Space Policy, Intergenerational Ethics, and the Environment

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The cost of an investment in extremely long-term exploration and research made by a nation financing large budget deficits will be borne by multiple generations. The decision to burden future citizens with the cost of a public space program begs a question of intergenerational equity with both economic and environmental aspects. While these two facets are most often been considered in a context of dialectical opposition, space exploration offers a paradigm shift that aligns economic development with environmental stewardship by actually offering to remove human economic activity from the planet. With that promise far off, the mid-term economic-environmental benefits of our public space investment are considered using historical and macroeconomic perspective[†]. The record shows America's space program has been one of the best ways to solve these "problems right here on Earth." The positive economic and environmental externalities created by secondary and tertiary functions of NASA, military, and private space programs far outweigh the current level of financial investment.

I. Introduction: Establishing the Vision

What good is a house, if you haven't got a tolerable planet to put it on?
-Henry David Thoreau, American essayist

When the crew of Apollo 8 returned from the moon with the first stunning pictures of the whole Earth[‡] the world caught its breath. It was a transcendental moment. As astronaut Bill Anders said "We came all this way to explore the moon and the most important thing is that we discovered the Earth."[1] Those photos and words have been credited as foundational contributions to the environmental movement. Yet, no one has shared that grand perspective since the crew of Apollo 17 returned to Earth in 1972. Today, the spirit of adventure that motivated that grand sort of exploration has dimmed and the space program is in constant budgetary jeopardy from those who see it as a misallocation of resources from the "important problems right here on Earth." For want of $17 billion[§] a year – less than the annual cost for providing air-conditioning to our forces in Iraq / Afghanistan – we may sacrifice our national economic and global environmental future.

Not only is expenditure on a public space program ethically justifiable, space research has been a remarkable way of truly "thinking outside the box" and in the end may offer the only real solution to the fundamental environmental and economic dilemmas that we face.

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[†] Understanding the AIAA audience is composed primarily of engineers and wishing to keep this article relevant to policy discussions, the economics presented here are non-technical.

[‡] Apollo 8 was the first manned spacecraft to orbit the moon and first to leave low Earth orbit. Its crew of three James Lovell, Frank Borman, and William Anders were the first human beings to step far enough back to see the Earth as a whole.

[§] NASA's annual budget is approximately $17billion. According to an NPR report the estimated cost of air-conditioning U.S. facilities and tents in Iraq and Afghanistan was $20.2billion in 2010. http://www.npr.org/2011/06/25/137414737/among-the-costs-of-war-20b-in-air-conditioning

II. Intergenerational Equity and Space

The trustees of endowed institutions are the guardians of the future against the claims of the present. Their task in managing the endowment is to preserve equity among generations.
-James Tobin, economist

From the start, the concept of intergenerational equity has had both economic and environmental interpretations. More often than not these two aspects have been viewed in a context of dialectical opposition. Those who would espouse environmental priorities find they are trampling the goals of those who place economic needs first and vice versa. Do we leave our children trees or jobs? Of what use is a pristine world to a generation without food, shelter, or medicine? Of what value is a long and secure life lived in a world of environmental degradation. This debate has drug on for fifty years now and with a very few pleasant exceptions the results have been dissatisfying to all concerned. Despite the wishes of a few stalwart "true believers," hope for a happy ending seems farther off than ever.

The debate over global warming has become the poster child for this larger dilemma. Despite forty years of science documenting a clear and present danger to life, as we know it, consensus on action remains stymied. The clock ticks on primarily because those who have a vested economic interest in the status quo are motivated to dismiss anything that threatens their income and those who have an political interest in upturning the status quo have been all too eager to exaggerate anything that challenges the current economic regime.

In his 1985 work *Filters Against Folly,* Garret Hardin wrote, "In sharp contrast to privatism, commonism privatizes the gain but commonizes the losses. The herdsman keeps the gain (increase in his herd) for himself while pushing the losses (in the form of environmental degradation) off onto the entire community. Such a system fails to meet the operational criterion of positive responsibility."[2]

Often such pushing off of losses is done across geographical (spatial shifting) or generational (time shifting) borders.[3] We have a moral obligation to avoid such behavior. In discussing transnational environmental challenges, Lorrain Elliot has noted, " . . . those who are most disadvantaged do not have the liberty to choose whether they harm the environment or not, or whether they are harmed by the environmental impact of the activity of others . . . their autonomy is undermined."[4] The situation is no different in our obligation to future generations who have no say in the quality of the environment they will inherit.

The fundamental assumption that has driven environmentalism and economics into conflict is the erroneous belief that humans are doomed to playing a zero sum game. When Bill Anders took his famous "Earthrise" photo in 1968 and we saw the world as a fragile blue sphere climbing above the sterile gray surface of a thoroughly inhospitable moon, many embraced the assumption that "we've got to make it here" and that to do so for any length of time would require seriously limiting the actions of individuals for a communal good.

This was a false assumption. The *context* of Apollo 8's vision of exploration should have made it clear that personal liberty and environmental responsibility need not be mutually exclusive. Only by removing man from Earth can Earth by saved from man. Every other plan simply delays the inevitable environmental and hence economic disaster, however far off that may be.

III. A Bigger Picture

Reflection will show that we ought not to think of interfering with the free use of the material wealth, which Providence has placed at our disposal, but that our duties wholly consist in the earnest and wise application of it. We may spend it on the one hand in increased luxury and ostentation and corruption, and we shall be blamed. We may spend it on the other hand in raising the social and moral condition of the people, and in reducing the burdens of future generations. Even if our successors be less happily placed than ourselves they will not then blame us.
-William Stanley Jevons, economist 1865

In 1798 the Reverend Thomas Robert Malthus published his masterful *Essay on Population*[5] which described humanity's certain doom at the conflux of an unavoidably exponential population growth curve and un-accelerable resource exploitation line. Anticipating the economic concepts of marginalism and diminishing returns, Malthus noted that putting more hands to work on the same land, past a certain point, fails to increase yields sufficiently to support the additional farmers. The birth rate and the technology of the 18th century left us very few years before his theory would be tested globally. While, the ingenuity of the human race allowed us to make a quantum population leap right over the Reverend's dire prophecy, the doomsayers of the dismal science and the advocates of environmentalism continue to cry out.

William Jevons, a further contributor to marginalism, predicted the first energy crisis in his 1865 publication *The Coal Question*.[6] Jevons was seriously off base when he prophesied England's industrial might collapsing due to a lack of that fuel. However, he presciently described a range of environmental and economic concepts we now know as: sustainability, resource peaking ("peak oil", "peak uranium", etc.), alternative energy, and renewable energy.

Civilization has dodged the bullets of these nineteenth century "dismal scientists" and their twentieth century followers (the Club of Rome and others) by pushing the Earth's production possibilities curve outward via productivity gains derived from *technological innovation*. As a planet (discounting serious issues of the efficiency of regional distribution of resources) we have never even come close to running out of food or despite the assurances of many experts in the 1970s and technology has been the primary reason for this continued state of grace. Homo Sapiens has proven to be a most clever animal, even when dealing with problems of its own making.

A prime example was the breaking Malthus's fundamental assumption that crop yields were linearly related to the area of arable land by (among other technologies) Fritz Haber's discovery of a chemical process to fix nitrogen. This miracle of chemistry resulted in new fertilizers that pushed 20th century agricultural production far beyond the imagination of any 19th century farmer's dream. One environmental author hailed the importance of this discovery as, "Nitrogen was the most commonly yield-limiting nutrient in all pre-industrial agricultures. Only the Haber-Bosch synthesis of ammonia broke this barrier . . . But for at least a third of humanity in the world's most populous countries the use of N fertilizers makes the difference between malnutrition and adequate diet."[7] A stunning gift for billions in future generations from a single brilliant and ultimately tragic mind[**].

However, it is important to note that Haber did not develop his Nobel Prize winning technology to feed the world; nitrates are also a critical ingredient in military explosives. As a German nationalist, Haber was keenly aware that a steady supply of nitrates would be required to sustain German military power in the years leading up to the coming Great War. The British control of the seas limited access to the supply of saltpeter (potassium nitrate) from guano mines in South America and Haber's work was critical in allowing Germany to enter World War I and to extend its length for years. As the great physicist Max Planck commented at Haber's memorial "had Haber not made his magnificent [ammonia synthesis] discovery, Germany would have collapsed, economically and militarily, in the first three months of World War I."[8]

It was the military development of the industrial process to exploit Haber's work that drove commercial production. To a great extent, feeding the modern world was a "positive externality" of weapons research. Like the microwave oven and superglue,[††] unintended benefits seem to fall out of big military research projects like consultation prizes for an injured world. Not that anyone besides the most zealous Keynesian would advocate war for the economic betterment of humankind.

This example points out the importance of understanding where positive technological externalities can best be generated without the pain of war and that leads me back to space. Outside of direct military projects (but often not so far removed), the U.S. space program has been the largest concentrated effort to direct technology and industry to a specific goal. If the assertion that such concentrated technological research efforts invariably develop valuable externalities holds, then we should find them all around the large public space program.

[**] The curious mind will find it is well worth reading the other amazing details of Haber's heroic and tragic life: http://www.fhi-berlin.mpg.de/~brich/Friedrich_HaberArticle.pdf

[††] The microwave or "radar range" was an insight from some tragic radar burn injuries during WWII. Superglue was developed as a battlefield wound suture for Vietnam (ever wonder why it sticks to skin better than to anything else?).

IV. Spinning Off and Cleaning Up

I also know that, as a consequence of the extraordinary work of NASA generally, that you inspired an entire generation of scientists and engineers that ended up really sparking the innovation, the drive, the entrepreneurship, the creativity back here on Earth. And I think it's very important for us to constantly remember that NASA was not only about feeding our curiosity, that sense of wonder, but also had extraordinary practical applications.

-Barak Obama, President of the Unites States of America

The immediate aspirations of the U.S. effort in space were far from environmental. The founding of the National Aeronautics and Space Administration and the boom in military space investments in the 1950s and 1960s were clearly made in response to a Soviet threat form space. However, regardless of motives, the externalities from solving basic engineering problems with large investments in leading-edge science quickly blossomed. Much has been made of NASA's contributions to material science that have yielded a cornucopia of useful products from high temperature ceramics to memory foam.[‡‡] Contributions to medical device telemetry, digital image processing (for MRI and CAT scans) and the like are also commonly cited as valuable "spin-offs." However, space being limited, I will focus on space technologies that have delivered both major environmental benefits and offered significant economic rewards.[§§]

Photovoltaics and Fuel Cells

Among the most fundamental requirements for spaceship operations is a reliable and safe energy source. Lifting heavy, single use batteries into orbit proved prohibitively costly as well as potentially dangerous on manned missions. Using internal combustion generators was impractical and again dangerous for human missions. Consequently, the space program became the first and still is the leading edge consumer of Photovoltaic (PV) and Fuel Cell technologies. Hoffman Electronics was the first company to offer commercial PV solar cells based on licensing of ATT's Bell Laboratory technology. In 1958 Hoffman was desperately looking for a real customer for this technology and the firm was gratified for the opportunity to provide backup power for America's second spacecraft, Vanguard I. The solar powered satellite experiment was so successful that almost every satellite and space station since then has relied on PV as its primary energy source.[9] The Vanguard project also served to make both business and the public aware of the possibilities of solar and the space business was even credited with "saving" solar power from commercial obscurity. The high-performance demands of commercial and government space vehicles have driven the development of greater efficiencies in PV solar panels since then.

By 1976, NASA was applying solar power knowledge gained in space to those "problems right here on Earth." Through the Ames-Lewis Research Center, NASA installed 83 solar power stations around the globe to support the diverse needs of many very remote communities. A 3.5kw system installed at the Papago Indian Reservation in Arizona in 1978 is widely considered to be the first example of a functional solar-powered community.

Placing large solar arrays on Earth has become increasingly difficult due to urban space constraints and environmental concerns in wilderness area. As Arnold Schwarzenegger said when environmentalists actually blocked a major state PV installation during his governorship, "If we cannot put solar power plants in the Mojave desert, I don't know where the hell we can put it." In 1968, NASA engineer Peter Glaser proposed placing these large solar arrays in space where they would not disturb the ground environment and could operate on 7 to 8 times the light energy that finds its way through the atmosphere to strike land based PV. The energy would then be transmitted to relatively small generating stations on Earth via microwave or laser power. In light of higher PV efficiencies available today, NASA has resurrected this idea and is conducting feasibility studies.[10] Such orbital stations are one of the few technologies with the potential to offer non-nuclear, gigawatt range power and hence the possibility of supplanting fossil fuels in a serious way.

Although Sir William Grove invented the fuel cell in 1839, the first commercial application was NASA's Gemini space project in 1965.[11] United Technologies Corporation's UTC Power division became the first commercial producer of fuel cells for industry after providing the fuel cells for NASA's Apollo and

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‡‡ Yes, your tempur-pedic mattress was created to make space shuttle seats less painful on astronaut butts. http://www.tempurpedic.com/about/history_heritage/

§§ Later we will consider how these economic opportunities might have been better captured.

Space Shuttle.[12] UTC has since applied the technologies developed in those programs into commercial products for building power, transportation engines, and military applications (Perry & Fuller, UTC website). Many hospitals and schools now rely on fuel cells for quiet, fast, non-polluting back up power. Fuel cell busses are in daily revenue service today and many auto manufacturers are testing fuel cell vehicles on the road.

Fuel cell technology has the potential to become the primary power system for transportation and stationary electrical generation in a "hydrogen economy." Such an economy would use a carbon-free power generation system – such as the previously described space based PV stations – to extract hydrogen, which would then serve as the medium of energy storage and transport, providing a complete solution for combating Anthropogenic Global Warming (AGW), courtesy of NASA.

Wind

Along with solar PV, NASA has been a pioneer in another major alternative energy source. The agency has developed high-tech wind turbines as part of its primary mission in aeronautics. At its Glenn Research Facility, NASA developed and deployed the first megawatt wind turbine generators and its four-megawatt installation at Medicine Bow, Wyoming remained the world's largest for over twenty years. Most of the world's commercial wind power generation systems use blade design models based on NASA research to limit stalling and optimize power output along with the strong tubular support towers the agency developed to support its huge experimental windmills.[13]

GPS

If there is one technology that has actually made a significant difference in greenhouse gas emissions it is clearly the Global Positioning System. This constellation of Mid Earth Orbit (MEO) satellites was developed by the U.S. military in the 1980s to assist in military navigation and ordinance placement. It was made available to private and commercial users worldwide by President Reagan via an executive order in 1983 following the tragedy of Korean Air 007.[***]

Various studies have shown efficiency gains from 15 to 21% for GPS guided vehicles. These include aircraft, marine transportation, autos and trucks in commercial fleets as well as private use. Before the advent of GPS, planes and ships at sea beyond land based markers and communications stations had to use dead reckoning and astronomical observation to navigate long trans-oceanic voyages. Even small errors in the routing for a huge tanker or container ship traveling thousands of miles results in a huge loss of fuel and unnecessary generation of CO_2. GPS takes that ship on the most direct path and cuts emissions more than any other technology. The same applies to millions of drivers who now arrive at their destinations quicker thanks to inexpensive GSP enabled navigation devices. A Navteq funded study showed that UK drivers with a GPS used 20% less fuel than non-GPS equipped drivers.[14]

A 2008 Motorola study estimated that U.S. tucking industry has a potential to save $53 billion in fuel per year due to GPS.[15] These savings represent an enormous reduction in greenhouse gas emission that has gone virtually unreported and certainly without due credit to America much less its space technology investments. It is interesting to note that entering climate change negotiations in Copenhagen, Russia insisted on credit for the huge drop in emissions created by the economic collapse of the Soviet Union. The US would be well advised to demand credit for its GPS contribution.

The Internet and the PC

The Internet has served the environmental cause in many ways including the rapid global dissemination of political, commercial, and technical information. It has also greatly reduced the need for the physical transportation of media as well as people. The indirect impact on emissions is simply so large and so diverse that it is extremely difficult to study. One-study reports:

During those same two years (1997, 1998), the nation's energy consumption—the principal source of air pollution and the gases linked to global warming—hardly grew at all. In the previous 10 years, U.S. energy intensity, measured in energy consumed per dollar of gross domestic product declined (i.e., improved) by under 1% per year. In both 1997 and 1998, it improved by more than 3%—an unprecedented change

[***] A fully loaded 747 shot down by a Soviet fighter plane when it strayed over the Russian's Kamchatka peninsula.

during a time of low energy prices. In 1998, U.S. emissions of greenhouse gases rose only 0.2%, the smallest rise since 1991 (which was a recession year).[16]

IBM reports that remote meeting solutions and home office work " reduced their corporate energy consumption by 4% per year throughout most of the 1990s."

The Internet was originally conceived at the Advanced Research Projects Agency (ARPA) an organization specifically created to address the technical challenges of the Soviet's Sputnik launch. In 1963, NASA engineer Robert Taylor initiated the project known as ARPAnet, which was later transferred to the NSF civilian authority and made available to the public in the 1990s as the Internet.[17] Taylor later moved on to Xerox's famous Palo Alto Research Center (PARC) where he headed up the team that among other achievements created the first personal computer (Altos), the laser printer, the graphical user interface (Windows and pull down menus, etc.), and Ethernet (the networking technology used in almost all offices and homes today). These systems served as the model for Apple's Macintosh computer, Microsoft's Windows OS, and the networked office environments we all work in today.

As the President's quote at the opening of this section underscores, many of the engineers who drove the PC and the Internet boom got their start in the aerospace industry or found their original inspiration to become engineers from NASA. A fact that has been made manifest by the recent efforts of many of top Personal Computer and Internet entrepreneurs to return to their "first love" of space. Witness Paul Allen (Microsoft co-founder), Jeff Bezos (Amazon.com founder), Elon Musk (Paypaly founder), John Carmack (DOOM and Quake games) and many others pouring their wealth into private spacecraft development efforts.

America saw a dramatic peak of engineering degrees awarded in the mid 1980s as those inspired by the space program entered school.[18] As NASA's budget and public image declined, so did American STEM education. Adjusting for population growth and the percentage of foreign students America's universities suffered a dramatic drop in degrees awarded that has not yet be corrected.

The Ozone Hole Case

In the late 1960s, the US DOT was working on a high altitude jet known as the Super Sonic Transport or SST. A group of environmentalists, including Dr. Harold Johnston of UC Berkley, contended that constant operation of a fleet of high-powered aircraft in the upper atmosphere might result in disruption of the thin, but vital layer of ozone that protected the Earth's surface from deadly doses of ultraviolet radiation. At the time, NASA was working on a space plane of its own – the Space Shuttle – and was duly alarmed. While it turned out that the potential damage from a handful of space shuttle missions was negligible, NASA took the monitoring of the ozone layer under its wing. It was a timely decision.

A 1974 *Nature* article published by two chemists from the University of California at Irvine; Mario J Molina and F. S. Rowland suggested that chemicals used as refrigerants and propellants in a number of industrial and common household products had the potential to seriously damage the stratospheric ozone.[19] Although balloon observations and sounding rockets had recorded the presence of these chemicals in the stratosphere, there was little empirical evidence of actual ozone depletion, much less a threat. Congress acted in banning the use of CFCs as propellants but held off on requiring changes in refrigerants and industrial applications. Most other countries ignored the warning. After some tussling with NOAA, in June 1975 NASA was granted authority by congress to be the lead agency in the investigation of possible depletion of the ozone layer.

By 1982 NASA scientists were seeing ozone depletion data over Antarctica that was much more widespread than their models had predicted. In fact, the results were so extreme that they concluded there must be a problem with their satellite data and continued to cautiously investigate the anomaly. They withheld publication on the topic awaiting more data.[20] However in 1985 a British Antarctica Research Team led by Joseph Farman (who was familiar with NASAs work on the issue) published a piece in *Nature* documenting that ozone protection over the south pole had dropped by 30% since 1957 and directly attributed the drop to CFCs. At that point, NASA released their data. The visual mapping from their NIMBUS satellites since 1980 confirmed the problem and the frightening color images of an expanding hole drove the point home to the public in a way that ground measurements never could.

Public pressure soon drove the Reagan administration to not only unilaterally commit the US to a 50% reduction in CFC use by 2000, but to make global adoption of a ban an important international mission. In 1987 the Montreal Protocol regulating CFC emissions was signed by 47 nations. The first environmental problem of truly global proportions requiring international action had been addressed with significant success. While the ozone hole remains a very real concern, CFC production has slowed dramatically and the hole's growth appears to be leveling out. European Space Agency measurements now indicate that we might be seeing an Ozone increase of about 1% per decade.[21] It looks very much like a real catastrophe has been narrowly averted and there is every reason to believe that this would not have happened without NASA.

In the same vein, NASA and NOAA satellite data have been the "go to" sources of information for climate change scientists and policy makers. This includes satellites monitoring the atmospheric CO_2 concentration, ocean temperatures, coral reef health, and even the journeys of individual polar bears from orbit. It is actually hard to imagine research on global atmospheric issues like AGW without public space science.

Going Negative

In closing our consideration of externalities, we must also note they come in a negative variety as well. For instance, those N-fertilizers from the Haber process have recently been revealed to have a large negative externality of another industry in the form of ocean pollution. The National Oceanic and Atmospheric Administration and the Pew Trust have reported that nitrogen fertilizer run-off from farms is now the main source of pollution in the world's seas. The abundant grain belt of the American Midwest now feeds an ever growing hypoxic or oxygen free "dead zone" in the Gulf of Mexico.

That unfortunate surprise revelation that increased agriculture efficiency has a downside is based in part on what is known as Jevons' Paradox: increases in efficiency from advanced technology make the use of resources more attractive and the net impact is nearly always a faster rate of consumption rather than conservation. Any negative externalities of the process itself are then multiplied. As Jevon's wrote in *The Coal Question*, " It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth." (Jevons) Which begs the question of what policies can possibly be adopted that allows for both the continuation of human civilization and the natural environment?

VI. Growth, Capital and Technology

These booms consist in the carrying out of innovations in the industrial and commercial organisms. By innovations I understand such changes in the combinations of the factors of production as cannot be effected by infinitesimal steps or variations on the margin. They consist primarily in changes of methods of production and transportation, or in changes of industrial organisation, or in the production of a new article, or in the opening up of new markets or of new sources of material. The recurring periods of prosperity of the cyclical movements are the form progress takes in a capitalist society."[22]

-Joseph Schumpeter, economist

The Solow-Swan Exongenous growth model suggests that *long-term* economic growth is achieved via capital deepening – the accumulation of capital per worker – and increases in worker productivity driven by the innovations in production technology, education, management, transportation efficiency, etc.[23] In the classic, simplified equation, eq. 1.

$$\mathbf{Q = A\,K^a\,L^b} \tag{1}$$

Q represents the aggregate quantity of production, A the multifactor production construct, K the stock of capital, and L available labor. Lower case a and b are the diminishing returns to labor and capital suggested by Malthus and the marginalists. Of the three factors, productivity (A) is the most powerful as it remains unchecked by diminishing returns. From a policy perspective, directly increasing L or K is politically challenging requiring either the external inputs of increased immigration and foreign direct investment (FDI) or a long process of accumulation via an increased savings rate and an increased birth rate respectively. The domestic growth option poses the economic conundrum of reducing *short-term* economic growth via reduced consumption and availability of labor (as parents rear children.)

From a policy perspective, increasing A is the obvious choice and therefore modernizing infrastructure and factories via the acquisition of new technology– generally derived from American innovation – has been the essential strategy behind the success of the "Asian tigers" Japan, South Korea, Singapore, Taiwan and more recently the state capitalism of communist China. The dramatic increases in standards of living for the citizens of all of these nations was no accident nor the simple by-product of market forces, but the expected outcome of conscious policy choices on the part of their leadership to ingest foreign technology – and to protect their domestic producers of technology from foreign competition, an issue I address later.

America, however as the traditional font of new technology and with markets wide open, is burdened with the greater challenge of maintaining continuous innovation to insure prosperity. When the government redirects either private capital (K) or labor (L) via taxes toward the goal of increasing short-term consumption it clearly risks reducing output (Q) in the long run *unless* such spending also results in a corresponding or higher increase in one of those factors or in productivity (A). For the reasons mentioned earlier, working on productivity is the best choice.

For example, spending income taxes on health care may indeed increase L by adding healthy people to the labor pool, but it must always be, to some extent, self-defeating as income taxes are essentially a disincentive to labor and must also reduce the savings that funds the capital stock. Expending a greater portion of that captured labor and capital on a population that is outside the labor pool (e.g.. Medicare) – understood to be both individually compelling and politically satisfying – produces no additional output, reduces savings and must surely decrease output and long-term standards of living. All wealth redistribution policies that expropriate capital gains and transfer them to income face the same long-term conundrum and the history of welfare states has provided clear empirical proof of it.

Only by simultaneously increasing productivity by a like or greater amount can any such economic drags – albeit sometimes deemed socially desirable – be sustained. Therefore the economic aspect of intergenerational equity again insists that such offsetting of investments in productivity growth must be made.

As detailed (albeit anecdotally) in the previous section, spending on space technology has had demonstrably higher returns to A than the reduction in K or L (e.g. the return on GPS, alone exceeding the investment in all public space expenditures). While this is a highly simplified model and past performance offers no guarantee of future gains, the intuitive implications are very clear. Absent any credible argument to the contrary, the conclusion must be that NASA's budget is far more important to the long-term benefit of Americans than is Medicare's. In fact it is possible to argue that the latter program would have been bankrupt much earlier if not for the indirect sustenance of the former. Imagine fiscal policy in an America that had not experienced the growth brought on by the technology boom of the 1990s and 2000s.

Education

Education is a critical driver of productivity as an educated work force delivers higher returns on capital and labor. However, like capital investment, the returns on all educational investment are not equal economically. The arguments in support of the returns on STEM education are well documented and compelling and have earned the backing of both Republican and Democratic administrations. History also demonstrates that maintaining the luxury of arts and letters depends upon a nation first securing its wealth via the productive trades. As noted earlier, there is a high correlation between interest in the space program and engineering education.

Keeping the Benefits of Technology

As noted earlier America's competitors – both allies and potential adversaries – have benefited immensely by augmenting their labor pools and capital stock with proven U.S. developed technologies. Often, this has been to the short-term benefit of American consumers who enjoy a plethora of Japanese, Korean and Chinese technology products. However, the long-term implications are less agreeable.

In John Maynard Keynes' famous equation (eq. 2) national Gross Domestic Product (Y) is dependent on aggregate consumption (C), investment (I), net exports (X_n), and government spending (G).[24] If investment increasingly goes outside the economy (overseas) and a steady portion of consumption funds a persistent trade imbalance a nation's future is dim.

$$\mathbf{Y = C + I + X_n + G} \tag{2}$$

For America the current account deficit (a trade and investment imbalance) has represented a continuous leakage of wealth and jobs for decades despite our constant level innovation. The current trade deficit is shaving nearly a full percentage off of America's GDP growth and the economic rule of thumb know as "Okun's Law" suggests that could be costing us a million jobs a year in the U.S.[25]

Extrapolating the business strategy "Resource Based View" (RBV) to the macro-economic level verifies this suggestion that any national "first mover advantage" is transitory. Sustainable competitive advantage can only be had through the possession of unique and valuable technologies (resources) that cannot be transferred (sold) or imitated.[26]

A prime example of this principal is the failure of America's recent investment in "green technologies" to generate jobs in the U.S. as solar factories close in Massachusetts (Evergreen) and California (Solyndra) and new ones open in Chengdu and Wuxi China. If the American firm can sellout to a foreign country (Evergreen) for an price attractive to short-term stock holders or simply have its technology poached, the investment will return little value to our nation.

While there are many policy solutions to retaining the value of America's technological edge that should have been considered (imagine the much happier fiscal situation if the NSF had collected a minimal annual fee for every non-US IP address and domain name when it released the Internet to commercial use or if the Federal government was recovering a licensing fee for every GPS receiver used abroad) the fundamental propulsion and guidance technology associated with an investment in space technology is uniquely protected from foreign acquisition via the otherwise controversial International Traffic in Arms Regulations, or ITAR. ITAR inadvertently makes our return on investment in NASA technologies an RBV compliant resource that continues to deliver value for America.

VI. Conclusion: In the Long Run We are Not All Dead

This is the first age that's ever paid much attention to the future, which is a little ironic since we may not have one.

-Arthur C. Clarke, science fiction author

In the end, despite the fact that ingenuity will surely push these limits back farther than I can ever guess, the Earth does contain a finite amount of habitable space, a limited amount of arable land and a fixed amount of resources – including fossil fuels. Even if the population stabilizes, as it appears to be doing at the moment, and even if we find the consensus to make the very best efforts in recycling, we are still playing a long end game for time. Everything is subject to friction loss and diminishing returns. Resources will be exhausted and waste will accumulate. In this entropic context, "sustainability" remains a dream we can only *approach* at best. Unless we are willing to truly accept that both human civilization and the Earth's biosphere are going to last only a few hundred or maybe a thousand years[†††] more we've got to find a better solution than that. With wise choices made now, we have some time to think about this, but it is time to think big.

We must offload the burden of human beings from this fragile planet. It is easy to dismiss such talk as the crazed ramblings of science fiction fans, but facts are what they are. In principle, shifting our problems out ten generations is no more ethically acceptable than simply dumping them on the next. In the end, real space exploration is the only hope for humans and their planet.

Such an effort would not require a Star Trek faster than light flight drive to the stars in search of Earth-like worlds. In 1976, Gerard K. O'Neill's brilliant publication, "The High Frontier" laid out a practical path to the moving humans off the Earth into self-sufficient space colonies that acquire their resources from near Earth asteroids.[27] The primary criticism of O'Neill's vision was the vast startup expense and NASA's funding for space colonies research was gutted by the colorful Senator William Proxmire.

However, we've now had another 30 years to consider the cost of not doing this and the environmental and economic considerations make it seem much more practical. In the mean time, the record shows the mid-term return on our investment in a public space program justifies its economic and environmental cost. To curtail this investment further is tantamount to abandoning the economic future of our nation and the environmental future of our planet.

††† Or 10,000 if you prefer. Whatever the number, the outcome is clearly inevitable.

References

[1] Anders, William, Maj. General. 12/20/2008 "The First Earthrise" Apollo 8 Astronaut Bill Anders recalls the first mission to the Moon, Presentation at the Museum of Flight, Seattle, Washington, http://www.museumofflight.org/press/first-earthrise-apollo-8-astronaut-bill-anders-recalls-first-mission-moon

[2] Hardin, Garrett, *Filters Against Folly: How To Survive Despite Economists, Ecologists, and the Merely Eloquent*. Penguin books. 1985.

[3] Wapner, Paule, "The Sovereignty of Nature? Environmental Protection in a Postmodern Age**,"** *International Studies Quarterly,* Vol. 46, No. 2, June 2002, pp. 167-187

[4] Elliot, Lorraine, "Transnational Environmental Harm, Inequity, and the Cosmopolitan response." *Handbook of Global Environmental Politics*: Edited by Peter Dauvergne. Edward Elgar Publishing. 2005.

[5] Malthus, Thomas, *An Essay on the Principle of Population, as it affects the future improvement of society with remarks on the speculations of Mr. Godwin, M. Condorcet, and other writers* Roger Chew Weightman, 1809 , (http://books.google.com/books?id=0sOuqFl0fh8C&dq=essay%20on%20population&pg=PR3#v=onepage&q=&f=false)

[6] Jevons, W. S., *The Coal Question, an inquiry concerning the progress of the nation, and the probable exhaustion of our coal mines.* McMillian and Company. 1906 http://books.google.com/books?id=cUgPAAAAIAAJ&printsec=frontcover&dq=the+coal+question#v=onepage&q=&f=false

[7] Smil, Vaclav, "Nitrogen and Food Production: Proteins for Human Diets," *AMBIO: A Journal of the Human Environment,* 2002, 31: 126-131

[8] Friedrich, Bretislav, *Angewandte Chemie (International Edition)* 2005, 44, 3957 http://www.fhi-berlin.mpg.de/~brich/Friedrich_HaberArticle.pdf

[9] Perlin, John, *From Space to Earth: The Story of Solar Electricity*. Harvard University Press, 1999.

[10] Dudenhoefer, James E. and George, Patrick J., *Space Solar Power Satellite Technology Development at the Glenn Research Center—An Overview*. NASA. 2000, NASA/TM—2000-210210.

[11] Perry, M.L. and Fuller, T.F., "A Historical Perspective of Fuel Cell Technology in the 20th Century," *Journal of The Electrochemical Society*, 2002, 149(7): S59-S67

[12] Warshay, Marvin and Prokopius, Paul R. *The Fuel Cell in Space: Yesterday, Today and Tomorrow*. Prepared for the Grove Anniversary Fuel Cell Symposium, Royal Institution London, 1989, NASA Technical Memorandum 102366

[13] NASA Scientific and Technical Information website, 2009, http://www.sti.nasa.gov/tto/Spinoff2009/er_3.html

[14] Navteq, 2009. http://corporate.navteq.com/webapps/NewsUserServlet?action=NewsDetail&newsId=765&lang=en&englishonly=false

[15] Motorola. 2008, http://www2.prnewswire.com/cgi-bin/stories.pl?ACCT=104&STORY=/www/story/07-01-2008/0004842303&EDATE

[16] Romm, Joseph, "The Internet Economy and Global Warming: A Scenario of the Impact of E-commerce on Energy and the Environment," 2000, http://www.p2pays.org/ref%5C04%5C03784/0378401.pdf

[17] Naughton, John, *A Brief History of the Future: The Origins of the Internet*. Weidenfeld & Nicolson. London, 1999.

[18] Engineering Trends, *Engineering and Engineering Discipline Degrees through AY2006-07 with Near Term Trend Predictions Via Enrollment Data*. 2008, http://engtrends.org/IEE/0208B.php

[19] Molina, Mario J and Rowland, F. S., "Stratospheric sink for chlorofluoromethanes: chlorine atom-catalyzed destruction of ozone." *Nature*. 1974, 249: 810-812

[20] Lambright, Henry W., *NASA and the Environment, The Case of Ozone Depletion.* NASA, 2005, SP-2005-4538.

[21] ESA, Ozone layer depletion leveling off. 2008, http://www.esa.int/esaEO/SEMHSZJVUZF_planet_0.html

[22] Schumpeter, Joseph, The Explanation of the Business Cycle, *Economica*
No. 21 (Dec., 1927), 1927, pp. 286-311.

[23] Solow Robert M. Solow, "Technical Change and the Aggregate Production Function*," The Review of Economics and Statistics* Vol. 39, No. 3, August 1957, pp. 312-320 and

Solow Robert M. Solow, "A Contribution to the Theory of Economic Growth," *The Quarterly Journal of Economics*, Vol. 70, No. 1, February 1956, pp. 65-94

[24] Keynes, John Maynard, *The General Theory of Employment, Interest and Money.* Palgrave Macmillan, 1936.

[25] Navarro, Peter and Autry, Greg. *Death by China*, Pearson/Financial Times Press, 2011.

[26] Wernerfelt, Birger, "A Resource Based View of the Firm", *Strategic Management Journal*. 1984. 5:2. pp. 171-180.

[27] O'Neill, Gerard K., *The High Frontier: Human Colonies in Space*, Apogee Books, 1976.