries, if they end up being used at all, play their part in maintaining the growth rate; they do not make its plotted curve and the positive incentive to leave redundant.

3.3 Can the Positive Incentive to Leave be Undermined?

In spite of the low probability of remarkable discoveries leading rapidly to advances in practical knowledge, the disincentive to leave may still be held if there is the belief that the overall long-term growth rates are prone to change greatly with time. The disincentive to travel may continue on past the minimum time to destination if there is strong evidence that future growth is likely to rise significantly and produce even faster velocities than earlier growth rates.

If long-term growth does exhibit a level of uncertainty, prospective interstellar voyagers will be able to assign a variety of statistical techniques to the growth curve, and will be able to give a probability value to each point on their minimum time to destination graph.

One of the simplest techniques is the use of variance and standard deviations from a mean.

If we made an observation each year of the value of the rate of growth, r, then the mean growth rate is simply,

$$M_r = (r_1 + r_2 \ldots. + r_t) / t$$

And the standard deviation will be

$$\text{“}((r_1 - M_1)^2 + (r_2 - M_2)^2 \ldots. + (r_t - M_t)^2) / t)$$

By using the statistical inference that the variability of the average of a set of observations is inversely proportional to the square root of the number of observations, we can see that the probability of a growth rate departing from the mean should fall as time goes on. The likely future growth rate becomes more predictable rather than less.

For the two cases where long term growth falls or rises, waiting too long is still irrational. Where growth falls, the available velocity of future travel fails to grow, in which case waiting puts off the arrival time at the destination considerably. In the second case where growth rises, the minimum time to destination will be less and occur earlier, giving a strong reason to leave earlier than the time predicted by constant growth.

Given this simple illustration and the historical picture of growth, we can be reasonably sure that neither great changes in growth nor great leaps in technology will alter the existence of the transition from the negative to the positive incentive to travel. The perceived ever-present disincentive to travel mentioned by Vulpetti can be overcome even allowing for uncertainties in growth rates.

4. DISCUSSION

The treatment of growth in this paper describes important factors and constraints to consider when deciding to journey to the stars.

It has been shown that by plotting minimum time to destination from now against waiting time for a growth rate in velocity of travel, there is a point where the negative incentive to wait turns into a positive incentive to leave. Leaving before the minimum time allows future growth to overtake the voyagers, leaving after the minimum time will mean the voyagers cannot catch up those who left at the minimum.

It has been shown that taking reasonable estimates for growth, an interstellar journey of 6 light years can best be made in about 635 years from now if growth continues at about 1.4% per annum. At this point, the journey could be made in 145 years. It is likely that genetic engineering and improved techniques of hibernation may make this journey feasible in an individual’s lifetime. Humans may also undertake this voyage if they can be sure that their children will see the destination. But the voyage times will rise if growth ever slows. At a growth rate of ½ % pa., the minimum time to destination for the same journey will require a journey of ~400 years, at a velocity of 1.5 % the speed of light. This will require the construction of ‘world ships’ or something close to them [25]. **The incentive trap of growth** will certainly come into play and few voyagers would be willing to risk such a long trip until they are sure they will not be overtaken. Even so, the time to destination minimum can be used to entice people to make long journeys by using a spread of launches around the minimum so that welcome and back-up can be engineered for any particular group of voyagers.

It is considered that the overall growth curve represents a summation of many inter-related sectors of growth, and that the probability of a discovery in any one sector contributing, on its own, to a sudden radical departure from the overall rate is not likely. While unpredictable changes can contribute to the overall growth rate, it would be wrong for interstellar voyagers to delay a departure based on the hope that a technological breakthrough will improve the journey times calculated on the basis of the known growth rate, and that to ignore the positive incentive described by the **wait equation** would be irrational.

REFERENCES

1. F. Hoyle, *Of Men and Galaxies,* University of Washington Press, Seattle, 1964.
2. *Telephone interview with Professor Edward C. Prescott after the announcement of the 2004 Bank of Sweden Prize in Economic Sciences in Memory of Alfred Nobel, October 11, 2004. Interviewer was Marika Griehsel, freelance journalist*. Nobel Foundation, 2004.
3. P. Ehrlich, *The Population Bomb*, 1968.
4. D. Meadows *et al.*, *Limits to Growth*, MIT, 1972.
5. R. Duncan, *The Olduvai Theory: Sliding towards a Post-Industrial Stone Age*, Institute on Energy and Man, 1996.

6. R.C. Duncan, "The life-expectancy of Industrial Civilization: The decline to global equilibrium", *Population and Environment,* **14***,* pp.325-357, 1993.
7. K.S. Deffeyes, *Hubbert's Peak: The Impending World Oil Shortage*, Princeton University Press, 2001.
8. Encyclopedia Britannica, 1997.
9. Charles Jones, *Was an Industrial Revolution Inevitable? Economic Growth Over the Very Long Run,* Advances in Macroeconomics, Berkeley Electronic Press, vol. 1(2), pages 1028-1028, 2001.
10. C.M.Hempsell, "The Investigation of Natural Global Catastrophes", *JBIS*, **57**, pp.2-13, 2004.
11. I. Asimov & I. White, *The March of The Millennia: A Key Look at History.* New York: Walker, 1991.
12. L.Garrett, *The Coming Plague*, Farrar, Strauss & Giroux, 1994.
13. PREDICTED POPULATIONS, 2050: India, 1,628m; China, 1,437m; United States, 420m; Indonesia, 308m; Nigeria, 307m; *2005 World Population Data Sheet*, Population Reference Bureau, Washington,US, 2005.
14. A.Bryant, *The Age of Chivalry*, William Collins & Sons, 1963.
15. C.M. Hempsell, "The Potential for Space Intervention in Global Catastrophes", *JBIS*, **57**, pp.14-21.
16. I.S.Shklovskii, C. Sagan, *Intelligent Life in the Universe*, Holden Day, Inc., 1966.
17. H.D. Froning Jr., "Requirements for Rapid Transport to the Further Stars", *JBIS*, **36**,pp.227-230, 1983.
18. R.L.Forward, "Space Warps: a review of one form or propulsionless transport", *JBIS*, **42**, pp.533-542, 1989.
19. Nordley, Gerald, "Application of Antimatter-Electric Power to Interstellar Propulsion", presented at the 38th IAF Congress, Brighton, October 1987 (reprinted in *JBIS*, **43**, pp.241-258, 1990).
20. Alan Bond, "An Analysis of the Potential Performance of the Ram Augmented Interstellar Rocket"*, JBIS*, **27**, pp.374-385, 1974.
21. A. Jackson, "Some Considerations on the Antimatter and Fusion Ram Augmented Interstellar Rocket", *JBIS*, **43**, pp.117-120, 1990.
22. G.L. Matloff, "The Perforated Solar Sail: Its Application to Interstellar Travel", *JBIS*, **56**, pp.250-254, 2003.
23. A. Bond & A.R.Martin (eds), *Project Daedalus*, BIS, London 1978
24. http://pluto.jhuapl.edu/ , New Horizons project home page, on-line resource.
25. G.Vulpetti, "Problems and Perspectives in Interstellar Exploration", *JBIS*, **52**, pp.307-323, 1999.
26. *Report #:DOE/EIA-0484(2005),* Energy Information Administration, Washington, US, July 2005.
27. A. Bryant, *The Elizabethan Deliverance*, Collins, UK, 1980
28. S. Wilkinson, *Electric Vehicles Gear Up*, Chemical & Engineering News, Washington, US, October 13, 1997
29. A. Einstein, Podolsky, Rosen, "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?", *Physical Review*, **47**, pp.777-780, 1935.

(Received 7 November 2005; 26 January 2006; 28 February 2006)

* * *