On the Dynamic Theory of Astroeconomics

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Abstract
This paper considers the possible theoretical modelling of space exploration in line with the classical assumptions of economic analysis. Three models are examined and analysed: a simple utility model; a game theoretic model in which each player or participating nation in space exploration follows some rules of rational behaviour involving some sort of strategy to maximize its winnings or successes and minimize losses or failures; as well as a dynamic optimization model.
Keywords: Astroeconomics, empyrean economics, psychological propensity drive

1. Introduction

Exploration of outer space has had significant effect on mankind over the past few decades even as it has been of fascinating interest to many governments and planners, including policymakers in space exploring nations across the globe. Since the launching of *Sputnik 1* in October 1957, the exploration of outer space by many countries has expanded and continues unabated. While the former Soviet Union (now the Russian federation) and U.S.A. have been the first and major participants in space explorations, new entrants such as Japan, European Union, China and India had joined the race in recent times. There have been huge investments in space exploration in many countries. It is estimated that over 6 percent of GDP in developed economies is devoted to space exploration. Investment in space exploration indeed have positive spin-offs or impact on growth and development as those trained in R&D in this domain more often than not went on to become the skilled manpower and human capital actively involved in developing new navigational and communication satellites in technological firms in many countries. The task of linking astronomy and economics is indeed a daunting exercise. The vast universe is made up of billions and even trillions of galaxies, one which is our own galaxy – the *Milky Way*. The *Milky Way* is also made up of billions of stars one of which is our own sun which lies at the centre of the solar system. Aside these infinite numbers of stars are other heavenly bodies such as the Magellanic Clouds, Nebulae and Supernovae, quasars, pulsars, asteroids or planetoids, exoplanets, Seyfert galaxies, meteors and meteorites, comets, stellar dusts as well as dark matter and black holes discovered in recent times through advancement in cosmology and astronomy[1].

How the resources of nations are been allocated to the ever growing endeavour of space exploration have not been given consideration in economic literature. Moreover, aside the problem of resource allocation is how to optimally deploy physical and human capital facing space agencies in various nations of the world. A consideration of the issues and problems of space exploration either from the standpoint of the exploitation of mineral resources in outer space and space tourism on the one hand as well as the launching of space probes and satellites by diverse nations all have implications on economic growth and development is timely. Nevertheless it suggests the very possibility of it not only been theoretically plausible for economic analysis but also worthy of concrete exposition. The behaviour of the competing forces in the market for space exploration given a nation's psychological propensity drive is the starting point of *Astroeconomics*. We would raise this proposition (the basis of that which will hereafter be called the 'Principles of Empyrean Economics') to the level of a theoretical postulate and laid the foundation vis-a-vis some basic premises and assumptions (which we would consider in a later section) and thereafter critically analyse them accordingly. There is the need to examine the economic considerations behind space exploration and mining activities in outer space. The word – *Astroeconomics* here implied the economic analysis of the fundamental parameters and variables involved in mankind's activity in exploring outer space. Astroeconomics or Empyrean Economics as explored here is primarily concerned with enquiry or investigations of the fundamental problems of space exploration using the

[1] Astronomy which is probably the oldest and most modern of physical sciences have brought up new discoveries of celestial bodies emitting all kinds of radiation – not only light and radio waves but also infra red radiation, short wave ultraviolet rays, x-rays as well as very penetrating gamma rays as well as cosmic rays from distant galaxies in the past few decades. The discoveries of celestial bodies such as neutron stars, black holes, pulsars, quasars, nebulae, novae and supernovae and thousands of earthlike planets and exoplanets (that is planets which orbit other stars outside the solar system) have opened up new possibilities of more discoveries of celestial bodies and systems hitherto unknown thereby pushing forward the frontiers of research in astronomy and cosmology. Fascination and interest with astronomy does not preclude an examination of any underlying economic parameters in the exploration of outer space. Economic considerations can definitely be found for some explorations of outer space e.g. for mining though the quest for scientific knowledge alone might be the reason for the establishment of more powerful telescopes and observatories. Astroeconomics unites astronomy and economics in perhaps a remarkable manner. It also possibly provides an interface between the physical sciences and the social sciences in the realm of space exploration.

basic theoretical tools of economic analysis. It seeks to examine the basic problems and underlying economic basis and foundations of space explorations as well as their consequences on growth and development. In other words, it represents contributions to the study of celestial economic mechanics. There is a growing market for space tourism as more people are eager to travel outside the terrestrial domain to outer space to experience zero weightlessness. Advances in robotic technology are extending the frontiers of space exploration and colonization. Private firms (mostly in the States) are now actively engaged in plans of first sending robots to the planets such as Mars and the Moon and thereafter intending space tourists to these heavenly bodies. The commercialization and economic exploration of outer space is now the new push or activity unlike in the past where national image or 'pride' as well as scientific and military considerations are what necessitates space exploration. Private entrepreneurs are now leading the next push or advances in space exploration. There are now the plans in the offing of establishing space colonies or camps on the Moon and planets with environments similar to the earth such as Mars. Psychological proclivity in terms of national pride and image perhaps may have been the principal driving force in space exploration by many countries it certainly has underlying economic considerations. What would make a country with a large poor populace to invest billions of dollars in space exploration would certainly have to be economic issues with strong underlying psychological parameters or factors. Some questions would also suffice. Does psychological perception for instance in terms of 'national pride' of one nation over another inherently linked to the whole idea of space exploration? Is profit maximization the sole objective driving firms which are actively engaged in space exploration? How do government policies in nations involved in the exploration of space affect the output, productivity and efficiency in space industries in those economies? These questions would be considered with a view to eliciting possible explanations in the course of the study. The choice of the caption *On the Dynamic Theory of Astroeconomics* in a 'Eurekæan' or Archimedean manner is meant to describe theoretically the changing nature of space exploration vis-à-vis its economics, particularly as the basis of this paper. The paper is organized as follows: following this introductory part or exordium is Section 2 (though the paper is more or less a theoretical one, a brief exploration of how the space age had evolved is perhaps necessary) which examines or rather provides an overview on space exploration with a particular consideration of a hypothetical system of outer space as a prelude to the modelling in the next section in order to elicit or bring out the raison d'être or rationale behind the exploration as well as exploitation of space in recent times. Section 3 presents a stylized framework of the economipotent planner under the subheadings: foundational premises and formulation; preferences and technology; and equilibrium. The dynamic astroeconomy is the focus of Section 4 with the game-theoretic model considered in subsection 4.1 while 4.2 examines the dynamic optimization model. Section 5 considers the analysis while Section 6 concludes the paper.

2 An Overview on Space Exploration

The launching of *Sputnik I* on 4 October 1957 by the former *Soviet Union* (now Russia) heralds the beginning of the space age. The Russians had an elaborate space programme culminating in the launch of so many satellites and space probes via the *Solyuz* rockets from the spaceports or sites such as the *Baikhanov space centre* in Kazakhstan, *Kasputin Yar* near Volgograd and *Plesetsk* in the north. This is because just in the wake of *Sputnik I*, they launched *Sputnik II* on 3 November, 1957 containing a dog called '*Laika*', the first living creature ever to go in to space[1]. This prepared the way for the flight that put Yuri Gagarin, the first man in space in to orbit on 12 April, 1961. These feats by the Russians took the Americans by surprise and spurned them in to efforts aimed at also sending a satellite in to orbit. Eventually, a modified *Jupiter C booster* rocket hurled the *Explorer I* satellite in to orbit on 31 January, 1958.The American space mission were conducted from three major sites with largest been the famous *John F. Kennedy* space centre on the eastern coast of Florida while the other two are the Western Test Range in California and the test range on Wallops Island in Virginia. The Americans however beat the Russians in the race towards putting a man on the Moon when on 20 July, 1969; astronauts Neil Armstrong, Michael Collins and Edwin Aldrin achieved the unprecedented feat of being the first men to land on the Moon via the *Apollo II* spacecraft. This was after several failed attempts through the American pioneer spaceships series and the Russians through their *Lunik* space probes series. The explorations of space have continued unabated since then. Moreover, after a slowdown or decline in the past two or three decades, there is a recent surge or revival in space exploration with the entrance of new nations such as India and China.[2] The advanced industrial economies of continental Europe also have a space programme through collaborative effort (vis-à-vis the European Space Agency) with the launch of the *Gayne* satellite for mapping the stars in our *Milky Way* so as

[1] The Americans also send two dogs, *Abel* and *Baika* in to space in May 1959 aboard an Explorer rocket or space craft to prepare the way for its space mission particularly its objective of manned space voyages later to the Moon.
[2] The entry of new emerging nations such as India and China in the exploration of space most certainly confirms the notion that knowledge no matter how advanced or sophisticated is not the exclusive preserve of any nation or race.

to discover more about the universe than we have previously known[1]. Also, the recent approach of a space probe near a comet over 550 million kilometers from the Earth present new possibilities for mankind in its exploration of outer space. This comet between Mars and Jupiter is believed by many scientists and astronomers to help our understanding of formation of these celestial bodies as well as their structures. Many comets and meteors are believed to contained rare and precious minerals that can be exploited possibly on a commercial basis later by the major participating nations. The Chinese moreso have a very ambitious programme with their lunar rovers landing on the Moon recently also and they intend to possibly establish a permanent space station there for exploitation of mineral resources that might be useful back here on Earth. This is also in the wake of the Indians who also sent a space probe to Mars. These developments are no surprise as the two most populous nations on planet Earth who are emerging economies have finally joined the space race which was once the exclusive preserve of the Russians and Americans. The ascendancy of space explorations have shifted from the developed *North* to the developing and emerging *South*. Nevertheless, how their efforts would advanced the frontiers of knowledge beyond what we already know remain to be seen. We now turn our attention to consider briefly a hypothetical system of planets.

Assuming Fig.1 represents a hypothetical system of planets and *planetoids* where a moderately sized planet B contains intelligent beings with an advanced civilization and technology capable of exploring the frontiers and expanses of outer space. The centre of this system is D while A is the galactic space. Now D is an ever burning star or *stellar mass* of immense gaseous energy. Let us also assume that it has been discovered by scientists in planet B that planet C contains vast and immense amounts of mineral resources that have useful applications on planet B. However, planet B is a two-country world and technology, especially space technology is nonrival, though excludable. The problem facing the nations on planet B is whether the exploration of space, let say on planet C can best be carried out or pursued separately by each country or together with each concentrating on aspects of the technology where it has comparative advantage.

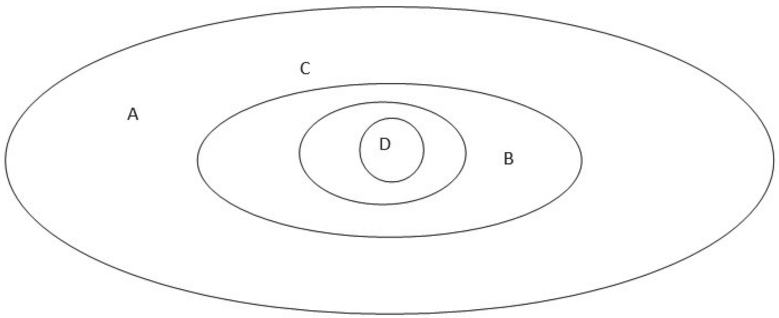

Fig.1: A Hypothetical System of Planets and Stellar Constellations

The nations have to allocate their resources efficiently especially with regard to the enterprise of space exploration which inevitably has implications and effects on economic growth and development through various outcomes in per capita output growth in the long run. Before proceeding, we would like to make perhaps a critical conjecture. If we assume or rather confirm the assertion that *psychological propensity* is the same as the inclination or drive of the psyche whether of whether an individual, firm or nation, then the psychological image of say, individuals in an economy can collectively or aggregatively be mirrored and mapped in to the *psychological space* of the nation, *ceteris paribus*. We can deduce that when for example, the per capita income of a nation rises, so also does its psychological propensity and expectation rise and by implication, vice versa. If we accept this proposition (which we hereafter raise to the level of a theoretical postulate), then we can easily proceed from there. Investments in the space industry by entrepreneurs is most probably motivated by profit maximization whereas investments by governments and their agencies such as the National Aeronautical and Space Agency (NASA) in the United States and the Russian Space Agency (*Roscosmos*) is obviously for

[1] A great deal is also now known through astronomy about the *Milky Way* and the nearest extragalactic clusters - the *Magellanic Clouds* as well as other galaxies in the vast expanse of the universe through the exploits of the astronomers and space probes such as the American Pioneer 10 space craft which has travelled beyond the Solar System as well as the International Space Station. Terrestrial-based observatories have also contributed significantly. All these endeavours in the exploration of outer space involved high capital intensity and immense financial commitments.

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psychological propensity drive as they tried to galvanized the “national image” profile of their countries through their space mission programmes. The same reason most probably true for the new entrants, India and China in their foray in to space exploration. Different possible scenarios can result from economic engagements by various nations in outer space vis-à-vis mining, tourism, as well as the formation space colonies. Next we turned our attention on attempting the theoretical modelling of Astroeconomics which can also be described as Empyrean Economics.

3 The *Economipotent* Planner’s Problem

3.1 Foundational Premises & Formulation

In our consideration of a theoretical modelling of the economic behaviour in space exploration in this section, we would critically examine some of the fundamental problems of this paper.[1] As all modelling begins with abstraction and simplification, we would start by considering the basic premises of the theoretical model which are four. The first assumption is that all nations have free and equal access to the exploration of outer space while the second is that all mineral resources explored and appropriated in space are solely the property and within the jurisdiction of the exploring country. The third premise is that space resources, including rare mineral deposits are nonrival and also nonexcludable in as much as there are appropriate technology to harness them. They only become excludable at the point where an exploring nation have established control over a certain part of space, say the Moon or Mars surface. The last and central premise however is that the *self-interest* motive of individuals as rational optimizing agents are *mapped* in to the aggregative national psychological expectations functions of diverse nations or countries which were then adjusted or modified for the sake of public policy vis-a-vis for instance, embarking on space exploration for the mere sake of psychological image or ‘national pride’. The condition under which the psychological propensity motive is *operative* is critical. Fiscal allocation to space exploration in a space exploring economy is a function of its psychological propensity drive, *ceteris paribus*. The fiscal in other words, depends on the level of the psychological propensity drive. If the latter is at its highest level, the former will be at a momentous level. Moreover, when the psychological propensity drive is at its lowest ebb, the fiscal allocation will be at a decreasing level.

The perception of a country’s national image or ‘pride’ by its citizens relative to or rather in the eyes of other nations can help us in observing the possibilities that can evolve when the psychological propensity motive is *operative* –which we have noted underlies the endeavour of space exploration. We assume that citizens of nations whether large or small behave and act in *rational* ways when it comes to endeavours that touch or rather promotes their national psyche. Large and wealthier nations embark upon endeavours or enterprises that promote and advanced their image or ‘pride’, one of which is space exploration. Small and poorer nations behold these activities by their large and rich counterparts in *awe* – obviously and certainly illustrating the psychological state of the former to such endeavours. Space exploration is moreover a fruitful and productive economic engagement with many spin-offs. Having noted the underlying assumptions of the model, it is imperative to stress that the competition among participating nations in the exploration of space basically reveals the *self-interest* of individuals as citizens of various nations which been mapped in to national psychological dispositions and expectations reinforces the capitalist model in the endeavour of space exploration. How this come about can be seen from the fact that rational self-interest concept is the bedrock of classical economics or economic theory and it has now becomes the basis of competitiveness among various nations of the world via the psychological dispositions and expectations in motivating them on embarking on space exploration. In as much as this paramount assumption of self-interest in individuals, albeit nations are true, it is imperative to stress the pre-eminent position of the economic model or system that perhaps best favoured space exploration –a free market economy, as that is the only economic system that can possibly incorporate our aforementioned premises which underlies classical economic analysis.[2] Briefly, the basic formulation of the model in the space exploring, though hypothetical Uranian economy consists of N agents or rather citizens (Uranians as it were) each of them producing different goods but nevertheless consuming exactly one good – space exploration. Each agent is characterized by a utility function:

$$U_i = Q_i^2 + \beta\varphi \qquad [1]$$

Where Q_i is the productivity of agent I, β is the psychological propensity parameter which underlies the

[1] In our attempt at the theoretical modelling of space exploration here, we employed a variety of different models or approaches and not just a particular model, as no single specific model is capable of explaining or describing all aspects of the economic behaviour of agents – individuals, firms and governments involved in the exploration of outer space. These frameworks might perhaps best describe the economic reality involved in space exploration. The theoretical model is based on sound microeconomic foundations of rationality, choice and resource allocation.

[2] Though one of the two major participating nations in space explorations in the early days of the space age in the 1950s and 1960s, Russia (former Soviet Union) runs its space mission within the framework of a centrally planned economy unlike its rival, the United States, which runs a *laissez faire* capitalist model, the underlying basis then was more of psychological considerations as the Cold War was on then and national ‘pride’ is at stake ultimately.

whole enterprise of space exploration; φ is the degree or magnitude of space exploration mission(s) embarked upon by Urania. There exists a non-negativity constraint to β, hence β≥0. There are two caveats or provisos to this formulation. First, the consumption of each agent of the only consumption good – space exploration does not decrease with N as it rather remain constant irrespective of the amount consumed. The second proviso is that the preferences vector consists of fundamentally space exploration on the one hand and technological progress on the other hand (which is inevitable for the state and growth of the former.) We would consider the preferences in more detail in the next subsection.

3.2 Preferences and Technology

Our theoretical model considers a two-nation global economy hypothetically referred to as *Urbania* and *Urania* where we attempt to model briefly the behaviour of the agents-individuals, firms and government in the business endeavour of space exploration. Our choice of a two-nation world framework is only a convenient analytical simplification as well as for theoretical plausibility. We assumed competitive equilibrium prevailed among the firms in the two economies- hence factor inputs are paid their marginal products. For there to be smooth signaling of preferences and prices (and costs) of space exploration, there is informational exactitude among the agents in the space exploring economy. Moreover, we assumed *endogenous growth* in this model since the conscious actions by economic agents – firms and governments in a space exploring economy is to *maximize* their objective functions which is profit and utility (in terms of national image and 'pride') respectively bring about *innovations* and *technological progress*. The governments in both Urania and Urbania are similar except for difference in preferences especially in the Uranian government which has a certain psychological image of its citizens and the sovereign nation, Urania, as perceived in the eyes of the world. In other words, the Uranian government assumes a certain perspective in regard to its national image and 'pride' in the eyes of the world; hence psychological proclivity is the *sole motive* and the driving force in its foray in to space exploration enterprise and mission. It perceives the citizens within its jurisdiction as possessing a certain image of themselves relative to the agents and citizens of other countries. Now since there are two nations - Urbania and Urania in our model, we assume specifically that the government in Urania has this distinct perception of itself and the sovereign nation, Urania in its relationship with the former. This is because while Urania is the space exploring nation, Urbania has no such perception and consequently has no preferences and enterprise in outer space. This gives rise to a national psychological expectation with respect to space exploration in the former. It is however important to note that the expectation system here is in terms of the psychological propensities driving the whole enterprise of space exploration – how they are formed in the agents especially the government sector and how it all translates in to *quantifiable output* ultimately. In the space exploring economy of Urania however, we assumed that the presence of a large population, high level of initial physical and human capital endowments, adequate capital accumulation etc gave it feasible advantages in embarking on a space mission programme. The notion is that the country's foray in to space exploration not only improve but also increase output growth and inevitably leads to wealth creation. Nevertheless, the patriotic *economipotent* planner in this space exploring economy -Urania while drawing up its space mission programme inevitably sought to increase the *pride profile* of the country particularly when the psychological propensity motive is *operative* vis-à-vis the magnification of the national image in the eyes of the rest of the world.[1] For inasmuch as productive economic activity in Urania is fueled and driven by scientific knowledge, discoveries and ideas, the basic nature and feature of knowledge spillovers in it is similar and can possibly be explained by the New Endogenous Growth Model. Though these knowledge, discoveries and ideas cost so much to be produce initially by reason of investments for instance in the R& D sector, their marginal cost of production is almost zero by virtue of their non-rivalry nature.

Before proceeding further, we would take a cursory view at the national expectation atmosphere in Urania especially at the activity of government in driving the enterprise of space exploration. The psychological perception and expectation of citizens in Urania is high and lofty in their own assessment of their relationship with the citizens of Urbania (hereafter to be referred to as *Uranians* and *Urbanians*.) In other words, Uranians are in *high spirits* when the country embarked on its space mission programme relative to Urbanians since the latter does not embarked on any such venture, *ceteris paribus*. This psychological perception by Uranians of themselves is what is *mirrored* and aggregatively *mapped* by the Uranian government in drawing up its own production function in terms of its spending outlays and priorities. Hence this singular factor is responsible for

[1]Though this is a conceptual clarification, it perhaps stems from the very possibility of the fact that the patriotic planner capitalizes on the huge *psychological capital* that characterizes nations embarking on such endeavours as space exploration which is fundamentally evident by a *buoyant spirit* of national psychological 'pride' and expectations. This stream of *psychological capital* propensity has the potential of translating in to immense economic goodwill vis-à-vis higher capital accumulation in the economy for output growth and improved productivity ultimately. Whether there exists a Pareto optimal equilibrium point between the whole lot or gamut of national psychological 'pride' and expectations on the one hand and the country' s space mission cost function on the other is another issue entirely.

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how it employs and deploys its aggregate capital stock, labour force and technology in developing its space exploration mission. The amount of resources it deploys in its space mission is equal to the *marginal national savings* (though we made some simplifying assumptions that this amount equals a fraction of the national income level and savings later in this section). Any amount of resources deployed for this purpose outside of this specification would not be Pareto optimal. Allocations to the space programme that are inefficient made the nation generally *worse off* vis-à-vis sub-optimal outcomes resulting in a *vainglory effect* in terms of the operability of the national psyche (particularly with regard to space exploration) and concomitantly productive economic engagements. The two countries and by extension their governments have different preferences and technology and this determined their perception or otherwise of each other particularly with regard to the enterprise of space exploration. The Uranian government (through its psychological propensity drive) hoped to unleash the *animal spirits* in the entrepreneurs in the private sector of the Uranian economy to fall in line with its policy priority and therefore be persuaded to shift their investment portfolios towards its space exploration mission and enterprise. Explicitly, Urania has absolute and comparative advantages in space exploration. Moreover, the psychological propensity drive and expectation regime in the Uranian economy enables the government there to raise easily a tax income which it entirely channels towards its space exploration mission to a distant galaxy.

It is expedient to stress that we assumed that the expectations of the economic agents as well as the psychological inclination of the nation in terms of pride in the eyes of the rest of the world is indeed palpable for anyone to see. The implication from henceforth is that there would definitely have to be a trade-off between space exploration and other pressing needs and priorities in our space exploring nation-Urania. A Pareto-optimal point exists and defines the threshold level where further away from it the *vainglory effect* would otherwise be established or rather effective. The trade-off between the employment of the capital stock or accumulation for space exploration and other macroeconomic priorities exist and the patriotic *economipotent* planner decides what and where the capital stock would be directed at.

3.3 Equilibrium

Now in order to solve for equilibrium, equation [1] is re-specified for the whole economy rather than for a single agent. Thus, the social or national psychological utility of country i (Urania) as a space exploring nation is defined as:

$$U_i = f(\psi_i, C_i) \quad [2]$$

where ψ_i denotes space exploration and C_i is the general consumption level. The function $f(\cdot,\cdot)$ is assumed to be twice continuously differentiable. If $f_\psi(\cdot,\cdot)$ and $f_C(\cdot,\cdot)$ are the derivatives of $f(\psi_i, C_i)$ with respect to its first and second arguments respectively, then: $f_\psi(\psi_i, C_i) > 0$; $f_C(\psi_i, C_i) > 0$. Utility from space exploration is however maximized subject to the constraint on the consumption level:

$$C_i = \alpha + \beta\psi_i \quad [3]$$

where $\beta > 0$ is the psychological propensity parameter that underlies the whole endeavour of space exploration in Urania and is a function of the size of the national income or GDP level. The restriction on this parameter is theoretically plausible because only a positive atmosphere of expectation in terms of national image or 'pride' can sustain an endeavour or enterprise as space exploration. In this framework, space exploration in the country is treated as a public good inasmuch as the psychological propensity motive is *operative*. Moreover, space exploration is considered as *consumption good* for the inhabitants of Urania (or Uranians). It is pertinent to note that whenever consumption in this paper, it refers solely to space exploration. The raison d'être is not far-fetched. Though space exploration is intangible like normal goods, it is however assumed to give a certain level of satisfaction or utility to Uranians and as such pass the consumption criterion. Since there is only one consumption good in the economy – space exploration (an intangible good, entirely psychological in nature), the constant term, α, inevitably entails all consumption of goods and services that are not directly linked to space exploration, *ab initio*. It is however pertinent to note that:

$$\psi_i = \delta Y_i \quad [4]$$

where $0 < \delta < 1$ and Y_i is the national income or GDP level for country i (Urania). We can rewrite [4] as:

$$\psi_i = \delta(C_i + S_i) = \delta C_i + \delta S_i \quad [5]$$

since $Y \equiv C + S$, is a definitional identity in economics. We however assumed that space exploration is a fraction of the savings level in the same proportion as the national income level in [4]. Thus

$$\Psi_i = \delta S_i\ ; \quad \delta < S \quad [6]$$

because consumption level is zero at that point so that derivative of space exploration with respect to savings is the parameter, δ. A further constraint from the definitional identity is that:

$$C_i = Y_i - S_i \quad [7]$$

where S_i is the level of saving. The meaning of [4] is that the allocation to space exploration in

Urania is a positive fraction of the GDP or national income level.[1] We assumed that space exploration and consumption have positive marginal utility:

$$\frac{\partial U_i}{\partial \psi_i} = \frac{\partial U_i}{\partial c_i} > 0 \qquad [8].$$

The country or rather its citizens (i.e. Uranians) maximizes the utility it obtains from space exploration (as an endeavour or enterprise) and consumption subject to the constraints [2] and [3]. The first order condition for this maximum can be obtained employing total differentials by differentiating the utility function [2] with respect to savings and setting the first derivatives to zero. Thus:

$$\frac{dU_i}{ds_i} = \frac{\partial U_i}{\partial \psi_i}\frac{d\psi_i}{ds_i} + \frac{\partial U_i}{\partial c_i}\frac{dc_i}{ds_i} = 0 \qquad [9]$$

From [3], $\frac{d\psi_i}{ds_i} = \delta$, and from [5], $\frac{dc_i}{ds_i} = -1$. Hence:

$$\delta\frac{\partial U_i}{\partial \psi_i} = \frac{\partial U_i}{\partial c_i} \qquad [10]$$

Equation [10] expresses the equilibrium position for space exploration utility maximization for Urania. The country will choose to save and allocate resources for its space mission programme at the point which equates the marginal social utility of space exploration to the marginal utility of consumption. In other words, the fraction of the country's GDP or national income equals the marginal rate of substitution of utility from consumption to utility from space exploration, $\frac{\partial U_i}{\partial c_i} / \frac{\partial U_i}{\partial \psi_i}$

Given that [2] defines the aggregate social utility for Urania, U_i/Q, is the *utility per capita* of an average Uranian where Q is the total population in the country, then the marginal *per capita* utility with respect to the space mission programme, i.e., $\frac{\partial (U_i/Q)}{\partial \psi_i}$>0 is constant and not a decreasing or diminishing quantity as the case is for normal goods. The implication here is that satisfaction or utility in terms of a sense of national image or 'pride' would always remain unchanged or constant in the psyche of many citizens in space exploring nations. Inasmuch as the capital intensity of the capital-labour ratio per effective worker deepens as the space exploration enterprise steadily grows, the steady state defined the balanced growth path of this variable. The variables are constant with regard to space exploration.

4 The Dynamic Astroeconomy

4.1 Games-Theoretic Model

We, next turn our attention to a brief consideration of a game theoretic approach to the enterprise of space exploration. The economic behavior of many nations in space exploration results in some possible outcomes in game like scenario. Moreover, such preferences would lead the rational agent to select the best outcome from among all available outcomes. Game theory provides a plausible approach for analyzing the outcomes of behavior by participating nations in the exploration of space[2]. Space exploration is certainly a game of strategy rather than a game of chance – the outcome depends primarily on the deliberate choice of a course of action (the strategy) by each nation. This domain or endeavour involves the fundamental problem of optimization. The circumstances are more often than not that of a constant sum game. The course of action or strategy by one nation might obviously set the stage for a counter strategy by another competitor nation which perhaps can result in conflicting scenario and outcome in their common exploration of outer space. The domain of space exploration might perhaps be described as involving complex strategic games where only a Nash Equilibrium is possible as noncooperation characterized this human endeavour. However, such a point may be a Pareto inferior equilibrium. The scenario involved in space exploration might be either a zero sum game or constant sum game (if there is cooperation among the participating nations.) A zero sum game implied that one country's gain psychologically is another nation's loss in terms of national 'pride'. Game theory particularly in regard to its application to the possible scenarios that can occur among competing nations has the merit of redistributing the

[1] Although this is a theoretical allusion, the magnitude of this fraction would definitely vary from one country to another depending on the relative size of the GDP, the *real per capita GDP* level (i.e., how rich or wealthy the country is) as well as the psychological mechanism underlying space mission funding or financing in such nation.

[2] Though the game theory provide a means of describing the strategic behaviour of one or more players or participants who have to make choices in conflict situations or games in which the payoffs or potential outcomes are a function of the choices made by all parties to the conflict, its application to the problem of space exploration while useful and critical is limited. This is because the possible spontaneous actions by the participating nations in the real world of strategic international geopolitics might not necessarily conform to a game-theoretic scenario nor can they be explained as such. The scenario in space exploration during the advent of the space age is very interesting. This is because the dynamics of space exploration especially in the early days when the Soviets pre-empt the Americans by the launch of the *Sputnik I* in October 1957 and other Firsts except the landing of the first man on the Moon was indeed a game changer at least then. The critical role of time factor during the advent of this endeavour in human history obviously not only boost the national psychological propensity drive and pride of the Russians but also change the geopolitical landscape of the world then especially considering the fact that that was at the height of the Cold War.

chance of each participating country in the exploration of outer space.[1] The simplest way to distinguish among games is to classify them by the number of players who are making the choices which lead to pay-offs. This introduces also the possibility of collusion or coalitions as soon as more than two players (with potentially conflicting interests) are present. Assuredly, going from two to three players or participants introduces coalitions, whereas going from five to six simply increases the number of potential coalitions. A simple two- nation world scenario is considered and this is illustrated in Table 1.

Table1: A Pay-off Matrix of Space Exploration;

	N_{2i}	N_{2j}
N_{1i}	3,3	1,6
N_{1j}	6,1	2,2

i = international cooperation & j = noncooperation –National interest

These two nations, Urania and Urbania in this brief game-theoretic model unlike in the utility model earlier considered are assumed to be rivals or competitors in the enterprise of space exploration. In other words, they are assumed here to be two space exploring nations who are rivals or competitors. They are designated as N_1 and N_2 respectively. In the light of possible space mission strategies by the nations, country N_1 would choose strategy Nij rather than N_{1i} because a noncooperative, national interest is better against whatever choice country N_2 would make: N_2 would likewise take a similar course of action. Both countries receive the equilibrium payoff 2. The choice of N_{1i}, N_{2i} leads to a Pareto-optimal outcome with payoff 3, 3. It can be cooperation among competing nations leads to or rather yield greater payoffs in space exploration as it is also true in other human endeavours. Nationalistic behavior however leads to globally conflicting outcomes. We now turn our attention to consider the perspective of dynamic optimization. It is however imperative to stress that the model represent only an approach in analyzing the issue of space exploration from an economic viewpoint. The case of a zero sum game in space exploration is however not something to be desired in this extremely interesting human endeavour and how that plays out is very much in doubt.

4.2 Dynamic Optimization Model

Turning our attention to the modelling on dynamic optimization, let us consider a model framework where there is a country i (Urania as in previous models) which has a space programme with instantaneous utility function given as:

$$\int_0^\infty u[G(t)].e^{-\rho t}.\varphi(t) \qquad [11],$$

where the discount rate parameter, $\rho>0$, represents the country's resilience or perseverance in pursuing a space programme despite its scarce resources and *per capita* income level. At time t, there are $\varphi_i(t)$ persons engaged in productive activities in the country with its exogenous rate of growth given as τ. Real *per capita expectation* by citizens of the country (in terms of psychological propensity or drive) towards the nation's space programme is a stream, G(t) , $t \geq 0$, of units of a single good (though intangible) – national image or pride. The rate of growth of country i' space mission is given by the function, $e^{-\rho t}$. If we assume that $A_i(t)$ is the total stock of country i's resources devoted to space exploration and $\dot{A}_i(t)$ as its rate of change at time t, then the country's total capital stock (whether physical or human) that is directed towards its space programme is therefore $\varphi_i(t)G_i(t) + \dot{A}_i(t)$. Exploration of outer space in this country therefore is assumed to depend on the level of the sum total of the rate of change of $A_i(t)$ and the product of the country's workforce, $\varphi_i(t)$ and the expectation function (in terms of psychological propensity or drive) by the citizens from its space programme, $G_i(t)$. Continuous operation or pursuance of the space mission programme however depends on optimizing the objective function: $\varphi_i(t)\,G_i(t) + \dot{A}_i(t)$, subject to the constraint $N_i(t)K_i(t)\lambda$ where K(t) is the aggregate capital stock (irrespective of whatever activity it is directed at-space exploration inclusive), $N_i(t)$ is the level of technological progress (in space technology) and λ is the country's learning coefficient in space exploration while the exogenously given rate of technological change, $\dot{N}/N$, is $\mu>0$. The allocation problem faced by this country is fundamentally how to choose an *optimal* time path, G(t), in terms of *per-capita expectations* by its citizens from its space mission programme. Now the optimal time path that maximizes the utility function subject to the constraint function above is the *Hamiltonian* H defined by:

[1] The entrance of new nations such as India and China representing emerging economies in space exploration which elsewhile was the exclusive preserve of two nations – Russia and U.S.A. provides the impetus of a game like scenario. The outcome can either be a win-win scenario or otherwise, though the former is deemed desirable. In the game-theoretic scenario between the two major players in the early stage of the space age – U.S.A. and Russia, it is imperative to stress that as the strategic competition continues between these nations, space technology spread to other nations through research and development (R&D). International cooperation and collaboration is indeed good for instance, in the smooth running of the International Space Station. The recent explosion of an unmanned American rocket carrying supplies to the Station is however worrisome. The American NASA which is responsible for the mission (though launched by a private firm, SpaceX) did not like to continue using Russian rockets to carry supplies to the International Space Station.

$H(N, G, \delta, t) = e^{-\rho t} G_i(t)\, \varphi_i(t) + \delta(N_i(t)K(t)\lambda - N_i G)$ [12]

which is basically the sum of the felicity function and the *Lagrangian* multiplier times the right hand side of the optimizing equation. The first order conditions are:

$H_G = e^{-\rho t} \varphi_i(t) - N_i \delta = 0$ [13]

as well as

$H_\delta = N_i(t)K(t)\lambda - N_i(t)G_i(t) = 0$ [14],

which implies that:

$G_i(t) = \lambda K(t)$ [15].

The implication of [15] is that the country's confidence or pride in embarking on a space mission programme is a function of, and or rather depends on its learning coefficient and its level of capital endowment at any point in time. An optimal expectation time path must maximize the *Hamiltonian* H at any time t, provided the *Lagrangian* δ(t) is correctly specified or chosen. The *transversality* condition is satisfied by

$\lim_{t \to \infty} e^{-\rho t} \delta(t) G(t) = 0$ [16],

which is the optimal path. The *Pontryagin's Maximum Principle* is the necessary condition for obtaining an optimal path. The sufficient condition can be easily deduced by the *Mangasarian's sufficiency theorem* which states that a path that satisfies the first order conditions and the transversality condition is optimal.
The implication of [15] is that the value of the real *per capita expectation*, G(t) must be asymptotically zero. This is depicted graphically in fig.3 in the (β(t), φ(t)) plane. This means the long run optimal time path of $G_i(t)$. The time path of $G_i(t)$ been asymptotically zero is apparently clear.

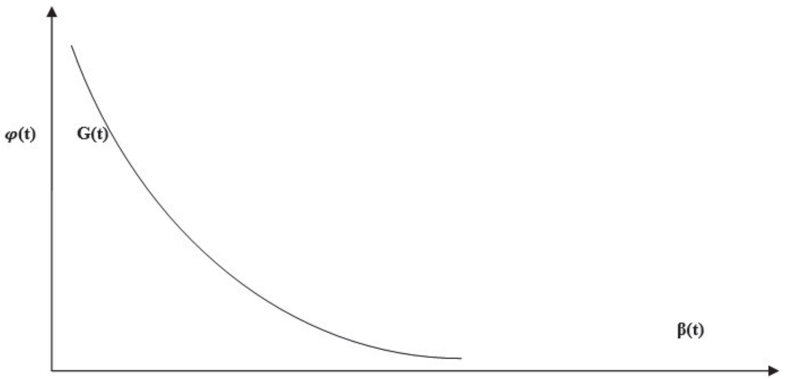

Fig.3: The Time Path of $G_i(t)$

5. Analysis and Appraisal

Psychological propensity has been seen from the 'Astroeconomic Model' in section 3 to be the sole and primary motive for nations foraying in to space exploration. Nevertheless, utility-maximization motive applies to the national psychological expectation system in our hypothetical Urania. Though profit-maximization applies to business firms involved in space exploration, utility-maximization in terms of national psyche applied to the psychological proclivity drive as well as the expectation mechanism in a space exploring nation like that of the hypothetical Urania as the country has as its primary motive to be the maximization of the psychic satisfaction it derives from the increased profile accorded its national image and 'pride' by embarking on its space mission programme. This inevitably produces *awe* and *marvel* in the eyes of other nations (or Urbania as the representative country) who are not involved in the enterprise of space exploration. While there may not necessarily be an image laundering programme with regard to space exploration in our hypothetical Urania, its space mission programme in itself primarily projects the national image in such a way to elicit utility or satisfaction for the country and its citizens vis-à-vis raising the level of its image and national psyche in the eyes of the rest of the world. Unlike business firms however, the returns from satisfaction or utility derived are not in monetary terms but rather in psychic terms. Activities involved in space exploration moreover result in to economic growth by and large the forces of demand and supply. There is long run equilibrium between the national psychic propensity and output growth in our hypothetical Urania.

Resources allocated to space exploration sometimes have consequential effect on not only the

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psychological atmosphere in a space exploring economy but the ability or capacity of such an economy for utilization of its available capital. We noted earlier on in the previous section that sometimes when allocations to space exploration that are inefficient are made, a space exploring nation becomes *worse off* vis-à-vis sub-optimal outcomes resulting in a *vainglory effect* in terms of the operability of the national psyche (particularly with regard to space exploration) and concomitantly productive economic engagements. Where this effect i.e. the 'vainglory effect' occurs, there is the very possibility of a *psychological aversion* to space exploration setting in thereafter in such a nation. It might also leads to aggregate *disutility* derived from space exploration missions and hence, a negative expectation regime (in terms of national image and 'pride') in such country.[1] At the point where the collective expectations of the economic agents in our hypothetical Urania matched the psychological propensity of the government there, which is also the threshold, λ*, a Pareto-optimal solution is attained. Beyond that however, the *vainglory effect* take place. In other words or fundamentally, if the capital stock in a space exploring economy where a fraction of the output level is directed for it reaches a certain threshold limit, λ*, a pseudo-psychological illusion set in given the marginal social expectation level which is constant for this enterprise or endeavour - the exploration of outer space. Beyond this point, the marginal social expectation level falls to zero. The implication of this whole lot is that the higher the psychological aversion the economic agents are toward a country' space mission programme, the higher the magnitude of resource misallocation. Also the resources (machinery, human capital, finance) assigned to space exploration become dynamically inefficient, *ceteris paribus*. The reason is not far-fetched. Inasmuch as the level of national expectation determines the underlying psychological motive in the enterprise of space exploration, the inverse relation between the former and the latter reveals that to a lesser extent, this proposition indeed holds. Beyond that point or threshold, the inverse relationship sets in and the concomitant result is the *vainglory effect*.

Nevertheless, psychological propensity drive continues to be primary motive in space exploration though the dimension has changed considerably over the past three decades.[2] Let us now consider technological leadership and followership in our hypothetical system of planets and stellar constellations earlier on in Section 2. Planet C contains vast mineral resources for exploration and appropriation- activities which can be carried out by either country 1 or country 2 on planet B. Therefore the scaling down of exploratory activity by country 1 (assuming is the leader) for instance implies a gain or impetus for country 2 (*ab initio*, the follower) to venture into this terrain since it also have access to the same technological know-how as country 1 which once occupied the position of technological leader nation in space exploration. Considering the game-theoretic model, especially the pay-off matrix in Table 1 in section 4, it is certainly clear that country N_1 and country N_2 are better off with cooperation between them than noncooperation with 3,3 against 2,2.[3] This would definitely leads to higher payoffs in the exploration of outer space. That ultimately results in a *win-win* situation or scenario for all the participating countries. Moreover, given the implications of space technology there is the need to ensure continuous improvements and innovations in technologies dealing with space exploration as that would keep countries involved abreast in terms of advancement. Space exploration indeed adds to the GDP, hence it is a source of economic growth.

From our dynamic model, it is apparently clear that a country that plans to embark upon a space

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[1] Let us define the aggregate social utility for space exploration in our hypothetical Urania as $U(x)$where x is the national image or 'pride.' The equilibrium path however is attained when $U'(\cdot)>0, U''(\cdot)<0$. Moreover, if the social disutility of space exploration which is an incongruent reflection of the former in the *psychic space* is now designated as $\bar{U}(\cdot)$, the equilibrium is Pareto inferior at the point where $\bar{U}'(\cdot)>0$; $\bar{U}''(\cdot)<0$. Now or rather to this end, if the same human enterprise of space exploration creates or somewhat results in a social utility function which primarily underlies the *psychological propensity drive* culminating in an increased profile and expectation of the national image and 'pride' (or 'glory') in the eyes of the world is also capable of bringing about a social disutility vis-a-vis *psychological aversion* whereby a space missions programme is perceived as more or less a *vanity project* as a results of sub-optimal or inefficient resource allocations and decisions, a sort of *psycho- illusion paradox* possibly characterized endeavour such as space explorations, *ceteris paribus*. Nevertheless, this paradox can be understood to occurs at the point of inflexion, i.e. $U''(\cdot)<0$, $\bar{U}''(\cdot)<0$. The same enterprise or endeavour which bring euphoric national pride and enthusiasm can also brought about disillusionment if space missions are not handled with utmost care. A *Psychological Propensity Trap* may emerge or develops when the national image in the eyes of the rest of the world falls below the expected outcome. Nevertheless, space exploration for the nations involved means more or less a sort of *psychological capital investment* ultimately.

[2] This is because the space mission programmes of Russia and the United States had witnessed a decline in the past three decades most probably due to a shift in the psychological warfare between the two nations as evident during the Cold War. The space missions of Russia and United States were obviously driven by Cold War considerations in terms of national pride and the *deterrent doctrine* in strategic international geopolitics. One obvious and remarkable fact is that psychological expectations in terms of national image or 'pride' primarily drives the endeavour or enterprise of space exploration ab initio in the few space exploring nations such as U.S.A., Russia, Japan, China and India. Also important is the dimension of *interplanetary* and *galactic* space exploration.

[3]The international space station is an excellent example of how cooperation in space exploration should be undertaken by participating nations, though they remain competitors.

programme must as a matter of utmost importance have an adequate physical and human capital base and endowment to enable it execute such lofty ambitions or objective. Human capital endowments and base more than any other factor is very important in embarking on space missions or programmes. Though, there is a global flow of knowledge and technology dealing with this human endeavour, a nation's pool of qualified and well-trained manpower or labour force is germane or critical to the success of any venture of such nature. Spatial and temporal considerations, or time are what reveal how technology has diffused across nations as well as how the global economy allocates resources in achieving the goal of space exploration. Also, or equally important is the learning behavior pattern of nations participating in space exploration, though this may largely be influenced by historical factors than by political or economic reasons.[1] Moreover, given the asymptotically zero value of the real *per capita expectation* of citizens, $G_t(t)$ in our dynamic optimization model, it is imperative upon the governments of all nations that have embarked upon such ventures as well as those aspiring to, to seek a more proactive collective effort at the international level for more of such activities in outer space rather than pursuing it alone as it would always decline to zero in the long run. Private and commercial involvement especially in the international space mission could also be encouraged. This is because advances in rocketry and space propulsion systems are incentives for entrepreneurs in the space tourism business. Likewise is government behaviour via lessening of restrictions to the kind of technological know-how critical to space travel. Just as the initiatives of private firms such as Boeing, Lockheed, McDonnell etc accelerate the aviation business and industry, so likewise would the initiatives of private firms in the space industry accelerate travel outside the stratosphere in to outer space. One important fact is that the development of some allied or industries such as aerospace and military industries aid or help the development of space exploration mission in the nations that have engaged in this endeavour. Economic growth essentially results from the activities of firms involved in space exploration.

Another interesting point is the issue of space tourism. There is indeed a growing demand for space tourism. These are further heightened by the growth and development of private enterprises and new technologies in space tourism. Nevertheless, the conceptualization as well as the growth and development of space tourism signifies the attainment of the point in the exploration of space where the priority, emphasis and considerations have shifted from the *competitive* race for space dominion and scientific discoveries or investigations to the more *liberal* aspects of leisure in the heavenly realm.[2] Nevertheless, it is important to stress that space technology and expertise would most possibly thrive in a capitalist economy than a centrally planned economy because of the sheer restrictions and *sub-optimal* allocation of resources in the latter.[3]

One remarkable aspect in the realm of space exploration is technical progress or technological advancement. Technologies that are very important in space explorations include jet propulsion, rocketry, advanced integrated electronics and satellite communications and most of them have been developed far back in the 1950s and 1960s vis-à-vis the human capital base in the pioneering nations or countries.[4]

The rate of change of space technology must equal or approximately approach the discount rate parameter, ρ (in our dynamic optimization model) in order to offset the decreasing or diminishing effect of this technology. Nevertheless, the spin-offs from the growth and development of new space technology are indeed great and numerous and these all need to be harnessed for long term economic growth. Developments that

[1] That is most probably why nations such as India and China though developing or emerging economies have overtook some of the advanced industrial economies such as Britain, France, Germany, Japan and Canada in sending space probes to the Moon and interplanetary mission to Mars. However, a country like India with a large poor populace would not invest billions in space mission and exploration just for 'national pride' alone as it would definitely be the first beneficiary of advances from such space technology.

[2] The pioneering effort of businessman, Richard Branson in space tourism is indeed notable and worth mentioning. The private spaceship, *Virgin Galactic*, launched by his company which experienced hitches and subsequently exploded in 2014 would have marked the first attempt of sending the first set of six tourists in to outer space.

[3] China, one of the new entrants in the space age while governed by a communist government, allows a *laissez faire* market model in the realm of economic activity and engagements though retaining a firm grip on public life in this great Oriental nation. India, the other major new entrant been the world's largest democracy operates a free-enterprise market economy.

[4] The advancements in rocketry and consequently space probes can be traced to the V-2 Rocket Programme of belligerent Germany in the Second World War with both the former Soviet Union as well as the United States which are the conquering powers took some of those expertise to developed their space missions as well as their strategic missiles programme. Dr. Wernher von Braun who for instance was the space pioneer in the United States was from Germany. Nevertheless, the pioneer of the Russian space initiative was Konstantin Eduardovich Tsiolkovsky, whose centenary birthday, that is, 17 September, 1957 was planned to coincide with the launching of *Sputnik I* but which eventually took place on 4 October, 1957. A remarkable human capital base was highly involved in space exploration which was not limited to the Russians as other personalities such as Robert Goddard, Hermann Oberth, and Reinhold Tiling were also critical in many regards. Nevertheless, pre-eminent personalities such as Sergey Korolyov and Kerim Kerimov were the brains behind the exploits of the Soviets in the early days of the space exploration. Several years and decades of investments in human capital development in these countries must have preceded the exploits of these pioneers and expertise in space exploration missions and projects.

emanate from investment in space exploration for example results in the first set of weather or meteorological as well as communication satellites were as a result of such activity. The spin-offs from space exploration include the development of navigational satellites, weather forecasting and new technologies. One last issue or problem resulting from space exploration is the huge mass of space debris or junk now in the atmosphere as a result of the activity of hundreds of communication satellites and space probes and other orbiting platforms in outer space. These fundamentally introduce obvious costs in space exploration. In other words these space junks create the new dimension of space exploration externalities and safety policy for governments and other international agencies actively involved in the business of space exploration. No doubt the space debris would create problems and difficulties for further and conceited efforts at space exploration in coming decades. These space junks obviously create economic and financial costs for nations involved in space exploration.

6. Concluding Remarks

Though there might have been economic analyses on space exploration projects by space agencies of nations involved in this human enterprise, this paper presented in a simple exposition the dynamics and economic analysis of space exploration and may perhaps set the stage for the formalization of the theory of *Astroeconomics* as a field of study in economic science. Astroeconomics or Empyrean Economics as a new theoretical vista is essentially conceptualize as the *Political Economy of Space Exploration* which might possibly identify some of the fundamental problems in the business of exploring outer space in line with the underlying principles of economic analysis. In other words, it is the economics of the heavenly firmament. It is expedient to note that it represents a possible break from conventional economics in the area of conceptualization as well as application of economic theory to a given problem. This might probably be the most obvious branch of economic science whose macro aspect basically encompasses the whole global economy as opposed to the traditional strands of macroeconomics which deals with a national economy.

Psychological propensity motive have been seen to be the primary force driving the whole enterprise of space exploration in many nations of the world. An atmosphere of huge presence of it in a nation inspires commendable push or direction on the path of space exploration. It also ultimately sustains a country's path or trajectory in the enterprise of space exploration. Nevertheless the behaviour of economic agents – space industry firms and governments in the exploration of outer space is definitely the focus and principal concern of astroeconomic theory. The construction and conceptualization of the economic considerations involved in space exploration in this paper is not meant to be a *pons asinorum* lately in economic science. The issues and problem of mankind's quest for the explorations of the vast frontiers of the universe have been pursued over the past few decades through the space mission programmes of several nations in outer space. Economic growth results from the enterprise of space exploration. In concluding, it is worth noting that the field of Astroeconomics or Empyrean Economics while possibly offering great possibilities no doubt would have its own challenges, difficulties and promises. Whether it would possibly influenced public policy in space exploring nations and prospective new entrants cannot be ascertain here. Nevertheless, it is meant to be and evolve as a theoretical and practical field of inquiry vis-a-vis thorough investigations as oppose to *conceptual idealization*. The latter is never intended or envisaged. Finally, the simple theoretical postulates of space exploration examined and appraised in the light of economic analysis might perhaps turn out some day in to empirically verifiable results though that is not our task or intention in this paper.

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