Towards Exoeconomics[1]

Developing an off-planet economy and its implications

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Abstract

Over the last two decades the seeds of a New Space Era have been planted as a result of significant leaps in knowledge and technology. Whilst hampered by the tumultuous nature of our times, these seeds are growing due to a wave of entrepreneurs, industrialists and billionaire space enthusiasts that, for the first time ever, have enough wealth and the technology to drive space exploration.

The main purpose of the essay is to extract the essence of the events to be analyzed and, if possible, make a couple of minuscule steps towards the establishment of a new (theoretical) framework that will enable a better understanding of the society we live in, within a world that is about to become larger.

[1] The term "exoeconomics" has been used before, since it is an obvious composition of "exo" (outside) and "economics" (the social science). However, Internet search results show no connection between the term and any research paper, article or work with intellectual property. Therefore, there is no association between the definition of the term in this essay and any other utilization of the word.

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Introduction

On 25 May 2012, Elon Musk's SpaceX made history as the world's first privately held company to send a cargo payload, carried on the Dragon spacecraft, to the International Space Station[3].

This event could represent a milestone, or a turning point, in the economic history and human history, having profound ramifications and implications at all levels. This essay aims at outlining and briefly exploring some of the implications of this event and other similar achievements that could have an impact on our global society in the long-run.

Since this will not be an extensive paper, I will not be able to get into much (technical) detail on any of the implications or drill very deep into the scenarios outlined. In this paper, I will try to look beyond the "space economy" and "space industry" structures of the present moment, into the future, in a context of increasingly rapid-growing technologies driven by a wave of entrepreneurs, engineers and private initiatives.

The year 2012 was called "the year of private spaceflight"[4], due to an impressive list of private space companies announcing ambitious plans to explore space, exploit asteroids, send tourists in space or put people on Mars.

Therefore, I will first look into the economic context of these space-related projects, focusing on the private initiatives and outlining some of the most important technological trends that are the background of these major economic shifts (Part 1). Then I will explore some of the economic implications and factors and make steps towards defining an extensive highly-interdisciplinary framework, or a proto-social-science, that we could call "exoeconomics", having technology and technological innovation at the core of its existence, and also one that will put together knowledge and experience from various scientific fields (Part 2). Since space exploration was conducted by governments with enough resources to support such complex and expensive endeavours, I will discuss briefly about the main challenges to politics, international treaties, policies and regulations that private spaceflight brings (Part 3).

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[3] For updates on the missions, check SpaceX official website, Updates section. https://spacex.com/updates.php

[4] "The Year's Most Audacious Private Space Exploration Plans", Adam Mann, Wired Science (27.12.2012)

Afterwards, I will try to put all the main ideas extracted along the way under an anthropological perspective, which, in my opinion, will know some of the most profound ramifications (Part 4). Finally, I will draw the conclusions of this essay.

I propose a dynamic and, hopefully, engaging essay, by providing links to videos, speeches, scientific articles, press releases, reports, books and other material that will support the arguments brought along the way.

"Three, two, one and launch of the SpaceX Falcon 9 rocket, as NASA turns to the private sector to resupply the International Space Station," said NASA commentator George Diller, as the spacecraft blasted off at 3:44 am (07:44 GMT, May 22, 2012)[5]

1. Towards Exoeconomics

1.1. Flight of the White Knight

Behind the key-events that could mark the beginning of a new privately-driven space age there are key-persons that have made sustained efforts over the last two decades towards this direction. One of the key-persons is **Peter H. Diamandis**, an American engineer, physician, author and entrepreneur. He is the founder and chair of the X Prize Foundation, a non-profit organization whose mission is simply "to bring about radical breakthroughs for the benefit of humanity", by offering large cash incentive prizes to inventors who can solve grand challenges like space flight, low-cost mobile medical diagnostics and oil spill cleanup.[6]

The **Ansari X Prize**, launched in May 1996, was a space competition in which the X Prize Foundation offered a US$10 Million prize for the first non-governmental organization to launch a reusable manned spacecraft into space twice within two weeks. It was modelled after early 20th-century aviation prizes, and aimed to spur development of low-cost spaceflight. The prize “sparked an explosion in the number of private companies hawking technologies they claimed could be the future of space

[5] “SpaceX blasts off to ISS in historic first”, Reuters, Global Times, 23 May 2012.
[6] See Peter Diamandis’ profile on Ted.com - http://www.ted.com/speakers/peter_diamandis.html

tourism"[7] and it was won on October 4, 2004, the 47th anniversary of the Sputnik 1 launch, by the Tier One project designed by **Burt Rutan** and financed by Microsoft co-founder **Paul Allen**, using the experimental spaceplane SpaceShipOne. [8]

Elbert Leander "Burt" Rutan[9] (born June 17, 1943) is an American aerospace engineer noted for his originality in designing light, strong, unusual-looking, energy-efficient aircraft, such as the record-breaking Voyager, which was the first plane to fly around the world without stopping or refuelling. Rutan designed the Tier One project as an ensemble of two crafts: SpaceShipOne (Sub-orbital air-launched spaceplane) + White Knight (Mother Ship). Both craft were developed and flown by Mojave Aerospace Ventures, which was a joint venture between Paul Allen and Scaled Composites, Burt Rutan's aviation company. Allen provided the funding of approximately US$25 million[10].

1.2. The New Space Era

Commercialization of space activities is not a new trend and, needless to say, there is already an ensemble of space and space-related activities, driven by various private and public actors around the world, which is called a "space economy", with a structure that extends for more than five decades in the past, throughout the Space Age. Space commercialization has its origins in the 1980s, when governments, through their national space agencies, started contracting corporations or establishing and funding private entities to develop aircraft and spacecraft components, rockets and propulsion systems, satellite platforms and robots, in order to increase safety and boost technological innovation. And since the space industry is a highly complex and expensive structure, having both civilian and military applications, geopolitical interests related to defence, security and communication have always been main priorities in the decisional process regarding national space

[7] "Up: the story behind Richard Branson's goal to make Virgin a galactic success", Adam Higgibotham, 07 March 2013, Wired.co.uk.
[8] For more information, check Ansari X Prize website - http://space.xprize.org/ansari-x-prize
[9] For more information about Burt Rutan and his projects, check official website - http://burtrutan.com/burtrutan/BurtRutan.php

[10] More information about Scaled Composites, SpaceShipOne and other projects on Scaled Composites website - http://www.scaled.com/

agencies budgets, projects and long-term strategies. Although important technological progress has been achieved and major steps in human history have been made (with setting foot on the Moon being probably the most important), this structure has become also very rigid and inefficient, even though large corporations have struggled to keep up with the contracts. American engineer Robert Zubrin offers very useful insights to this matter in the first part of his book "Entering Space – Creating a Spacefaring Civilization" (Zubrin, 2000).

Thus, I will not discuss about large companies (such as Boeing, Lockheed Martin, EADS, Thales or Dassault) with decades of experience within the aerospace industry or satellite manufacturing, companies which eventually developed space-related activities, platforms and products, providing governments and space agencies with aircrafts, propulsion systems, technology with civilian and military applications and equipment. My focus will be on a new segment of small companies founded over the last 10-15 years, setting an explosive trend which had an impressive peak in 2012 and continuing in 2013. These small teams and private/non-governmental entities are struggling to develop their own propulsion and launch systems, capsules and spacecrafts, and an entire infrastructure for human space exploration, space tourism and exploitation of space resources, dreaming beyond the limits that have been so far reached. Peter Diamandis says that "we're living in a period in time where exponential growth is enabling small teams to do extraordinary things, things that only governments and large corporations could do before"[11]. Thus, this essay is concerned with this new wave of techno-philanthropists, engineers, space enthusiasts and visionaries that have set new goals for the New Age of Space Exploration and have a different approach, with no direct connection to governments and their national space agencies, although partnerships are developing (the most important so far being NASA contracting SpaceX and Orbital Sciences for the ISS ressuply).

It will be very interesting to see the long-term results of this new wave of innovators and visionaries, contouring a paradigm shift or probably a series of paradigm shifts in the economic theory and the economic thinking. Soon these key-

[11] See video of Peter H. Diamandis – "We are evolving into meta-intelligence group-minds" for GF2045. https://www.youtube.com/watch?v=nV1M5ARfHAc

events and the underlying drivers will have to be incorporated in the theoretical framework of various fields.

The Ansari X Prize, the largest prize in history, has shown that spaceflight was no longer the exclusive realm of government. With that single flight, and the winning of the $ 10 million prize, a new industry was born (reference, website). Dr. Buzz Aldrin (NASA Astronaut, Apollo 11 crew member) said that "I think the [Ansari] X Prize should be viewed as the beginning of one giant leap…" And indeed it was. Following the success of **Burt Rutan's SpaceShipOne**, the vehicle's successor, **SpaceShipTwo** was developed by **The Spaceship Company** (TSC), a joint venture of **Scaled Composites** and Richard Branson's Virgin Galactic. **Sir Richard Charles Nicholas Branson** (born 18 July 1950), the English business magnate, best known as the founder and chairman of Virgin Group and many other companies, is developing a suborbital commercial human spaceflight platform for space tourism, called Tier 1b (SpaceShipTwo space plane + WhiteKnightTwo "mothership"), which uses all the same basic technology, carbon composite construction and design as SpaceShipOne. **Virgin Galactic** plans to provide sub-orbital spaceflights to space tourists, suborbital launches for space science missions and orbital launches of small satellites. Further in the future Virgin Galactic hopes to offer orbital human spaceflights as well[12].

In October 2012, it was confirmed that SpaceShipTwo had completed the subsonic portion of its flight card successfully and that it was preparing for the supersonic, powered flight. SpaceShipTwo is expected to begin commercial operations in late 2013 or 2014. In order to reduce risks to minimum, commercial flights have been postponed, while more safety tests are completed. More than 500 persons have enrolled for the sub-orbital flights, paying a price of $200 000 for a ticket. "Virgin Galactic has managed to reduce drastically the price of getting to space and over time will reduce it further" (Virgin Galactic website – Overview – Tickets). Virgin Galactic's Spaceport America is almost completed, but due to legal debates and safety issues, its future functionality is still uncertain.[13]

[12] For more information on the project and test updates, check official website - http://www.virgingalactic.com/

[13] To learn more about the Spaceships, the Spaceport and Safety, check official website – Overview section.

Founded in 1998 by spaceflight and technology entrepreneur **Eric C. Anderson**[14], **Space Adventures**, Ltd. is the world's first private space exploration company and the only company currently providing opportunities for actual private spaceflight and space tourism. Space Adventures is the only company the have sent self-funded individuals to space, seven clients with completed missions so far. However, they have utilized Russian Space Agency's Soyuz platform, capsule and rockets to reach the International Space Station. Clients have paid prices going from $20 million to $35 million.[15][16]

If Richard Branson succeeds in developing this space tourism platform and starts commercial flights, it would mark a significant achievement, both technologically and in terms of costs, substantially reducing the price of a sub-orbital flight.

Some of these new space companies are developing joint projects and platforms with national space agencies. In 2006, NASA announced the Commercial Orbital Transportation Services (COTS) program to coordinate the delivery of cargo and crew to the International Space Station by private companies, with **SpaceX** and **Orbital Sciences** being the two private groups to be awarded contracts at the end of the competition.

While Orbital Sciences is still testing its Cygnus capsule and the Antares rocket, SpaceX has already successfully accomplished the first experimental mission to the International Space Station (22-25 May 2012) and the first mission out of 12 contracted (CR-1 Mission, October 2012), with the second mission still in progress (CR-2). As I write, the Dragon capsule is connected to the ISS, after the successful launch on March 1st and docking with the ISS Sunday, March 3rd[17].[18]

[14] Eric Anderson's official website - http://www.ecanderson.com/

[15] Official Space Adventures website - http://www.spaceadventures.com/

[16] For more information and updates on Space Adventures, visit NewSpaceJournal, Space Adventures section - http://www.newspacejournal.com/

[17] Official page for NASA's COTS program - http://www.nasa.gov/offices/c3po/home/cots_project.html

[18] Official Orbital Sciences website - http://www.orbital.com/

SpaceX[19] is in fact the only private company at the present moment to have an entire operational platform with an ensemble of a launching system and a cargo transport vehicle (a capsule that it is expected to be soon human-rated). SpaceX has built its own infrastructure, manufacturing their own capsule (Dragon), launch systems (Falcon 1, Falcon 9 and Falcon Heavy – under development), propulsion systems (Kestrel, Merlin, Raptor) and the experimental tech demonstrator Grasshopper. I will discuss more about SpaceX in a short case study.

On NewSpaceJournal[20] website I could find a list of around 40 private space companies and non-governmental entities. Some of them are profit-driven, developing ambitious business plans in space (Virgin Galactic, Planetary Resources, Deep Space Industries), while others are non-profit organization funded by wealthy space enthusiasts and technophilantropists (such as Inspiration Mars). Not all of the companies listed are within the segment I am targeting in this essay. Some groups have large corporations that support the projects, such as Boeing or EADS. Virgin Galactic could be placed in the same category; however, SpaceShipTwo is based on its predecessor developed by Scaled Composites which had a different technological approach, creating an efficient, light-weight space plane, launched from a mothership. Of course these large corporations have brought and will bring tremendous contributions to the space industry, with projects such as the Dream Chaser, developed by Sierra Nevada or Boeing's CST-100 capsule. Other private space companies that have achieved technological progress over the last decade are Bigelow Aerospace (founded in 1999), Armadillo Aerospace (founded in 2000), XCOR Aerospace (founded in 1999).

1.3. Year of private space companies

I will now briefly go through some of the most important private space exploration projects that have been announced in 2012, following an explosive trend

[19] Official SpaceX website - https://spacex.com/
[20] For more information and updates on most of the companies listed here, check New Space Journal website - http://www.newspacejournal.com/

that continued in 2013. At the end of 2012, Wired made a list of "the year's most audacious private space exploration plans"[21], offering a plausibility score for each of the project listed. More detailed information, news and updated can be accessed on New Space Journal online channel.

Wired website writes "So how did 2012 turn into the year of private space? Perhaps the most important factor was the trailblazing success of SpaceX, a commercial rocket business started by entrepreneur and PayPal founder Elon Musk. This year, the company conducted two launches to the International Space Station using their Falcon 9 vehicle, with the second mission bringing supplies and helping prove that SpaceX was on the path to ferrying astronauts."

SpaceX is already planning their next rocket, the powerful Falcon Heavy, for launch in 2013 and recently won important contracts with the U.S. military to deliver hardware to space. Though not announced in 2012, "**SpaceX's Falcon Heavy** has been a hot topic as the company prepares to launch this new rocket in 2013. Once operational, the vehicle would be the most capable existing rocket, able to bring 120,000 pounds (approx. 54,500 kg) to low-Earth orbit for as little as $1,000 per pound (0.5 kg). The closest current spacecraft is United Launch Alliance's Delta rocket, which can take 50,000 pounds (22,700 kg) up at a cost of $6,000 per pound." writes Wired.

Falcon Heavy has a number of other companies hoping to ride on its success. Both Golden Spike and Mars One plan to use the vehicle in their operation while NASA and the military are also looking forward to its capabilities. Elon Musk has recently stated that he plans to put people on Mars and help establish a colony in the next 10 to 20 years, by providing the transportation[22].

Space venture **Golden Spike Company** announced the plants to take people back to the moon by 2020. For the price of $1.5 billion, Golden Spike will land a two-person crew on the lunar surface and safely return them.

B612 Foundation, a non-profit company hopes to raise money to launch an infrared telescope that will look out for dangerous asteroids coming toward Earth. Though NASA is already watching for these potentially civilization destroying rocks,

[21] See the entire article here - http://www.wired.com/wiredscience/2012/12/audacious-space-companies-2012/
[22]See article here - http://www.wired.com/wiredscience/2012/11/elon-musk-mars-colony/

B612 said they would be able to more than double the near-Earth object catalogue in their first month of observation.

Announced in May, **MarsOne** has an extremely aggressive goal: land a crew of four on the Red Planet by 2023. The company hopes to cut costs with a radical mission. They intend to send people on a one-way trip to set up a colony, with a new set of four settlers arriving every two years after the initial touchdown. However, most sceptics and specialists say that this is one of the least probable space projects.

Intended to stimulate new ideas for exploring the moon, the **Google Lunar X-Prize** was announced in 2007. The goal is for a small private team to land an autonomous rover on the lunar surface, travel about 300m, and send back high-definition images and video. The first team to do so will win $20 million, and constellation prizes are offered for other tasks. The prize's deadline was originally meant to expire in 2012, but after insufficient progress was made, the foundation extended their target date to the end of 2015.

Regarding the development of private space tourism, Wired writes that "Should **Virgin Galactic** (and Scaled Composites) somehow fail in its venture, there are plenty of other space tourism companies waiting in the wings. While somewhat behind Virgin, XCOR's Lynx spaceplane could begin testing in 2013. The company hopes to offer tourist flights to the edge of space for the bargain price of $95,000. Amazon founder Jeff Bezos' secretive Blue Origin could also stun everyone by unveiling a new rocket plane in the near future, though this seems less likely. But all the private space companies are worth keeping an eye on."

In April 2012, **Planetary Resources** revealed their asteroid mining plans. The company hopes to extract water and precious metals, such as platinum, in order to get a return on their investment. Planetary Resources' biggest strength comes from its financial backing, with founders Eric Anderson and Peter Diamandis veterans of both Silicon Valley and space technology. Investors behind the company include Google CEO Larry Page, Eric Schmidt (Google), Microsoft chief architect Charles Simonyi, and even filmmaker James Cameron. The company's goals are very long term, with simple plans to launch telescopes to identify and catalogue near-Earth asteroids in the next few years, and the actual mining and resource extraction as much as 20 years away.

As I wrote earlier, this trend of ambitious projects has continued in 2013. Another asteroid mining company has been founded and announced the strategies, plans and visions – **Deep Space Industries**. I will discuss more about the asteroid mining issue and prospects in a sub-chapter to come.

Also, the first space tourist, Dennis Tito, made public the intention to send a manned mission to flyby Mars in 2018, establishing the non-profit organization **Inspiration Mars.**

1.4. SpaceX – A Case Study

One of the key-persons in this wave of visionaries is **Elon Musk** (born 28 June 1971), an American entrepreneur, co-founder of PayPal, chairman and CEO of Tesla Motors, founder, CEO and CTO of **SpaceX**, chairman of SolarCity, and the man who has has been called "the 21st Century Industrialist"[23].

During his studies (in physics and economics), Elon considered three areas that were important problems that would most affect the future of humanity. One was the Internet, one was clean energy, and one was space. Musk views space exploration as an important step in expanding, if not preserving, the consciousness of human life. Musk has said that multiplanetary life may serve as a hedge against threats to the survival of the human species.

Elon Musk founded SpaceX in 2002 with $100 million of his early fortune. It has now nearly 2000 employees. In 10 years it has become a successful business model, an example of an efficiently integrated microeconomic structure and, thus, a very interesting business case study. Musk's goal is to reduce the cost of human spaceflight by a factor of 100. Elon declared that "because SpaceX is so vertically integrated, we know and can control the overwhelming majority of our costs. This is why I am so confident that our performance will increase and our prices will decline over time, as in the case with every other technology" (May 4, 2011, SpaceX updates).

[23] "Elon Musk – the 21st Century Industrialist" on Bloomberg Businessweek - http://www.businessweek.com/articles/2012-09-13/elon-musk-the-21st-century-industrialist

On SpaceX website, the company presents itself as “the only private company ever to return a spacecraft from low-Earth orbit, which it first accomplished in December 2010. The company made history again in May 2012 when its Dragon spacecraft attached to the International Space Station, exchanged cargo payloads, and returned safely to Earth – a technically challenging feat previously accomplished only by governments. In October 2012, Dragon again successfully delivered cargo to and from the space station, in the first official cargo resupply mission for NASA.”

In order to control quality and costs, **SpaceX** designs, tests and fabricates the majority of its components in-house, including the Merlin, Kestrel, and Draco rocket engines used on the Falcon launch vehicles and the Dragon spacecraft. SpaceX website offers some useful information.

- The price of a standard flight on a Falcon 9 rocket is $54 million.
- The average price of a full-up NASA Dragon cargo mission to the International Space Station is $133 million including inflation (fixed price contract with NASA for 12 missions).
- The total company expenditures since being founded in 2002 through the 2010 fiscal year were less than $800 million.
- The Falcon 9 launch vehicle was developed from a blank sheet to first launch in four and half years for just over $300 million.
- The Dragon spacecraft was developed from a blank sheet to the first demonstration flight in just over four years for about $300 million.
- SpaceX has been profitable every year since 2007, despite dramatic employee growth and major infrastructure and operations investments. We have over 40 flights on manifest representing over $3 billion in revenues.

(SpaceX updates, May 4, 2011)

“Moreover, SpaceX intends to make far more dramatic reductions in price in the long term when full launch vehicle reusability is achieved. We will not be satisfied with our progress until we have achieved this long sought goal of the space industry” (Elon Musk, May 4, 2011, SpaceX updates).

Under a $1.6 billion contract with NASA, SpaceX will fly at least 11 more cargo supply missions to the ISS, in addition to the October 2012 mission – and in the near future, SpaceX plans to carry crew as well. Dragon was designed from the outset to

carry astronauts and now, under a $440 million agreement with NASA, SpaceX is making modifications to make Dragon crew-ready (SpaceX website – Company section).

In order to put SpaceX costs, expenditures and revenues in perspective, we could make a few comparisons, just to set a couple of reference points. On NASA website, we find that "the average cost to launch a Space Shuttle is about $450 million per mission." Other sources write that "the average cost per launch was about $1.2 billion (in 2010 dollars) during the shuttle's operational years from 1982 to 2010. But it rises to $1.5 billion per flight when factoring in lifetime program costs, according to the new analysis, which covered the 131 shuttle missions flown between 1982 and 2010."[24]

The costs of space exploration driven by national space agencies were often an impediment, alongside political and social pressure. NASA's requested budget for 2007 was nearly $17 billion, in 2012 was almost $18 billion. There are some who argue that money would be better spent on solid ground, for medical research, social programs or in finding solutions to major problems. By comparing the budget of NASA with the Military budget of the United States, we form an idea about the national priorities. "The 2007 budget allocates roughly $609 billion to defense, not including the budget for the Department of Homeland Security. This is nearly 38 times the amount of money spent on NASA. If you include funding for the Department of Homeland Security, defense spending adds up to $652.5 billion, which is more than 40 times NASA's budget. While few question the need to maintain a strong military in an uncertain age, some might consider it excessive for the United States to spend more on its military than the next fifteen biggest defense spenders put together, especially as most of them are American allies." (TheSpaceReview,2011). So how does the notion that we should solve our problems on Earth before we go into space" look in front of these numbers and comparisons?

The economics and the politics behind the Space Shuttle program (and the entire NASA strategy) form a very intricate web that has pushed the national agency into an identity crisis.

Although this essay is not about the American space industry, it happens that most of the private space companies are American, while NASA still remains the

[24] "Total Cost of NASA's Space Shuttle Program" on space.com - http://www.space.com/11358-nasa-space-shuttle-program-cost-30-years.html

largest national space agency. While NASA had a budget of around $17 billion over the last 5 years, the Russian Federal Space Agency (ROSCOSMOS) has a budget of approximately $5 billion. The European Space Agency (ESA), which is an intergovernmental organization, currently with 20 member states, has an annual budget of about $5.4 billion.

The series of achievements and milestones set by SpaceX fired an explosion of private space companies and projects with various goals, spreading a wave of enthusiasm and confidence in the future of space exploration. Therefore, SpaceX could represent a “game changer” at many levels, in terms of technology, costs, efficiency and also changing the dynamics of the space industry, marking the dawn of a New Space Age.

1.5. Asteroid mining companies

Planetary Resources presented in April 2012 probably one of the most ambitious and spectacular projects in outer space – asteroid mining. “Planetary Resources is establishing a new paradigm for resource discovery and utilization that will bring the solar system into humanity’s sphere of influence. Our technical principals boast extensive experience in all phases of robotic space missions, from designing and building, to testing and operating. We are visionaries, pioneers, rocket scientists and industry leaders with proven track records on—and off—this planet.”

The team of entrepreneurs[25], engineers and specialized advisors claim that Space Economy will become a modern day Gold Rush. "If you look back historically at what has caused humanity to make its largest investments in exploration and in transportation, it has been going after resources, whether it's the Europeans going after the spice routes or the American settlers looking toward the west for gold, oil, timber or land," Diamandis said (Reuters, 2012).

They argue that asteroid mining will open a trillion-dollar industry and provide a near-infinite supply of Platinum Group Metals and water to support our growth both

[25] http://www.planetaryresources.com/team/

on this planet and off. There are over 1,500 asteroids that are as easy to get to as the surface of the Moon. They are also in Earth-like orbits with small gravity fields, making them easier to approach and depart. Over 8800 asteroids have been discovered to date, and more than 1000 are found every year.

Platinum-rich asteroids could contain more Platinum Group Metals than what's been mined on Earth in all of history, which could mean near-infinite supply of precious resources.

One water-rich asteroid could produce enough fuel for every rocket launched in history. The uses of water in space include rocket fuel, drinkable water, and breathable air.

One single 500M water-rich asteroid would produce over $5 trillion worth of water for use in space and one single 500M platinum-rich asteroid could be worth more than $2.9 trillion. These resources could fuel and support spaceships, spate stations, colonies, life, agriculture and future exploration, reducing the costs of activities and transportation and reducing dependence on supplies and support from Earth.

Following Planetary Resources, other groups and companies presented similar projects and visions. **Deep Space Industries** believes the human race is ready to begin harvesting the resources of space both for their use *in* space *and* to increase the wealth and prosperity of the people of planet Earth.

"Asteroids are plentiful throughout the solar system. Many orbit close to the Earth and many of these carry vast deposits of resources ranging from water to metals such as iron, gold and platinum – everything we need to expand our civilization into space, to provide for our needs here at home and to increase the wealth of our planetary economy." (Deep Space Industries website)

Asteroids are not the only objects targeted by space companies. There are also plans to mine the Moon, which could contain useful and valuable resources, such as so-called rare-earth minerals, which are used in a range of technologies and which are currently refined almost exclusively in China. Other resources include water frozen in the dark recesses of polar craters (which can be split into hydrogen for rocket fuel and oxygen for breathing), Helium-3 (He-3), which apparently exists in

abundance on the Moon and could be a future energy source, and valuable titanium deposits[26].

1.6. Exponentially Growing Technologies and the Law of Accelerating Returns

Having the possibility to exploit near-infinite resources is probably the most important paradigm shift in economic history, since it reaches the core of our economic thinking – the problem of "resource scarcity". A finite system with finite resources sets limits to economic growth.

Diamandis argues that "scarcity is contextual and technology is a resource liberating force" (both here on Earth and out is space) and that "for the first time ever we have enough wealth concentrated in the hands of a few individuals and the technology accessible that will allow us to really drive space exploration" (Peter Diamandis[27]).

Decades of analysis of the history of technology have lead to the conclusion that technological change is exponential, contrary to the common-sense "intuitive linear" view. Engineer and entrepreneur Ray Kurzweil argues that "we won't experience 100 years of progress in the 21st century – it will be more like 20 000 years of progress (at today's rate). The "returns", such as chip speed and cost-effectiveness, also increase exponentially. There's even an exponential growth in the rate of exponential growth". (Kurzweil, Law of Accelerating Returns, 2001).

Moore's law is the observation that over the history of computing hardware, the number of transistors on integrated circuits doubles approximately every two years (12 to 24 months, over the past years).

Extensive research shows that technological progress is a smooth curve. Through war time and peace time, recession, depression and economic boom, it did not slow for any of our grand challenges. This is the result of faster computers being used to build faster computers. Even more the rate at which the technology is getting faster is itself getting faster.

[26] "What if you could mine the Moon?", Regan Morris, BBC News.
[27] See videography for Peter Diamandis and Ray Kurzweil Ted Video

Fast growing technologies such as Artificial Intelligence, robotics, nanomaterials, synthetic biology, digital medicine, 3D manufacturing, infinite computing, sensors and networks, are the powerful tools that are riding on Moore's Law, growing at an exponential rate, reshaping our societies, our industries and our economies, and offering new solutions to our challenges (Diamandis, 2012).

These technologies, alongside the recent shifts in business dynamics within a more integrated global information society, are the reason small groups of people are able to engage in activities that were once the exclusive realm of governments and large corporations. Forty years after the Apollo missions (1969 - 1972), the average smartphone today has more computing power than Apollo 11 did when it journeyed to the Moon.

Ten years ago, Dolman was writing: "That the space race is over and the Space Age is in decay seems dismally obvious. That it will some day revive seems nonetheless assured. Humanity's future is in the stars. […] Our insatiable appetites require vast new resources. Eventually we will fill this niche that is Earth and spill out into the cosmos. But when and how this inevitable migration takes place is not at all known." (Dolman, 2001). Only a decade later, SpaceX becomes world's first privately held company to send a cargo payload to the ISS and starts testing the most capable existing rocket, with plans to go to Mars.

"In the long run, a single-planet species will not survive. One day, I don't know when, but one day, there will be more humans living off the Earth than on it."
NASA director Mike Griffin, quoted in "Mars or Bust," Rolling Stone, 2006

2. Creating an off-planet economy

2.1. From financial turmoil to an age of abundance

Man has conquered the physical environment and changed the world in a profound way, but, in this process, created a human environment that is overwhelmingly complicated. Paradigm shifts are becoming increasingly common, "change" defines "normality" and the global landscape looks more and more like a

“plotless, post-modern work starring a menagerie of wildly incongruent themes and protagonists” (Schweller, 2009).

The last couple of years have thrown our (global) society into a multi-dimensional/ multi-level crisis. Perhaps a more ardent issue than the financial and economic crisis is the intellectual and theoretical crisis we are facing. The neoclassical theoretical framework has failed to explain today’s reality and the changes occurred at the global scale (Krugman, 2009). While the global “metabolism” has accelerated and the growing complexity of the international human society brings new challenges, we find ourselves offering old answers to new questions.

However, while the entire world was struggling with turbulent financial times and economists and scholars were desperately trying to grasp the roots and threads of the global crisis, some economic major paradigm shifts have been brewing in the background.

It has become private companies’ responsibility not only to open the space frontier, but to drive innovation and stimulate breakthroughs in order to solve Humanity’s grand challenges, here on Earth.

But in order to do so, the market place for investment in space technologies (as well as in other fast growing technologies) needs to become more integrated and flexible. It is during these early days of the New Space Age that we shape new economic models and expand our economic thinking to a new level of understanding of the world around us.

OECD report “The Space Economy at a Glance 2011” shows that the space economy is an engine of economic growth, with the sector playing an increasingly pivotal role in the efficient functioning of modern societies and their economic development (OECD, 2011, p.27). Moreover, despite the economic crisis, the space sector has fared relatively well since 2008. Space remains a strategic sector, often sheltered because of national imperatives and institutional funding. The main commercial markets for space services are telecommunications, satellite broadcasting, Earth observation products and services, with the role of public institutions remaining essential in the space sector.

However, there is a long way from satellite launching systems to asteroid mining capabilities and spaceships that will assure transportation from Earth to colonies and space stations at an affordable price.

With fast growing technologies, the next decades could bring solutions to various problems our world faces today and help make the transition from “resource scarcity” to “resource abundance”.

2.2. The Entropy Law and the Planetary Thermodynamic System

Romanian mathematician, statistician and economist Nicholas-Georgescu Roegen (1906 – 1994) was the first economist to realize that the Entropy Law imposes limits to the economic process, considering it “the most economic of physical laws”. Entropy irreversibly degrades, matter, energy, life, in a world consumed by an increasing thirst for all of them. Every process in our world uses low-entropy resources and transforms them, dissipating matter and energy in an irreversible way. As usable “free energy” tends to disperse or become lost in the form of “bound energy”, the material universe is subject to irreversible qualitative changes in an evolutionary process.

The First Law of Thermodynamics (conservation of energy) states that energy can be neither created nor destroyed. However, energy can change forms, and energy can flow from one place to another. The total energy of an *isolated* system remains the same. However planet Earth (or the global economy) is not an isolated system, but it could be analyzed as a closed thermodynamic system. In a closed system, no mass may be transferred in or out of the system boundaries. The system always contains the same amount of matter, but heat and work can be exchanged across the boundaries of the system. If we were to set the boundaries of this physical system to 2000 km above Earth surface, the boundary between LEO (Low-Earth Orbit) and MEO (Medium-Earth Orbit), and ignore the Geosynchronous and Geostationary satellites in MEO, as well as the probes that were sent farther into the Solar System and occasional pieces of asteroids that hit Earth’s atmosphere, we could obtain a theoretical representation of Earth as a closed thermodynamic system. There is a flow of heat, radiation, energy over this boarder, but no matter

transfer. The amount of matter and energy remains the same, since they cannot be destroyed or created, but their availability for natural and economic processes decreases over time, until it reached a point of inability of a system's energy to perform work. In order to bring the system to the initial state of order and efficiency, exogenous intervention is needed.

Humans survive by using low-entropy resources from the environment, such as fossil fuels and concentrated mineral, and converting them into useless (high-entropy) waste (Daly, 2005). In entropic terms, the outcome of every economic process is a deficit, an irreplaceable loss in the quality of the environment. The main idea is that **in a finite environment, it is impossible to have infinite growth.**

In this context, we understand what mining the asteroids and bringing the resources back to Earth would mean. For the first time in economic history, global economy would become an open system, incorporating valuable resources into its production systems and preserving the environment. Thus, it becomes even more obvious that opening the space frontier is not only a moral imperative, but a pragmatic physical and material imperative in the long-run.

2.3. Defining "Exoeconomics"

Perhaps it is not too early to think of a macro-exo-economic model that an off-planet economy would imply. By extending the economic theories, instruments and research tools and adapt them to the future paradigm shifts, we could develop a (social) science that analyzes the production, distribution, and consumption of goods and services within a man-made structure, settlement, or colony that engages in economic activities (such as mining or manufacturing), placed in outer space. The economic activities of these structures will have to be put, of course, in relationship to the global economy, since there should be a clear distinction between what we call today "space economy" and the future off-planet economy, analyzed by "exoeconomics".

Technological progress speeds up while inequalities around the world are growing. There are means to produce a world of abundance, but the economic

models and the institutional framework are still stuck in old paradigms. “Successful political/economic systems [that] have evolved flexible institutional structures […] can survive the shocks and changes that are a part of successful evolution.” (North, 1994, p.367). Acemoglu and Robinson re-affirm that the reason nations are rich and others are poor, divided by wealth and poverty, health and sickness, food and famine, is not culture, nor weather, nor geography, nor ignorance. Based on fifteen years of research, Acemoglu and Robinson brought historical evidence to show that is man-made political and economic institutions that underlie economic success (or the lack of it) (Acemoglu, Robinson, 2012).

Since institutions and economic models are structures that humans have evolved, they are constructs that represent sets of rules and norms and abstractions of our world/society. Although these constructs evolve through time, they still follow our “intuitive linear” view, as Kurzweil argues. This is what makes our current economic thinking and institutions fundamentally flawed in a context of exponentially growing technologies.

If we are to exploit the full potential of the technologies available, open the space frontier, reduce the inequalities around the world, and create a world of abundance and countless possibilities, we will have to adapt our institutions.

3. Political challenges and regulatory implications

Opening the space frontier with private projects brings a series of legal issues that will have to be solved and integrated into a still young regulatory framework. During the 1960s and the 1970s, a number of basic treaties and principles have been enacted internationally, concerning the peaceful uses and non-appropriation of space. Based on this regime, governments are liable under international space law whenever a space object is launched from their territory, even if it is by a private entity (OECD, 2011, p.32)

The trend of commercialization of space has become stronger over the last decade as shown by two indicators (2011): the increasing number of commercial actors in the sector and the rapid development of national space laws, simplifying the rules of the road for institutional and commercial actors alike (OECD, 2011, p.31).

The **Outer Space Treaty**, formally the **Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies**, is a treaty that forms the basis of international space law. The treaty was opened for signature in the United States, the United Kingdom and the Soviet Union on January 27, 1967, and entered into force on October 10, 1967.

According to the Outer Space Treaty, “the exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.” (Part one, A, Art.I). In addition, “The Moon and its natural resources are the common heritage of mankind” (Part one, section E, Art.11)

How would we deal with claims of property rights on different objects in space, such as asteroids, once private companies will go out there and exploit them, and how should the resources be distributed after extraction?

The geopolitical factors and implications entailed are and will be numerous. Will nations take advantage of this wave of private space companies and fight for geopolitical and astro-political superiority? We could soon have the first nation that would claim the Moon and its resources, even though international treaties forbid it. China has already announced a mission in the next decade and intentions to build a settlement.

Space exploration requires a certain level of maturity of the species that engages in such activities, and indeed the international community has gathered scientific knowledge and experience as nations worked together to build the International Space Station, to develop communication systems and various joint space projects with multiple applications.

However, once the race for resources, the modern age Gold Rush, will begin, other geopolitical factors could be activated and a new wave of resource nationalism would arise. A nation could claim the Moon or other celestial bodies and the resources contained, by putting a flag on them, in the same manner Russia planted a flag on the Arctic seabed in August 2007, in a symbolic move to enhance the government’s disputed claim to nearly half of the floor of the Arctic Ocean and potential oil and resources there.

“Currently, the biggest hurdle in actually mining these asteroids is that the law hasn’t been settled yet,” says space lawyer Michael Listner.

If Planetary Resources is to succeed, the international community will have to decide if the venture is legal. Currently, asteroid mining companies are placed in a grey legal area. In the end, regardless of who claims which object or resources, a regulatory framework will have to be outlines soon. Companies that will be able to mine asteroid or the Moon could extract valuable resources “for the benefit and in the interest of all countries”, but they will still have to obtain profit and invest further in order to increase efficiency and reduce costs.

Until now, this debate was somewhere in the realm of political philosophy, but it is to become a pressing issue that will need to be solved. This could represent one of the most intense legislative, political and intellectual challenges that we have faced so far. The outcome of this legislative debate could have an extremely important impact, being able to mark the dawn of a golden age of prosperity for all Humankind.

With a change in the context of business and the economic dynamics due to fast-growing technologies, space will become more accessible to private companies than to large governments with budgetary constraints and socio-political pressures. We could see a transition from what Dolman called Astropolitiks to an era of Astro-economics and Space Corporatism.

4. Anthropological perspectives

"There are so many benefits to be derived from space exploration and exploitation; why not take what seems to me the only chance of escaping what is otherwise the sure destruction of all that humanity has struggled to achieve for 50,000 years?"

Isaac Asimov, speech at Rutgers University

The entire history of Homo Sapiens is a story of technological evolution. 40 000 years ago, Homo Sapiens Sapiens remains the only humanoid species left surviving

on Earth. 10 000 years ago, in Neolithic, the modern era of technology begins with the Agrarian Revolution. In time, humans have created increasingly complex tools built on previous tools, through a long chain of technological and economic paradigm shifts.

Today, the modern world is rapidly transforming as it goes through the transition from the “industrial epoch” to the “information society” or “post-industrial epoch” (Fukuyama, 1999). Humankind is facing the third major revolution in ten millennia, after the Agrarian Revolution in Neolithic and the Industrial Revolution at the end of the 18th, beginning of the 19th century. These “waves” have restructured the societies of those times and their institutions and there is no reason to believe that this “third wave” would spare a world that is more integrated and interconnected than ever of profound changes.

With exponential growing technologies we could experience paradigm shifts at an increasing rate, going through not only one revolution, but a series of technological and industrial revolutions, constantly reshaping our economies and societies.

The **Kardashev scale** is a method of measuring a civilization's level of technological advancement, based on the amount of usable energy a civilization has at its disposal. The scale has three designated categories called *Type I*, *II*, and *III*. In 1964, Kardashev defined the three levels of civilizations based on the order of magnitude of the amount of power available to them. Metrics other than pure power usage have also been proposed, such as 'mastery' of a planet, system or galaxy rather than considering energy alone, or considering the amount of information controlled by a civilization rather than the amount of energy.

Robert Zubrin uses the terms to refer to how widespread a civilization is in space, rather than to its energy use. In other words, a Type I civilization has spread across its planet, a Type II has extensive colonies in its respective stellar system, and a Type III has colonized its galaxy. (Zubrin, 2000)

Exponentially growing technologies could speed up the achievement of the level of a Type I civilization and rapidly making the transition to a Type II civilization. If some of the ambitious private space projects that have been announced recently succeed, it will be during the next decades that Humankind will become a multi-world species, with Moon and Mars as the next probable locations.

For the first time in Human history people are making plans to leave the planet. In my opinion, two major upcoming events will represent milestones in Human history and economic history: the first temporary or permanent colony/settlement on a celestial body (there are already astronauts living for short time intervals on the ISS) and the first artefact that will be produced using raw materials from outer space (by asteroid mining) in an off-planet facility. In the light of all the arguments brought throughout this paper, we could say these events are likely to happen within two decades[28].

Conclusions

These events and initiatives presented could represent the beginning of what will become a new type of economic system, with an off-planet economic layer added to the global economy and implicitly, a new way of thinking about resources and scarcity. The social science that we presently broadly call "economics" could see new frontiers and new intellectual challenges, being forced to develop into a theoretical and applicable framework that integrates the "Earthly affairs" with the space-related business activities. Once private companies will open space and go beyond the levels that have been achieved only by national space agencies, Humankind will most probably enter a new Era of existence.

The reasons for creating an off-planet economy are multiple: near-infinite resources, a flourishing economic and financial system here on Earth, reducing inequalities around the world by creating a world of abundance and countless opportunities by efficiently using exponentially growing technologies, a dynamic space industry that could help create human colonies and settlements, accumulation of scientific knowledge, a boost in technological innovation, new solutions for Humanity's grand challenges, increased chances of survival in the long-run. Mining

[28] "Building a lunar base with 3D printing" on ESA website - http://www.esa.int/Our_Activities/Technology/Building_a_lunar_base_with_3D_printing

the Moon and the near-Earth asteroids could open an off-planet industry that would inject trillions of dollars into the global GDP.

Ten millennia after the Agrarian Revolution in Neolithic, Homo Faber, Homo Oeconomicus and Homo Technologicus are preparing to explore and exploit space and to live on other worlds.

"A planet is the cradle of mind, but one cannot live in a cradle forever" –

Konstantin E.Tsiolkovsky

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