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EXPLORING THE SPACE ECONOMY

The present and future of capitalism beyond our planet

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About the author

Rainer Zitelmann studied history and political science. In 1986, he was awarded a PhD for his thesis *Hitler's National Socialism*; in 2016, he was awarded his second doctorate, this time in sociology, with his thesis on the psychology of the super-rich (*The Wealth Elite*). He has written and edited a total of 30 books, which have been translated into 35 languages.

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Summary

- The Space Economy is defined by the OECD as 'activities and use of space resources that create value and benefits for humanity in the course of exploring, researching, understanding, managing and utilizing space.'
- The value of the Space Economy in the early 2020s was somewhere between $370 billion and $470 billion (depending on how you count it), with satellite navigation and communication accounting for the lion's share. It employed around 400,000 people. These figures are projected to grow rapidly.
- The Space Economy is no longer primarily about government research and defence projects. Private enterprise and commercial projects now account for the bulk of it.
- One of the most important consequences of the growing involvement of private companies has been the dramatic reduction in costs, especially of satellite production and rocket launches. Under the old, state-centric model, there was little incentive for cost-cutting innovation, since government agencies would simply pick up the tab whatever the cost.
- The old state-dominated Space Economy was often overtly politicised, with too many contracts awarded on nakedly political grounds (e.g. biased towards swing states and election years), and abrupt swings in priorities after changes in government.
- Limited forms of asteroid mining, i.e. the extraction of valuable resources from asteroids, are already technologically

feasible, and may become economically feasible too in the future. This might require some legal clarifications, namely, defining some form of private property rights in outer space.

- In the West, the Space Economy is being held back by a form of 'Space NIMBYism', where opponents use public consultations to weaponise regulatory constraints. As one publication puts it, 'Opponents of progress understand they can "paper" a project to death in America.'
- In the 19th and early 20th centuries, early forms of space exploration, namely, the building of space observatories, were typically privately financed and organised. In a sense, the state-dominated Space Economy of the mid-to-late 20th century was the exception, and the recent rise of private space entrepreneurs can be seen as a return to the historic norm.

Foreword

The Space Economy is a new frontier in economics. It is the extension of economics into outer space.

Thus far, it was our implicit understanding that 'economics' only applies to activities that happen on the surface of planet Earth and that the rest of the universe is an 'extra-economic' area. But the realm of economics expands with our technological possibilities. Adam Smith and David Ricardo never wrote about spectrum auctions because, even if they had known about the concept of 'the radio spectrum', it would not have occurred to them to think of it as a scarce resource. 'Radio spectrum economics' only became a thing when we discovered technologies that made use of the spectrum, and when it turned out that when different people try to use the same frequency within it, they get in each other's way. Thus, we suddenly had to ask ourselves questions such as: How do we assign usage rights to different parts of the spectrum? Who can hold such rights, and how can they be transferred? What is the nature of those rights: are they like permanent property rights, like a long-term lease, or like a short-term rental contract?

Similarly, most of what we consider 'natural resources' today were not really 'resources' until we found industrial applications for them. Once we did, we suddenly needed answers to questions such as, if I discover an oil field on your land, who owns it? Is it you, because it is underneath your land? Is it me, because I discovered it? Or is it neither of us? Does it belong to 'the community', and if so, who exactly is that community?

In the 1960s, we get the first international treaties trying to establish some ground rules for the governance of outer space. To call this the beginning of a 'space economy' would be a stretch. Unsurprisingly, given the context of the time, the treaties were more concerned with intergovernmental relations, and especially military matters, than with economics. But we can see some germs of economic thinking.

For example, Article VIII of the Outer Space Treaty 1967 clarifies that property rights that are valid on Earth remain valid in outer space. A Soviet satellite in space remains property of the Soviet Union, and if it somehow ends up in American custody, it has to be returned to its rightful owner:

> Ownership of objects launched into outer space, including objects landed or constructed on a celestial body, ... is not affected by their presence in outer space ... or by their return to the earth. Such objects ... found beyond the limits of the State Party to the Treaty on whose registry they are carried shall be returned to that State Party, which shall, upon request, furnish identifying data prior to their return.

Article VII establishes liability. If, for example, an American satellite crashes into a Soviet one, or on Soviet territory, and causes damage in the process, the American government is liable for that damage:

> Each State Party to the Treaty that launches ... an object into outer space, including the Moon and other celestial bodies, ... is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object ... on the Earth, in air space or in outer space, including the Moon and other celestial bodies.

Perhaps most relevant, the treaty ruled out sovereignty claims by any signatory country over celestial bodies and propagated

open access, which, by extension, rules out private ownership rights by citizens of a signatory country as well. This made sense at the time, when the possibility for economic use of resources in outer space was remote, and staking out a claim would have served no useful purpose. Today, though, some forms of asteroid mining are, in principle, already technologically feasible, even if they may still be some way away from economic viability. Once this changes, an 'Outer Space Enclosure Act' might become necessary.

The Space Economy is still in its early stages, but it is no longer the realm of science fiction literature. It is at an advanced enough stage to merit attention from an economics-focused think tank, even if it is not yet sufficiently advanced for the sort of think tank report that advocates bold, radical policy recommendations. Systematic research into the subject has only really begun in the last few years. A literature review that summarises the state of that research is the publication format that seems most appropriate at this stage.

The present review of the literature on space economics by Dr Rainer Zitelmann has to be the most comprehensive one of its kind to date. The first thing that readers will notice, just by a quick glance at the bibliography, is how new this field of research really is: the 'oldest' of the publications discussed here is from 2017, while most are less than two years old.

The second thing that springs out is how much of the Space Economy is already happening here and now. Thus, the literature on the Space Economy is not just speculation about the future; it is, in fact, possible to write about the subject without mentioning the future at all. It is possible to write about it in a way that looks more like a dry industry report rather than a futurist manifesto, no different in principle from a report on recent developments in

the pharmaceutical or the wood-processing industry. (Although that is not the form the literature actually takes.)

Thirdly, and perhaps most interestingly for IEA readers, despite the novelty of the field, a few themes that will look familiar to classical liberals quickly emerge.

To the extent that the issue of space exploration pops up in our economic policy debates at all, it often does so in the form of attacks on free-market economics. The book *Mission Economy* by Mariana Mazzucato, the guru of state-led industrial policy, is subtitled 'A Moonshot Guide to Changing Capitalism'. 'Moonshot' is a reference to the Apollo space flight programme, which, in Mazzucato's world, illustrates the superiority of activist government over laissez-faire. Going further back, the fact that it was a socialist state (the USSR) which launched the first satellite (Sputnik) was a major symbolic victory for proponents of a planned economy. It still plays a role in folk memory today. If we take a longer-term perspective, though, these apparent successes of state-led space exploration are the exception rather than the norm.

For a start, space exploration did not begin in the second half of the 20th century. It is just that before then, it meant observatories and telescopes rather than satellites and space rockets. Much of that early research was privately funded and organised, so, in one sense, we can see the recent emergence of private-sector space entrepreneurs as a return to a historic norm rather than a fundamentally novel phenomenon.

The early successes of government-led space exploration were not sustained. After a few spectacular breakthroughs, space exploration all but stalled for many decades. Its current revival has much to do with private initiative and entrepreneurship, and it is happening in ways that will feel familiar to IEA readers.

We cannot know what the Space Economy of the future will look like. But we can already say that if it is to succeed, it will look neither like a planned socialist economy nor like a state-directed corporatist one. It will have substantial elements of 'Space Schumpeterianism'.

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Space Economy
Simonetta Di Pippo

The book ***Space Economy. The New Frontier for Development***, published in 2023 by the astrophysicist **Simonetta Di Pippo**, former Human Spaceflight Director of the European Space Agency (ESA), is one of the most useful introductions to the Space Economy. It is an excellent resource for anyone who is exploring the subject matter for the first time. The OECD defines the Space Economy as 'the full range of activities and use of space resources that create value and benefits for humanity in the course of exploring, researching, understanding, managing and utilizing space' (Di Pippo 2023: 10). Various estimates suggest the value of the Space Economy reached USD 370 to 470 billion in 2021 (Di Pippo 2023: 10-11), with satellite navigation and communication accounting for the lion's share of this figure. However, the correct figure is probably closer to the lower end of this range. According to these estimates, around 400,000 people were working in the space industry in 2022 (Di Pippo 2023: 130). Looking ahead, the Bank of America projects that the space industry will be worth USD 1.4 trillion by the year 2030 (Di Pippo 2023: 12).

But this is just the beginning. The author emphasises the wide-ranging importance of the space industry:

> From agriculture to public health, from education to disaster management, from smart cities to the growing need for water and food for a population that is also growing on a global scale, from tapping alternative energy sources to monitoring the seas; we are progressively becoming a space-based society … Space,

> therefore, represents today's new frontier and the backbone of tomorrow's economy (Di Pippo 2023: 19).

What was once confined to the realm of science fiction is now partly reality. As the physicist and science fiction author Arthur C. Clarke wrote back in 1977: 'The impact of satellites on the entire human race will be at least the same impact as the advent of the telephone in so-called developed societies' (Di Pippo 2023: 39).

Satellite mega-constellations such as Starlink, OneWeb, Kuiper, and Sat Net will ensure that the third of the world's population that does not currently have access to the internet will soon be connected – with far-reaching economic implications.

While military applications are of course important, the Space Economy is today dominated by private enterprise: '… if we analyze the space market from a customer-type perspective, 82% are commercial, 9% are government or civilian, and 9% are defense-related' (Di Pippo 2023: 47).

In recent years, the terms *new space* and *old space* have gained traction. *Old space* typically refers to state-funded endeavours, whereas the *new space* sector is dominated by commercial activity and an increasingly entrepreneurial approach (Di Pippo 2023: 65).

What are the next logical steps? While still a futuristic dream, the potential value of extracting resources such as gold and platinum from Psyche and other asteroids is estimated to be around USD 10,000 quadrillion (Di Pippo 2023: 78). However, more recent studies have concluded that this figure is probably a massive overestimation. Nevertheless, the extraction of raw materials, including rare earth elements, from the Moon and asteroids is expected to become increasingly important in decades to come.

In the future, there could be a 'Lunar Economy' and a 'Martian Economy' (Di Pippo 2023: 102-103), and missions to the Moon and Mars will presumably – as in the 1960s – spark a surge of interest in STEM subjects among young people, ultimately benefiting the entire economy (Di Pippo 2023: 103 & 127). Products such as optical fibre are already being produced on the International Space Station (ISS), but in future 'Made in Space' will become an important economic driver, for example in the fields of medicine and pharmaceuticals (Di Pippo 2023: 119-126).

The Space Economy
Chad Anderson

Chad Anderson, author of the 2023 book ***The Space Economy*** and founder of the US investment firm Space Capital, estimates that 'Over a quarter of trillion dollars has been invested into nearly two thousand unique space companies over the past decade alone' (Anderson 2023: xx).

CNBC has called space 'Wall Street's next trillion-dollar industry', and according to a study by the World Economic Forum in April 2024, the Space Economy is expected to be worth USD 1.8 trillion by 2035. Morgan Stanley expects a space-based business to create the world's first trillionaire (Anderson 2023: xi).

In his book, Anderson showcases a range of cutting-edge companies, including Planet Labs, a San Francisco-based company that specialises in the development of miniature satellites known as Doves. These satellites are equipped with powerful telescopes and cameras, allowing them to capture images of various parts of the Earth's surface at regular intervals. Each miniature satellite is programmed to continuously scan the Earth and transmit data to ground stations as it orbits overhead.

The images collected by the satellites provide information that is crucial for various applications, such as climate and environmental protection, forest monitoring, crop yield prediction, water quality assessment in lakes and disaster management.

Whereas in the past satellites were as large as school buses – which led to considerable transport costs –, the Dove satellites are the size of a shoebox and can be launched into space at a much lower cost.

Figures on the number of satellites in orbit confirm the explosive growth of the Space Economy:

> In 2010, 74 satellites were launched into space. Ten years later, the Satellite Industry Association reported nearly 1,200 – a 16-fold increase – and projected rapid growth from there. As of this writing, there are well over 4,000 active satellites in orbit, with estimates of as many as 100,000 more in the decade to come (Anderson 2023: 188).

The rapid pace of development is evident when comparing the data presented in Anderson's book, which was published in 2023, with more recent data: As of November 2024, more than 13,000 satellites were orbiting the Earth, of which around 10,200 were operational. Many of the active satellites are part of the Starlink programme operated by Elon Musk's company SpaceX, which had transported a total of 7,149 Starlink satellites into space by October 2024.

But space, Anderson points out, is developing into a 'hot market', and it is important to distinguish between the areas where real money is being made today and what will only be feasible the day after tomorrow (such as asteroid mining). 'Nearly all equity investment into the Space Economy over the past decade has been made in Satellites and Launch' (Anderson 2023: 185). Anderson also identifies Stations, Lunar, Logistics and Industrials as four emerging industries in the Space Economy. These projects are exciting and attract a disproportionate amount of media coverage compared to satellites, for example.

> Over the past decade, a relatively minor USD 2.7 billion has been invested across all four. However, while most investment capital in the Space Industry has gone toward satellites and launch, we are beginning to see founders raise capital and build businesses around ambitious new directions ranging from commercial space stations to Lunar transportation services (Anderson 2023: 47).

Elon Musk's colossal Starship, which is designed to carry crew and cargo to Earth orbit as well as the Moon, Mars and beyond, is poised to revolutionise space travel. 'With the ability to carry 100 tons that fit within 1,100 cubic meters for essentially the cost of fuel alone, Starship will completely change how we operate in space' (Anderson 2023: 184). Of course, it is an exaggeration to say that Starship will do all this for 'the cost of fuel alone', but Elon Musk has indeed succeeded in drastically reducing costs through the reusability and series production of rockets. According to the German space expert Eugen Reichl, 'SpaceX currently builds about 6-8 first stages per year, about 120-140 second stages and about 250 Merlin engines per year. In comparison: At its peak, ArianeGroup only managed to build around seven Vulcain engines per year.' And this is just the beginning!

Musk's Starship, Anderson is convinced,

> will change everything: Starship will further remove the barriers to entry and stimulate the development of entirely new applications. Space exploration has stagnated for decades. Today, commercial capabilities are quickly outpacing those of governments (Anderson 2023: 19-20).

Musk has also changed – at least for his company – the nonsensical rules of the game when it comes to government contracts, which in the past led to such high costs. Anderson describes the cost-plus system that was prevalent before Musk arrived on the scene as follows:

If NASA wanted a rocket or satellite built, it went to a small group of defense contractors and paid one of them a vast sum of money to go build it according to a fixed set of specifications. These were known as 'cost-plus' contracts. The contractors figured out pretty quickly that they could make more money by dragging things out than by getting the job done on time and under budget. If they spent years and billions working toward a critical objective without much progress, they could go back to the trough for more money: 'This engineering stuff is tougher than we'd expected,' they'd tell the bureaucrats. 'We need two more years and X billion more dollars to finish the job' (Anderson 2023: 17).

To Infinity
Raphael Roettgen

A third general overview of the Space Economy dates from 2024: ***To Infinity. The Space Economy & How You Can Participate*** by **Raphael Roettgen**, founder of the investment firm E2MC.

As Roettgen explains, the Space Economy encompasses a wider range of categories than most people realise. In addition to companies that focus on producing rockets (launchers) or manufacturing satellites, there is a distinct sector known as 'remote sensing', which involves the space-based collection of Earth observation data and is of major importance to business, science and the military. This is a particularly attractive sector for start-ups because, unlike futuristic endeavours such as asteroid mining, money can be earned right here, right now. The same applies to the fields of satellite communications and satellite navigation, which already play a crucial role in modern society and have a positive impact on the everyday lives of individuals and the overall economy.

Then there are companies that specialise in conducting scientific experiments in space and others that go as far as manufacturing products in space, doing so because the special conditions found in space (most importantly, weightlessness) allow interesting use cases and cannot be easily replicated on Earth. Finally, there is the field of space tourism, which many experts predict will have a great future as soon as costs decrease.

Reducing costs is undeniably one of the most significant outcomes of the growing involvement of private companies.

While the exact extent of the cost reduction is difficult to pinpoint, it is clear that there has been a substantial decrease. As such, it is realistic when Roettgen writes:

> These days, an uncrewed payload flight to Low Earth Orbit (LEO) on a SpaceX Falcon 9 costs between fifty and sixty million dollars. Since the vehicle has a maximum payload capacity of over twenty-three tons (but usually carries less, in part because extra propellant is needed to bring back the first stages), the price per kilogram (2.2 pounds) of payload is less than USD 3,000 (Roettgen 2024: 26).

Other rockets, such as the European Ariane 5, which was retired in July 2023, cost well over 10,000 dollars per kilogram of payload. 'Although SpaceX does not publish figures regarding its own costs, it can be estimated from various data points that the Falcon 9 rocket probably costs less than half of what SpaceX's end customers pay' (Roettgen 2024: 27). SpaceX probably orients its pricing strategy to align with its next cheapest competitor.

The author believes that launch costs as low as USD 1,000 per kilogram will soon be achievable, representing a potential reduction of around 90% compared to the previous standard in public-sector space travel prior to the emergence of private space flights (Roettgen 2024: 28). This substantial decrease in costs is projected to open up new opportunities for business models within the space industry that were previously considered unprofitable. As a result, demand for transportation options is expected to surge, which will in turn drive further cost reductions and foster a positive cycle of decreasing costs and an expanding space industry.

SpaceX, for example, frequently launches a number of satellites into space at once and releases them all at the same location, which is not always where they are actually needed. These shared flights are part of SpaceX's ride-share programme, which gives

smaller satellite providers more affordable access to space but little opportunity to determine exactly where their satellites are deployed. Until now, it has taken a long time for the satellites to reach their final target orbit. Recognising this challenge, companies have begun developing micro-launchers – smaller rockets that launch satellites at the exact time and place that the customer wants. Additionally, new business models have emerged, including so-called 'space tugs', which are modelled on tugboats pulling barges on rivers. Also known as orbital transfer vehicles, these space tugs transport satellites to their intended destinations in space.

Other companies are working on building the equivalent of orbiting gas stations to provide a means of refuelling satellites or rockets that have run out of propellant. And, of course, there are also business models that hope to generate money in the more distant future, such as constructing data centres in space or asteroid mining.

The author presents a wide array of business ideas, some of which are already earning a lot of money today, others – perhaps – only in the distant future. The beauty of capitalism is that, unlike government-funded space programmes, which usually only select and finance a few large and very expensive projects, capitalism gives rise to thousands of companies and ideas. While many will fall by the wayside, some, like SpaceX, have the potential to revolutionise entire industries in ways that state-owned enterprises cannot. Wherever there is a problem, there are creative companies developing solutions and business models. For instance, the issue of space debris is becoming increasingly problematic, and new methods need to be devised for its disposal. Entrepreneurs are simply more adept at developing innovative solutions to problems than government-run entities. However, this does not mean that public-sector space programmes such as NASA will become obsolete. These programmes will continue to play a crucial role in basic research and serve as clients and partners for private space companies.

The Cosmos Economy
Jack Gregg

In contrast to the three books by Di Pippo, Anderson and Roettgen, **Jack Gregg**, an adjunct professor of management, explores the long-term potentials of the Space Economy in his 2021 book, ***The Cosmos Economy: The Industrialization of Space***:

> Most of the current commercial space activities center on ventures in Low Earth Orbit (LEO) such as imaging, communication, data analytics, and the launch services that move payloads into space. But today's commercial space activities are decidedly a short-term prospect. My focus is a much longer term. Space settlement, whether on Mars, our Moon, or somewhere cislunar (located in space between the Moon and Earth), is a long-term engagement … (Gregg 2021: 4-5).

Like the other authors, Gregg believes that now – as well as in the future – the Space Economy will be dominated not by government space programmes, but by private enterprise. While private companies do also receive contracts from NASA, something decisive has changed:

> The intersection of public space programs and private space companies has shifted control of space from government-backed space agencies like NASA to private providers like Blue Origin and SpaceX seeking to set their own agenda and who wish to establish their own priorities about space sector economic development. Instead of putting NASA projects at the top of the priority list, private companies have taken the upper hand and established where space activities are going based

> upon their own business strategies and profitability targets. They have also set a more rapid pace of implementation that has proven cheaper and faster to market than the old bureaucratic process typified by NASA (Gregg 2021: 118).

Private investment in the space sector has come to dominate: most of the money invested in commercial space ventures (77.1%) comes from private (non-governmental, non-tax) sources (Gregg 2021: 66-67). A cursory glance at the number of rockets launched in recent years confirms that the private company SpaceX dominates across the board, having launched more rockets into space than all the countries in the world combined. In 2024 there were 134 SpaceX launches out of 261 space missions worldwide. If SpaceX were a country, it would by far surpass the second-largest country in the world, China, with its 68 launches. SpaceX has carried out 86% of all US launches and placed more than 80% of the world's total payload weight into orbit or beyond.

The author is optimistic that asteroid mining and space manufacturing will prove successful in the long term (Gregg 2021: 145-158). At the same time, he believes that the conquest of space will not primarily be carried out by astronauts, i.e., humans, but by robots:

> The use of robots to build structures and infrastructure raises the question of why people are needed in space at all. If the purpose of establishing a space outpost is for purely industrial reasons, then most of the labor-related activities can be delegated to robots or some other automated process. The role of human managers would be to monitor robotic activities, make corrections, and initiate periodic maintenance via teleoperation (Gregg 2021: 31).

As Gregg points out, this could not be accomplished from Earth given the long distances that radio waves would need to travel to Mars, for example.

> The indirect overhead expenses of furnishing livable workspace, safety concerns, and other expenses make human labor in space prohibitive. It's no wonder that employers would prefer robots over human workers. Further, humans tend to work between 40 and 60 hours a week on average, whereas robots can work non-stop 168 hours in a week (7 days x 24 h) and don't need special housing, food, air, bathrooms, entertainment, vacation time off, paternity leave, a corner office with windows, or other ancillary human-centric expensive enhancements (Gregg 2021: 51).

According to the author, one significant challenge facing industrial production in space is the 'down to earth-problem' (Gregg 2021: 63-64). Contrary to popular belief, it is both more expensive and more complex to transport cargo from space to Earth than vice versa.

> Significantly, until this critical technical glitch is solved, the vector of the space economy will aim away from Earth and point instead to serving budding markets in the new off-Earth space-based economy. This shift will cause the space economy to adjust itself to best serve itself. In this setting the products and services that will be manufactured in space will be designed to satisfy the specific demands of space-based customers and consumers instead of targeting the broader (and more profitable) consumer base on earth (Gregg 2021: 64).

Space Mining and Manufacturing
Davide Sivolella

There is a wealth of literature available on the topic of space mining and manufacturing. One of the most renowned works in this field is *Mining the Sky* by John S. Lewis, Professor of Planetary Sciences, first published in 1996. Lewis also authored a more recent study, *Asteroid Mining 101: Wealth of the New Space Economy*, which was published in 2015. The best overview is provided by *Asteroids. Prospective Energy and Material Resources*, a collection of essays edited by Viorel Badescu and published in 2013. The most recent study, ***Space Mining and Manufacturing. Off-World Resources and Revolutionary Engineering Techniques*** by **Davide Sivolella (2019)**, focuses on innovative techniques and technical challenges associated with space mining.

'The demise of the Apollo program, which ended after only six trips to the surface of the Moon, was due to the absence of a compelling reason for such missions,' explains Sivolella (2019: 155). Accordingly, one section of his book is called 'The Road to a Worthy Space Program' (Sivolella 2019: 154-155).

All of the authors agree: Asteroids not only represent a potential threat to humanity; they also offer great opportunities. Current estimates suggest that there are between 700,000 and 1,700,000 asteroids in our solar system with a diameter of at least 1 kilometre. The majority of these asteroids are located within the asteroid belt between Mars and Jupiter. However, there are

also approximately 34,000 known near-Earth asteroids (NEAs) – and around 2,000 to 3,000 more are discovered every year. Some of these can be a threat; others present valuable opportunities.

The media sometimes covers stories about asteroids, such as Psyche, a celestial body with a diameter of 250 kilometres, larger than the area of England. The value of this asteroid has been estimated at up to 700 trillion dollars due to suspected large deposits of precious platinum-group metals (PGMs). However, some scientists have recently raised doubts about these estimates. And of course, these prices could never be achieved if the market were flooded with large quantities of such metals. We will know more in 2029 when NASA's Psyche probe, launched in October 2023, reaches the asteroid with which it shares its name.

The fact is, however, that valuable raw materials such as PGMs are found in much higher concentrations on some asteroids than on Earth. We know from the analysis of meteorites that the concentration of PGMs, at 6 to 230 ppm, can be many times greater than those found in the Earth's crust. This is because most asteroids never experienced the 'differentiation' that took place on planets such as the Earth. Differentiation is the process by which heavier materials, such as metals, gravitate towards the core of a celestial body, while lighter materials, such as silicates, form the outer layers.

As soon as you start to discuss the topic of asteroid mining, you quickly realise that there are many common misconceptions. One is the belief that asteroids are too far away, that the distances are too great. However, leading expert John S. Lewis estimates that there are around 3,800 NEAs that are more accessible and require less fuel to reach than the Moon.

You also often hear that the cost of transporting extracted raw materials is so high that mining them makes no economic sense.

Of course, this is partly true, but it misses the point. Experts such as Lewis argue in favour of using the raw materials mined from asteroids in space. For instance, numerous asteroids contain water, which can be harvested and separated into hydrogen and oxygen to serve as rocket fuel. Raw materials from asteroids can also be used to build space stations or large solar panels in space.

Furthermore, thanks to the emergence of private space travel, the cost of transporting materials into space has fallen dramatically. And these developments have a significant impact on the profitability of asteroid mining.

Movies like *Armageddon*, which shows Bruce Willis and his team bringing super-heavy drilling machines onto an asteroid, have distorted the way we think about these celestial bodies. In fact, many asteroids are nothing more than flying piles of rubble, the material barely sticking together due to an almost complete lack of gravity. In many cases, crushing rocks with heavy equipment is not even necessary. On the contrary, the real problems lie elsewhere, such as dealing with the challenges of landing on small piles of rubble or finding a way to securely anchor a spaceship or mining equipment. These tasks are more feasible on larger asteroids.

And when mining starts, there's also the problem of materials floating off into space due to the lack of gravity. But there are solutions for that, too. The cable-cutter bag principle, developed by NASA in the 1990s, aims to efficiently collect material from asteroids. A net or bag is stretched over the asteroid's surface, using cables and cutting devices to enclose and secure rock samples. This method allows for the controlled and safe collection of samples without complex anchoring or drilling mechanisms, which is particularly advantageous in microgravity. The strength of Sivolella's book is that it describes these techniques in detail

and provides a clear overview of the technical challenges and possible solutions for asteroid mining.

Some people also argue that the legal framework for asteroid mining is inadequate, but this is also only partially true. Yes, the Outer Space Treaty of 1967, which has been ratified by 116 nations, does prohibit the ownership of 'celestial bodies' (although the term is not clearly defined and there is debate among legal experts as to whether it includes smaller asteroids). In contrast, the US Commercial Launch Competitiveness Act of 2015 does allow Americans to engage in the commercial exploitation of space resources. Luxembourg has a similar law.

Several companies are currently engaged in the field. One company, AstroForge, is planning to launch a 200-kilogram spacecraft to an asteroid in 2025 to analyse its composition. Other companies, such as Karman+, are pioneering the technique of optical mining, which uses directed sunlight to heat and break down rocks in space. This would allow valuable resources such as water and metals to be extracted from asteroids.

Asteroid mining is still in its infancy but has the potential to become a reality over the next few decades, especially as it is far too expensive to transport large quantities of propellants and other materials into space, even as costs continue to plummet. 'On-site' production therefore makes much more sense.

Red Moon Rising
Greg Autry and Peter Navarro

However, this lies in the distant future and will probably only become relevant in decades to come. Back to the here and now and the key takeaways from the book ***Red Moon Rising*** by **Greg Autry and Peter Navarro** (2024). Autry was a member of the NASA Agency Review Team for the Trump administration in 2016 and also served as a temporary liaison to the White House at NASA in 2017; Navarro also worked for the first Trump administration, including as Director of Trade and Manufacturing Policy. The first space race was between the Soviet Union (USSR) and the United States. This competition indirectly showcased the superiority of capitalism, despite both countries funding their space programmes via state resources. Thanks to its economic superiority, the capitalist United States ultimately had more resources and greater innovative strength, allowing it to emerge victorious in this race.

But the second space race, between China and the United States, has already begun. And this time around, the stakes are even higher: the competition extends beyond the mere prestige of being the first to reach a destination or demonstrate ideological superiority. It now encompasses tangible economic and military interests. And above all, what sets this race apart from the first is that this time the private sector will determine the outcome.

Autry and Navarro's book serves as both a wake-up call and a reminder of the importance of space exploration, not only for the economic prosperity of the United States but also for its national security. According to the authors, the Moon landing on 20 July

1969 was a remarkable feat, but it would never have been possible without the fierce competition between the USSR and the United States. However, following the United States' victory in the first space race, the authors argue, there was a total absence of clear objectives in the nation's space policy.

These lost years of manned space travel are symbolised by the Space Shuttle, which failed on every level: 'NASA expected to fly shuttles every two weeks and told Congress that each mission would cost only $10 million. Payload costs were to be as low as $100/lb ($250/kg) in 1972 dollars' (Autry & Navarro 2024: 109). But NASA never even came close. Instead, the authors estimate that each flight cost about USD 1.5 billion, and instead of flying every fortnight, the space shuttle never flew more than nine times a year. In the wake of the Challenger and Columbia disasters, the Space Shuttle programme was completely grounded for several years.

> Nearly everyone in the space community has been frustrated by the lack of substantial progress in space since the demise of Apollo. Today, a few bold dreamers are doing something about that. Free markets and entrepreneurship are America's real space weapons (Autry & Navarro 2024: 122).

The authors repeatedly highlight the fact that China has recognised the critical role that space plays in both economic and military domains and provide numerous examples to support their assertion. However, they note, 'We will not beat China at socialism by running a centrally planned governmental space race' (Autry & Navarro, 2024: 137). And add: 'Winning the second space race is all about the private sector. We won't beat China in a competition of large governmental programs; commercial space is America's best weapon' (Autry & Navarro 2024: 180). China's main weakness remains its lack of creativity and innovation – and these qualities cannot be mandated by

the state; they can only flourish in a capitalist system (Autry & Navarro 2024: 137).

While this is true in principle, China has been closely monitoring Elon Musk's success in the space industry, and space exploration in China is no longer exclusively state-controlled: there are now over 400 private Chinese space companies striving to emulate the success of private space companies in the United States. It remains to be seen whether state intervention will continue to dominate Chinese policy, as has been increasingly evident in recent years, or if private space companies will be given more freedom to operate.

This makes it all the more important – as the authors rightly argue – that the bureaucratic hurdles in the United States that hinder the development of private space exploration be radically dismantled. The red tape that preceded the test flights for Elon Musk's gigantic Starship rocket is a prime example:

> When SpaceX submitted its launch application, the FAA received 18,000 public comments on the environmental impact. Respondents worried about everything from bird reproduction to Civil War artifacts. Processing these consumed resources, money, and time. Opponents of progress understand they can 'paper' a project to death in America, but regulatory delays and public concerns will not delay China's Starship clone (Autry & Navarro 2024: 169).

Private companies such as SpaceX also secure government contracts in the United States, albeit at a significantly lower cost compared to traditional government programmes. After Musk's first three rocket launches failed, he was successful with the fourth launch of the Falcon 1 in 2008 and was subsequently awarded a USD 1.6 billion contract with NASA to provide twelve resupply flights to the ISS. 'Most of the funds invested into the SpaceX Falcon 9 rocket and Dragon capsule would come from

private sources. It would be by far the least expensive and most effective space launch program that NASA had ever participated in' (Autry & Navarro 2024: 143). In fact, it was even better than the authors write: the money from the contract, which was intended to cover the firm's initial costs, was enough for SpaceX to complete the entire development!

According to Autry and Navarro, space exploration needs clear goals: it is not merely about planting a flag and leaving footprints on the Moon and then Mars, as was the case with the first Moon landing programme, but about establishing a permanent presence on the Moon and Mars. And, if the United States does not do it, the authors warn, the Chinese certainly will.

Dark Star: A New History of the Space Shuttle
Matthew H. Hersch

Although the US Apollo programme was successful, this was followed by a period often referred to as the 'lost years' of manned space flight. In particular, the aforementioned Space Shuttle programme is worth noting here. The US space shuttle programme burned through almost USD 200 billion over the course of the three decades from 1981 to 2011, but failed to live up to expectations.

According to **Matthew H. Hersch,** Professor of the History of Science at Harvard University in his 2023 book ***Dark Star: A New History of the Space Shuttle***, this was not due to any technical failings or management errors but rather stemmed from 'the shuttle's design and its fundamental lack of purpose' (Hersch 2023: 7).

The book's devastating conclusion: 'By every measure, the shuttle had fallen short of even the modest hopes that had surrounded it. And the shuttle remained flying only because every effort to replace it with a better-winged, reusable craft also failed' (Hersch 2023: 7).

Many at NASA and within the US Air Force were not convinced by the concept of a 'jack of all trades' spacecraft that took off like a rocket and landed like a plane. The whole idea of building such a spacecraft with wings, even though they were a hindrance for most of the journey and only needed for landing, failed to garner

widespread support. Ultimately, the Space Shuttle was a political compromise that was intended to satisfy a large number of frequently conflicting interests and requirements (Hersch 2023: 74). The shuttle was expected to fulfil a range of tasks, including:

- as a carrier for scientific satellites
- as an orbital laboratory
- as a craft to service space stations and interplanetary ships
- as a delivery vehicle for commercial payloads
- as a tool of diplomacy and international cooperation
- as a military spaceplane.

As Hersch explains, many of these functions could have been accomplished without the need for a manned spacecraft. And given that all 14 astronauts died in the Challenger accident in 1986 and the Columbia accident in 2003, the author also questions whether it was appropriate to expose people to such risk when almost all of these tasks could have been performed more cheaply and with less risk by unmanned spacecraft.

As Hersch also points out, the costs were much higher than expected: each flight cost an estimated USD 500 million, which was similar to the cost of Apollo-era launches. Carrying a one-pound payload proved to be about ten times more expensive than the optimistic forecasts had predicted and certainly not less than the costs associated with traditional, non-reusable rockets. Looking beyond Hersch, other experts even estimate the costs at USD 1.5 billion if development costs, maintenance, renewal etc. are included.

Often, extraneous motives played a role: for example, Rockwell International was commissioned to manufacture the spaceship because President Nixon wanted to award the contract to a

company based in the swing state of California in the run-up to elections. 'Compromise and thrift had driven its configuration, and its principal benefit lay in its authorization in an election year' (Hersch 2023: 104). Contracts were frequently awarded based on political considerations, a practice that continues to this day:

> Companies in congressional districts across the country manufactured the wings, rudder, and other portions of the orbiters to ensure the shuttle's support by a diverse array of lawmakers, and then shipped the parts to Rockwell's plant in Palmdale, California, for final assembly (Hersch 2023: 105).

For instance, the decision to commission the company Thiokol to manufacture the space shuttle's solid rocket boosters, or SRBs for short, remained clouded by accusations of favouritism by Utah politicians and civil servants (Hersch 2023: 159). The tragic Challenger accident in January 1986 could have been prevented if Thiokol's management had not made the misguided decision to authorise the launch. This is all the more tragic because one of the company's employees had emphatically warned that the O-rings that sealed the joints in the shuttle's SRBs could become dangerously stiff in cold weather, which is what happened on that day and led to the accident.

The crew included a teacher, who died along with the six astronauts – effectively ending any plans for private space tourism with the shuttle for the foreseeable future. While – objectively – flying on the shuttle was no more dangerous than the Apollo spacecraft, and the higher casualty count was simply a result of the larger crew size, some had mistakenly believed that shuttle flights were as safe as a trip on an aeroplane. The professional astronauts, however, knew very well that this was not true.

Following the Challenger accident, all launches were suspended for over two years, which meant that another task, that of transporting private satellites into space, was also suspended. This unexpected pause in operations turned out to have a positive impact.

Hersch is right to criticise the fact that,

> Instead of exploring space, NASA would replace the embryonic free market for launch services with a single government provider that purchased expensive, unreliable rockets from key defense contractors selected by political appointees, and then priced their flights below cost for favored users, destroying the competitive pressures that might have improved the technology (Hersch 2023: 122-123).

In August 1986, President Ronald Reagan decided that 'NASA will no longer be in the business of launching private satellites.' This paved the way for private providers, especially as Reagan had already outlined his vision in a speech a year and a half earlier: 'Companies interested in putting payloads into space, for example, should have ready access to private sector launch services … So, we're going to bring into play America's greatest asset – the vitality of our free enterprise system.'

Reagan's predictions have indeed come to fruition over the last two decades, with Elon Musk and his company SpaceX playing a pivotal role in this transformation.

Reentry
Eric Berger

There are plenty of books about SpaceX, and I have read most of them. But the book by astronomer and space expert **Eric Berger,** ***Reentry. SpaceX, Elon Musk and the Reusable Rockets that Launched a Second Space Age*** (2024), stands out as the best. In particular, it portrays the chequered relationship between NASA and SpaceX.

Initially, Elon Musk faced significant opposition from both political figures and NASA officials. Charles Bolden, who would serve as NASA Administrator during President Obama's tenure in the White House, was a self-described extreme sceptic of Musk and SpaceX. And the powerful US senator who held NASA's purse strings, Richard Shelby of Alabama, declared that efforts to rely on private companies like SpaceX represented a 'death march' for NASA: 'We cannot continue to coddle the dreams of rocket hobbyists and so-called "commercial" providers who claim the future of U.S. human spaceflight can be achieved faster and cheaper,' Shelby said in 2010 (Berger 2024: 3).

These were strong words, especially after NASA's shuttle programme had fallen far short of every one of its stated objectives. They were also strong words when you consider that launch costs more or less stagnated between 1970 and 2010 and that several attempts by NASA to develop reusable rockets (the X-33 and X-34) were abandoned after costing around a billion dollars.

And those were strong words given the fact that after the shuttle programme was terminated, the United States had to rely on the increasingly expensive services of old Russian rockets to reach the ISS. Thanks to SpaceX, launch costs have been cut by approximately 80%. Musk's Starship is a superlative spacecraft, the likes of which have never been built before. SpaceX currently launches about 150 rockets a year and has completed 47 flights to the ISS.

The decision by NASA to procure services from private companies such as SpaceX was initially born out of necessity. According to Berger, a small number of individuals at NASA, including Kathy Lueders, played a crucial role in fostering a partnership with SpaceX. Lueders, who headed a small team and was responsible for liaising with SpaceX, actively supported Elon Musk's vision for success. Inside NASA, Lueders fought against the excessive bureaucracy and pushed back on mid-level managers at the space agency seeking to levy additional rules and requirements on the private companies. Mostly, she succeeded. Whereas the space shuttle had more than 10,000 requirements, Dragon from SpaceX ended up with about 400 (Berger 2024: 109).

Three or four times a week, someone at NASA would come to Lueders and tell her, 'I'd hate to have your job.' Hardly anyone believed that SpaceX would succeed. 'But Lueders', Berger writes, 'understood that NASA had no choice' (Berger 2024: 116). Ultimately, a productive partnership blossomed between NASA and SpaceX, largely due to the efforts of Gwynne Shotwell, the president and chief operating officer of SpaceX. Shotwell was specifically chosen by Musk because she compensated for his own shortcomings.

The decisive factor in the collaboration between SpaceX and NASA was a paradigm shift: Previously, NASA provided private companies with specific instructions on how to construct a

rocket, leading to high costs as the companies followed these instructions meticulously. Through cost-plus programmes, there was not the slightest incentive to reduce costs; instead, they were incentivised to increase costs. Musk insisted on fixed prices, and instead of telling SpaceX what to build, NASA specified what services it wanted to buy. 'Musk did not want to build a spacecraft and sell it outright to NASA. Rather, he wanted to build the spacecraft and charge NASA a fee to fly its cargo.' As one employee put it, 'It's like FedEx. You provide us a package, and we'll deliver it to space for you.' Adding: 'This seems obvious today, but the look of horror on their faces was very, very real' (Berger 2024: 106-107).

This new approach was the foundation for NASA and SpaceX's mutual success. Nevertheless, tensions arose because Musk always made his goal of one day flying to Mars the basis for all his decisions, which sometimes conflicted with NASA's objectives, as this was by no means a priority for NASA. Berger shows that many of Musk's technical decisions can only be understood through the prism of his unwavering commitment to his ultimate goal of establishing a human presence on Mars.

A recurring theme throughout Berger's book is the bureaucratic rules and regulations that drove Musk to despair because they ate up time and energy that could have been invested in more important things. Hans Königsmann, one of SpaceX's top engineers, lamented: 'They were really extreme with their environmental tests, which had nothing to do with the real environment' (Berger 2024: 66). Traditional space companies, often resembling cumbersome government agencies, had no issue navigating the countless bureaucratic requirements, but they drove an innovative and impatient entrepreneur such as Elon Musk to despair.

Elon Musk
Walter Isaacson

To understand the success of SpaceX, you also need to understand Elon Musk's personality and entrepreneurial philosophy. The best book for this is the biography ***Elon Musk*** by **Walter Isaacson**, who has a long track record of publishing outstanding biographies of exceptional figures such as Steve Jobs, Albert Einstein and many more besides.

According to Isaacson, in the early 2000s, after selling the company PayPal, Musk was sitting with some of the company's alumni in Las Vegas, and one of them asked him what he was planning to do next. Musk answered, 'I'm going to colonize Mars. My mission in life is to make mankind a multiplanetary civilization.' His former colleague's reaction? 'Dude, you're bananas' (Isaacson 2023: 92).

What are Musk's motives? Isaacson names three in particular: Musk found it astonishing – and frightening – that technological progress was not inevitable but could come to a halt. Musk saw such a standstill after the end of the Apollo missions: 'Do we want to tell our children that going to the Moon is the best we did, and then we gave up?' he asked (Isaacson 2023: 93).

Another motive that Musk repeatedly mentions is that only the colonisation of another planet can ensure the survival of humanity. Throughout history, Earth has faced repeated asteroid impacts, and it is only a matter of time before another catastrophic event occurs. 'If we are able to go to other planets, the probable lifespan of human consciousness is going to be far

greater than if we are stuck on one planet that could get hit by an asteroid or destroy its civilization' (Isaacson 2023: 94).

His personal motive was inspiration, the will to achieve great and seemingly impossible goals. 'To have a base on Mars would be incredibly difficult, and people will probably die along the way, just as happened in the settling of the United States. But it will be incredibly inspiring, and we must have inspiring things in the world.' There has to be more to life, Musk explained, than merely solving problems. We also need to pursue great dreams. 'That's what can get us up in the morning' (Isaacson 2023: 94).

Since Musk had agreed to fixed costs in his negotiations with NASA, he had an economic incentive to reduce costs. Musk consistently set seemingly impossible targets, such as cutting the cost of each engine to around USD 200,000, a tenth of what it then cost (Isaacson 2023: 363). Musk coined the term 'idiot index', which referred to the ratio of the total cost of a component to the cost of its raw materials. A component with a high idiot index – for example, a component that cost USD 1,000 although the aluminium that it was made from cost only USD 100 – was likely to have a design that was too complex or a manufacturing process that was too inefficient. As Musk put it, 'If the ratio is too high, you're an idiot' (Isaacson 2023: 363). Musk warned one employee: 'If you ever come into a meeting and do not know what are the idiot parts, then your resignation will be accepted immediately' (Isaacson 2023: 364). And: 'We should ask each of them to see if they can get the cost of their part down by eighty percent. And if they can't, we should consider asking them to step aside if someone else might be able to do so' (Isaacson 2023: 365).

That represented a paradigm shift from the prevailing mindset up to that point. Before SpaceX, the cumbersome companies that supplied rockets to NASA operated under a different model.

According to the absurd logic of cost-plus contracts, the more costs a company generated, the more profitable a contract ended up being to them. In his 2019 book *The Case for Space. How the Revolution in Spaceflight Opens up a Future of Limitless Possibility*, Robert Zubrin, Founder of the Mars Society, writes:

> As a result, it is the norm for such contractors to have overhead rates exceeding 300 percent. Indeed, at the Martin Marietta company (later Lockheed Martin), where I was employed from the late 1980s through mid-1990s (and which was, along with Boeing, one of the two most successful of the eight major aerospace companies of that era), we at one point had more than 13,000 people at our primary facility, with fewer than 1,000 working in the factory – leading one wit to scoff: 'At Martin Marietta, overhead is our most important product' (Zubrin 2019: 22).

The only way to understand Elon Musk's business decisions is to recognise that they are all guided by his ultimate goal of getting to Mars. Isaacson demonstrates this in various decisions, including the choice of fuel for Starship. Isaacson quotes Musk in his biography: 'The lens of getting to Mars has motivated every SpaceX decision.' (Isaacson 2023: 321).

For instance, the Raptor engines deployed by Musk's SpaceX are fuelled with liquid methane and liquid oxygen. Musk chose methane because it can be extracted on Mars. This will significantly reduce the amount of fuel that Starship needs to carry. Musk is planning to send an unmanned rocket to Mars, which will generate methane fuel on site. This fuel will then be used to refuel a subsequent manned rocket for its return journey to Earth. Methane can be synthesised on Mars using the Sabatier process, which combines CO_2 from the Martian atmosphere with hydrogen.

While Starship has a wide range of potential uses, including journeys to and from the Moon, the entire design is ultimately focused on a single goal: transporting large numbers of people to Mars. Musk has consistently emphasised his vision of regular flights to Mars by the mid-21st century, with the ultimate aim of establishing a thriving colony of 1 million people on the Red Planet.

Elon Musk's business philosophy, which he proclaimed over and over again, can be summarised in five points (Isaacson 2023: 370):

1. Question every requirement.
2. Delete any part or process you can.
3. Simplify and optimise.
4. Accelerate cycle time. Every process can be speeded up.
5. Automate.

And above all this was the motto Musk emphasised time and time again: 'A maniacal sense of urgency is our operating principle' (Isaacson 2023: 286). This relentless focus on efficiency and speed is what so fundamentally distinguishes his company from the industry's old, cumbersome companies – and even more so from government agencies.

Breaking All the Rules
Jim Cantrell

Engineer **Jim Cantrell** played a pivotal role in the early stages of Elon Musk's interest in space travel. His firsthand account of this groundbreaking period is recounted in his 2023 book, ***Breaking All the Rules: The Inside Story of the New Space Race***, which, as well as chronicling the origins of the second space race, also provides insights into the story that led to the founding of SpaceX.

In July 2001, Cantrell received an unexpected phone call from a stranger who introduced himself as an internet millionaire by the name of Elon Musk and said he had been given Cantrell's number by Robert Zubrin, the founder of the Mars Society: 'I am the founder of Zip2 and PayPal and believe that mankind has to become a multi-planetary species to survive, and I want to do something with my money to show that this is possible' (Cantrell 2023: 204).

Cantrell did not know what to think. Was it a crank call? When the call came in, he was driving in his convertible with the top down, so he asked if he could call back in 15 minutes. Once he was home, Cantrell checked to see whether a company called PayPal actually existed. Once he was satisfied that the call was legitimate, he tried to call back, but instead of Musk's voice, Cantrell heard the beeps of a fax machine. Shortly afterwards, Musk called him again, and they arranged to meet at the airport along with Zubrin.

Elon Musk outlined his plan to send a mouse to Mars as part of a public relations campaign to demonstrate the feasibility of interplanetary travel. Due to the high cost of US rockets, Musk was weighing up whether to buy Russian rockets and wanted Cantrell to make the contacts for him. Cantrell was not particularly keen on the idea of sending a mouse to Mars. The next idea was to send a rocket to Mars and show that a plant could grow in a small greenhouse on the Red Planet.

At the beginning of November 2001, Musk, Cantrell and the later NASA director Mike Griffin flew to Moscow to explore their options.

> It's important to realize that Elon was, at the time, a twenty-something 'kid' from Silicon Valley who had done very well financially and dressed much like the other entrepreneurs in Silicon Valley. He dressed poorly in the eyes of the Russians, which was something of great importance to them. I had warned Elon about this and how the Russians would judge him based on his appearance (Cantrell 2023: 223).

During a discussion with Russian officials, Elon Musk shared his ambitious vision of establishing human colonies on Mars. One of the Russians was so annoyed that he spat on Musk's and Cantrell's shoes. They met with other Russians to negotiate a deal for a rocket, but these talks were equally unsuccessful.

On the flight back from the failed negotiations, Cantrell saw Musk working on his laptop: 'Hey guys, I think we can build the rocket ourselves,' Musk declared (Cantrell 2023: 226). The others laughed at him. But a quick glance at Musk's calculations convinced the rocket engineer that Musk was right and had clearly immersed himself in the subject matter, extensively studying books on fuels and rockets.

Cantrell could have played an important role in SpaceX, but he soon began to have reservations:

> My doubts began to nag at me, and I started questioning what I was doing. I knew that Elon aimed to send humans to Mars and eventually build a settlement there. Strangely, this was not something I was very passionate about. Maybe, it's because I didn't consider it a realistic kind of thing to be doing. Or perhaps I just preferred something a little more modest' (Cantrell 2023: 232-233).

Tensions escalated between Cantrell and Musk, particularly when Musk asked Cantrell how much the tanks for the rocket would cost. Musk was known for making cost estimates that everyone else considered completely unrealistic – as was the case in this instance. Later, however, Musk would often prove that what everyone else considered completely unrealistic was actually possible after all. In a heated exchange, Musk shouted at Cantrell, who in turn decided to resign from SpaceX at the end of August 2002 because he believed he could earn more money as a consultant in the space industry. In any case, Cantrell was convinced it would be impossible for him to continue working alongside Musk. Looking back, the decision was of course a serious mistake for Cantrell, at least financially. For SpaceX, however, it turned out to be a stroke of luck, as Cantrell suggested Gwynne Shotwell as his replacement, and she has gone on to become president of SpaceX, playing a crucial role in the company's success story in the process.

Cantrell's verdict:

> I am optimistic and believe in the spirit and power of capitalism and its ability to deploy capital, innovate, and produce value efficiently. Our aerospace industry will change and adapt to this new reality, and the U.S. government will find new ways

> to harness the more efficient capital deployment of the private sector (Cantrell 2023: 7).

Elon Musk met the renowned aerospace engineer Robert Zubrin, founder of the Mars Society, for the first time at a dinner in 2001. Five years earlier, Zubrin had gained widespread recognition for his groundbreaking book *The Case for Mars: The Plan to Settle the Red Planet and Why We Must*. Inspired by Zubrin's vision and passion for Mars exploration, Musk founded SpaceX just six months after their meeting, with the primary objective of taking humans to the Red Planet.

While there had been a long period of stagnation in state-funded manned space travel after the Moon landing and the cost of a space launch had remained static for 40 years, thanks to the introduction of mostly reusable launch vehicles, Elon Musk's company, SpaceX, had managed to cut launch costs by a factor of five over the past decade. The conquest of Mars has become more realistic.

The New World on Mars Robert Zubrin

Nearly thirty years after the release of his first Mars book, in 2024 **Robert Zubrin** published a new book, ***The New World on Mars: What We Can Create on the Red Planet*****,** which excels in presenting the economic basis for the colonisation of Mars. Zubrin's medium-term objective is to establish a settlement of 50,000 individuals on Mars. This goal, while ambitious, pales in comparison to Elon Musk's grand vision, which envisions sending 1,000 starships, each carrying 100 passengers, to Mars every year for ten years.

What was merely a vision not so long ago now seems within the realms of possibility, all thanks to the revolution in private space travel:

> It is possible for a well-led, entrepreneurial team to do things that, previously, it was thought only major-power governments could do, and that such a team could do them in one-third the time, at one-tenth the cost, and even accomplish things that had been deemed impossible altogether. As a result, SpaceX has unleashed an entrepreneurial space race. Worldwide, groups of engineers are now finding investors willing to finance new launch companies, spacecraft companies, and space technology companies (Zubrin 2024: 48).

Thanks to the evaluation of numerous unmanned Mars missions, we now know that Mars is endowed with all of the resources needed to support not only life but also the development of a technological civilisation. There is plenty of water on the planet, albeit in frozen form. Mars also holds vast quantities of carbon,

nitrogen, hydrogen and oxygen, all in forms readily accessible to those clever enough to use them. But how could a mission to conquer Mars be financed?

According to Zubrin, the initial stages of Mars colonisation would likely be funded by the government, but the involvement of private investors would then be essential moving forward (Zubrin 2024: 90-91). The harsh conditions and limited workforce on Mars, he explains, would require the settlers to be highly innovative, developing new inventions and patents to establish a sustainable economy. This would, Zubrin writes, require advancements in technologies such as genetic engineering at a much faster pace than on Earth to guarantee a stable food supply. 'In my view, the best, early, large-scale source of cash income that Mars colonists can generate will come from the sale and licensing of intellectual property. This will come naturally from the nature of the Martians themselves and their situation' (Zubrin 2024: 91-92).

The reason:

> The Martians will be a group of technically adept people in a frontier environment that will challenge them, indeed force them, to innovate. They will face a terrific labor shortage. This will compel them to innovate in the areas of labor-saving machinery, automation, robotics, and artificial intelligence. Limited to greenhouse agriculture, they will have a shortage of land and livestock. This will force them to innovate in the area of biotechnology, to create ultra-productive and highly nutritious crops. Lacking attractive sources of fossil fuels, wind or water power, or solar energy, they will be impelled to innovate in areas of nuclear power, including advanced fission designs … and fusion, as the deuterium fuel for fusion reactors is five times as common on the Red Planet as it is on Earth. All these innovations will have tremendous utility on Earth. The Martians therefore will patent them and license the patents

> for use on the home planet. The revenue from such intellectual property sales could be enormous (Zubrin 2024: 92).

Later, Zubrin continues, they would open up additional revenue streams, such as real estate, tourism, luxury goods, spectator sports, material exports and asteroid mining, which, from a logistical point of view, is about 100 times easier to support from Mars than from Earth.

Zubrin is convinced that both the conquest of Mars and its subsequent colonisation can only be financed under capitalism. 'Liberty will be necessary for us to settle space. We will need to create ever cheaper and more cost-effective launch systems, spacecraft, and space transportation systems, and these require liberty' (Zubrin 2024: 192). However, economic freedom is not only important for sending rockets to Mars but even more important for its colonisation, Zubrin argues, because only maximum economic freedom can foster conditions to promote innovation and entrepreneurship, and only this will create the necessary foundations for the economic sustainability of a society on Mars.

Zubrin is optimistic that Mars, much like America in the past, will appeal to freedom-loving, energetic people. After all, without the promise of freedom, the society that emerges on Mars would never be able to attract enough people willing to take the risks and endure the hardships required to colonise the Red Planet.

Spacefareres
Christopher Wanjek

Christopher Wanjek's book ***Spacefarers. How Humans Will Settle the Moon, Mars, and Beyond*** was published by Harvard University Press in 2020. He also emphasises the vital importance of private space travel: 'Private Sector as the New Rocket Fuel' (Wanjek 2020: 107). Wanjek regards political interference in private space travel as a major cause of the long phase of stagnation in the post-Apollo era, as he illustrates in the case of the Space Shuttle programme: 'More operational costs for the shuttle came as a result of Congress distributing pork and setting up contracts for shuttle parts in their own districts, from Florida clear across the nation to Washington, creating unnecessarily complex, expensive logistics.' Ultimately, even NASA had to admit that the programme was a mistake (Wanjek 2020: 108).

Post-Apollo, NASA has continued to chalk up notable successes in *unmanned* space flight. NASA has launched every probe that has visited Jupiter, Saturn, Uranus, Neptune and Pluto, as well as deploying outstanding telescopes such as Hubble, Chandra, Kepler and WMAP. The key to NASA's success in these unmanned projects is that its scientists have been allowed to make decisions free from political influence. However, the situation is completely different in relation to manned space travel:

> I and others would argue that the primary reason NASA has done so little in human space exploration for the last forty years is that the space agency is directed by ever-changing US presidents (twelve since its creation) and micromanaged by

> the US Congress. The 'vision' – stay in low-earth orbit; no, go to the Moon; no, go to Mars instead; no go to the Moon – is a blurry, moving target. Jimmy Carter pushed for space science over human activities; Ronald Reagan supported the ISS as a stepping stone to a larger presence in orbit; George H. W. Bush pushed for a return to the Moon and then a journey to Mars; Bill Clinton focused on cooperation with the Russians to complete the ISS, which was over budget and less international when he took office; George W. Bush wanted to return to the Moon; and Barack Obama wanted to skip the Moon and go to the asteroids and Mars. Donald Trump has advocated, at various times, to go to the Moon, or to Mars, and to create a Pentagon-led space force (Wanjek 2020: 222-223).

According to Wanjek, had Barry Goldwater won the 1964 election instead of Lyndon B. Johnson, the United States would not have landed on the Moon.

In his analysis, the author critically examines common arguments as to why humans should settle on the Moon or Mars. He is not convinced by the argument that an asteroid would destroy all life on Earth or that a nuclear war or other catastrophes could lead to humanity's extinction. After exploring various catastrophic scenarios, Wanjek concludes that even in the face of the worst possible disasters, some people would always survive – and that, in any case, it would take hundreds of years for a Mars colony to become truly independent and self-sustaining without Earth's support (Wanjek 2020: 18-28).

Despite his scepticism towards the urgency of colonising the Moon or Mars, Wanjek is not opposed to the idea – quite the opposite. He simply believes there must be compelling reasons to justify such endeavours. In particular, two reasons play a central role in his view: First and foremost, the United States' rivalry with China. Just as there would have been no Moon landing if the United States had not been competing with the

Soviet Union, it is now imperative the United States does not fall behind China, because the Chinese would otherwise establish a massive advantage, including militarily.

Secondly, Wanjek cites economic reasons. He is very optimistic about space tourism and envisions a 'Lunar Disneyland'. A two-week trip to the Moon will be an event for the 'Aspen ski crowd' and the 'Davos attendees', in the same way an African safari was for the rich 150 years ago (Wanjek 2020: 186). He expects a growing number of tourists to be attracted by the allure of sporting activities in one-sixth of Earth's gravity and breathtaking views of the Earth, which for Moon tourists would appear six times larger than the Moon does when seen from the Earth.

Furthermore, he also sees the Moon as an important long-term source of raw materials: as resources on Earth become increasingly scarce, it will become increasingly economically viable to extract rare earth elements from celestial bodies such as Mars. And if nuclear fusion technology advances, helium-3 could be extracted on the Moon, where it is far more concentrated than on Earth (Wanjek 2020: 161).

Whether humans could live permanently on the Moon or Mars, however, would, in Wanjek's view, depend above all on whether it would be possible to bring children into the world and raise them under the conditions of low gravity:

> If 0.16 G is not enough force to allow for proper gestation of a fetus and subsequent infant and child development, then no one can raise a family on the Moon, period. End of settlement. The Moon would be limited to an industrial park and science wonderland with some elements of tourism and maybe retirement. That, in turn, dictates the modest architecture for these transient lunar dwellers (Wanjek 2020: 183).

Nobody knows today whether the gravity on the Moon will be strong enough – or even the stronger gravity on Mars.

However, the author agrees with the other authors presented here that private space exploration, as free from political interference as possible, is the key to mankind successfully taking the next decisive steps in the conquest of space.

While the increasing importance of private space travel since the beginning of the 2010s may seem like an anomaly when considering the past 70 years, it is by no means as unusual from a longer historical perspective as it might initially appear. And if we adopt a timescale not of 70 but of 200 years, it becomes clear that the private financing of space exploration has been much more important than previously assumed.

The Long Space Age
Alexander MacDonald

Alexander MacDonald's excellent book, ***The Long Space Age***, published in 2017, deserves recognition for demonstrating this. Its central finding:

> … if we look at the history of American space exploration on a longer timescale, a very different history emerges – one in which personal initiative and private funding is the dominant trend and government funding is a recent one. The long-run history thus turns the conventional wisdom on its head: it is the governmental leadership of space exploration that is the more recent phenomenon, while the resurgence of private-sector space efforts in the early twenty-first century represents a return to an earlier pattern (MacDonald 2017: 3).

In the first two chapters of his book, MacDonald conducts a thorough examination of the emergence of ever larger and increasingly expensive observatories in the United States. It is certainly an unusual approach to include observatories alongside space probes, rockets and satellites, but fundamentally they served the same purpose: space exploration.

Starting in 1830 and lasting about four decades, there was a real 'American Observatory Movement' (MacDonald 2017: 33). This movement was primarily funded by private sources rather than the government.

> To put the extent of the private support for astronomy within context, of the 38 observatories listed, only two – the U.S. Naval Observatory and the Observatory of the U.S. Military Academy

> at West Point – were not privately owned observatories with large optical telescopes (MacDonald 2017: 20).

One notable example is the renowned Lick Observatory, which was funded by the entrepreneur James Lick (1796-1876), who made his fortune in real estate during the California Gold Rush (MacDonald 2017: 73). Lick was the richest man in California at the time and was a visionary space enthusiast who once remarked to a friend, 'We will know the secrets of the spheres and it will be as common for man to take an inter-orbital trip into space as it is for you or me to walk down Montgomery Street' (MacDonald 2017: 73). Upon his passing, he stipulated that USD 700,000 (equivalent to USD 1.3 billion in 2015) be allocated to the construction of an observatory that would become one of the leading institutions of American astronomy and astrophysics for decades to come.

Another example is the Hale Observatory, named after the tireless fundraiser and astronomer George Ellery Hale. Hale secured a grant of USD 6 million from the Rockefeller Foundation for 'the construction of an observatory, including a 200-inch reflecting telescope' in 1928, which was finally completed in 1948. Until 1976, Hale Observatory was the largest observatory in the world. MacDonald's insights provide a completely different viewpoint on modern private space exploration, especially when he writes:

> In the long historical perspective, the trend in the late twentieth and early twenty-first century toward increased funding for space exploration projects coming from the private sector – specifically from wealthy individuals such as Paul Allen, Jeff Bezos, and Elon Musk – is understood not as a new emerging phenomenon but rather as the reemergence of a dominant thread in space exploration that dates back to over a hundred years before Sputnik. Incorporating the history of astronomical observatories into the overall narrative of American space history shows that, in fact, it has been private sources that

> have supplied the resources for the nation's exploration of the solar system and the universe for most of its history to date (MacDonald 2017: 104).

The author examines in detail the financing of the rockets developed by the space pioneer Robert H. Goddard, who was – at least in the eyes of Americans – ahead of everyone in the design, construction and launching of liquid-fuel rockets which eventually paved the way into space. Goddard spent much of his life seeking funding for his research, including from the US military. But 'the most significant financial support for Goddard came from private-sector individuals who shared with Goddard a deeply felt intrinsic desire to explore the limit of flight' (MacDonald 2017: 157). Based on the constant-price value in US dollars adjusted by the PWC index (base year 2015 GDP), private sources of funding to Goddard totalled USD 12 million, while state funding from the US military amounted to USD 9 million (MacDonald 2017: 155).

From this longer-term perspective, the dominance of government funding during the Apollo programme era was the exception rather than the rule – and the current trend of wealthy individuals such as Jeff Bezos and Elon Musk playing a significant role in funding space exploration aligns with longer-term trends (MacDonald 2017: 208).

Space Capitalism
Peter Lothian Nelson

Peter Lothian Nelson and the economist **Walter E. Block** adopt a radical libertarian approach in their 2018 book ***Space Capitalism. How Humans Will Colonize Planets, Moons, and Asteroids***.

Their central thesis is 'that free enterprise, and it alone, is the last best hope for space travel, colonization, and getting some significant numbers off our home planet and that relying on government to pursue this goal is a snare and a delusion' (Nelson & Block 2018: 137). Despite their 'anarcho-capitalist' approach, the authors also acknowledge that a significant portion of the orders for companies such as SpaceX and Blue Origin come from government agencies such as NASA. But they justify this with the argument:

> However, a significant part of these payments concerns contracts between them and the government to provide specific services. Are these categorically incompatible with free markets? In the early days of flight, a significant part of commercial airline revenue emanated from contracts with the U.S. post office to transport mail. Were these firms banished from the honor roll of free enterprise for interacting with the state in this manner? No, to do so would amount to an extreme form of puritanism (Nelson & Block 2018: 200).

The authors are correct in their assessment; however, the criteria they utilise to determine an entrepreneur's eligibility for inclusion in the honour roll of free enterprise are not convincing. Because their benchmark, which is based on the political beliefs

of these entrepreneurs, is not a sensible criterion. For instance, they mention Musk in their analysis:

> Has Musk been outspoken and well-known in support of anarcho-capitalist principles? The Libertarian Party? The Mises Institute? There is no evidence we could uncover to demonstrate that, as a counterbalance to his acceptance of government money, he has shown any support whatsoever for the free enterprise system (Nelson & Block 2018: 189).

They conclude that Musk's endeavours to reach the stars and colonise them 'cannot be counted as a part of the free market system. Indeed, they constitute the very opposite: economic fascism, government interventionism, crony capitalism' (Nelson & Block 2018: 190). They also criticise Richard Branson for not being libertarian enough, although they do praise him for his support of drug legalisation (Nelson & Block 2018: 193). They give Bezos somewhat more credit because a significant portion of his investments stem from his profits at Amazon (Nelson & Block 2018: 192).

The authors present compelling arguments for the superiority of private space travel (Chapter 4) and for the establishment of property rights in space, including on moons and asteroids (Nelson & Block 2018: 51-62). They are also right when they point out that without property rights, endeavours like asteroid mining will be almost impossible to implement (Nelson & Block 2018: 105-116). However, their dogmatic approach of rejecting any state involvement in this domain diminishes the strength of their arguments. Furthermore, they themselves acknowledge that the chances of realising their utopian approach are very slim (Nelson & Block 2018: 240-242).

The Dimming of Starlight
Gonzalo Munévar

Gonzalo Munévar, Professor Emeritus at Lawrence Technological University, has published a comprehensive examination of the philosophy of space exploration under the title ***The Dimming of Starlight*** (2023). Munévar distinguishes between 'ideological' and 'social' criticisms of space exploration. Intellectuals who are convinced that technology, growth and capitalism have caused a lot of harm on Earth see space travel as a continuation of a path they think is wrong anyway. In addition, critics claim that the billions allocated to space exploration would be better utilised in addressing pressing issues such as hunger, poverty, climate change and other urgent human problems.

The second argument is relatively easy to refute, as it suggests that eradicating hunger and poverty is simply a matter of spending enough money on development aid. However, evidence from 60 years of development aid in Africa demonstrates that this approach is not only ineffective; it is often detrimental, as I show in detail in my book *How Nations Escape Poverty* (Zitelmann 2024). The only thing that helps against poverty is more economic freedom.

In addition to the well-known and commonly cited arguments regarding the 'spillover' effect, Munévar puts forward several very interesting arguments that highlight the importance of space exploration, such as understanding other planets is essential for gaining a deeper understanding of our own planet (just like you cannot understand a country without comparing it

with others): 'We cannot vary the global conditions of our planet at will. But we can look at other worlds in which those variations occur naturally and see how other factors are correlated with them' (Munévar 2023: 96).

One example of the practical use of comparative planetology is that when NASA scientists found fluorine and chlorine compounds in the atmosphere of Venus, they investigated the chemistry of those molecules and determined the rate constants of their chemical reactions. Those rate constants were later used by Sherwood Rowland and Mario Molina to discover that chlorofluorocarbons (CFCs) destroy ozone in the presence of high ultraviolet radiation (Munévar 2023: 66).

This is just one example of Munévar's thesis that understanding other worlds advances the way we understand our own planet. Only space exploration allows us to understand how the solar system and the Earth developed and opens 'opportunities to test our ideas about the Earth – the solar system serves as a natural laboratory' (Munévar 2023: 72).

Research, Munévar asserts, is never predictable but often leads to surprising and unexpected results and applications. One example of this phenomenon is the work of astrophysicists Anil Pradhan and Sultana Nahar from Ohio State University, who studied the composition of stars by analysing the flow of radiation. This research led directly to revolutionary insights into cancer treatment (Munévar 2023: 107).

Without weather satellites, we would hardly know anything about weather systems and how climates change. We would be much less able to understand the causes and, in particular, the consequences of climate change. Research into Venus has also provided us with valuable insights into the greenhouse effect.

Munévar's book presents several compelling arguments. However, anyone who believes that technology, science and capitalism have steered society in the wrong direction will not be convinced by these arguments. It is important to note, though, that this approach has been very successful in combating hunger and poverty. Just 200 years ago, 90% of the global population was living in extreme poverty; today it is less than 9% – thanks to technology, science and capitalism.

One key strength of the book lies in its extensive use of examples to illustrate how space exploration has significantly advanced scientific knowledge, sometimes in areas where no one, including the researchers themselves, would have expected it. The obvious counter-argument – that significant cost savings could have been achieved by bypassing space exploration and focusing solely on the discoveries that emerged as its byproducts and spinoffs – is convincingly refuted by the philosopher of science Munévar: the entire history of science shows that the most groundbreaking discoveries are not the product of conventional research, but the product of serendipity, emerging spontaneously, inadvertently and without prior planning (Munévar 2023: 36-37).

Conclusion

In summary, there is a growing number of excellent books on the Space Economy, a field that is also of particular interest to free-market economists due to the unique trend within the space industry towards more market-orientated practices and less state intervention over the past two decades. This means that developments in the Space Economy are running contrary to general economic developments around the world in the wake of the global financial crisis of 2008, which have led to a reversal of the progress made in the 1980s and 1990s when many countries moved towards more market, less state (Deng Xiaoping, Margaret Thatcher, Ronald Reagan, etc.). Since the financial crisis, if not before, the world has seen a resurgence of government interventionism, planned economy approaches and over-regulation – in China, the United States, Latin America and Europe. The Space Economy is perhaps the only economic sphere in which the private sector has bucked this general trend and is playing an increasingly important role in the industry. And it is no coincidence that these private companies in the Space Economy have consistently delivered such remarkable scientific advancements and groundbreaking innovations.

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