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Global Space Futures - 2050

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Abstract

Looking ahead approximately to roughly 2050, what might global space activities look like across civil, commercial, and national security space sectors? In particular, what are the international security implications of space commerce over the next 30 years? Rather than trying to predict a likely or singular future, the aim of this paper is to understand what alternative futures are possible and indicators that a particular future is emerging. Positing a range of futures enables the bounding of uncertainty and mitigation of surprises. Identifying indicators of emerging futures allows the creation of strategies to exploit or hedge against events, without necessarily assuming a particular future will occur. Depending on the time horizon, various "shocks" may occur that change the course of future events. Exogenous events can be "normal" or "radical" changes. Examples of radical changes, which are difficult to foresee and bound, include a future Carrington event, Kessler syndrome, or catastrophic planetary impact. What might be key signposts of different scenarios or futures emerging? A loss of U.S. support for human space exploration would leave China the global leader by default. Successful demonstrations of a reusable heavy-lift capability and the Starship-based Human Landing System would make the Artemis scenario both feasible and likely. Demonstration of effective use of lunar resources would make a "McMurdo Station" on the Moon more sustainable and likely. Finally, an expansion of economic activity in space distinct from direct government subsidies could accelerate human expansion and could create vital national interests beyond the Earth.

Keywords: Qualitative forecasting, future scenarios, assumption-based planning, spaceflight

1.0 Introduction

The first Space Age, or Space 1.0, was a key element of the Cold War competition between the United States and the Soviet Union.[1] Human and robotic space exploration, the creation of space-based military and intelligence capabilities, and the growth of space capabilities among other advanced, industrial countries, were driven by national governments. The immediate post-Cold War environment saw the continued centrality of State priorities, even as the incorporation of Russia into the International Space Station program symbolized hopes for a peaceful, post-Soviet relationship. Similarly, the rise of China's space capabilities were driven by national priorities of the Chinese Communist Party. China is rapidly demonstrating advanced scientific, military, and potential commercial space capabilities. Russia remains a significant military space power, but its technical and economic capabilities in space have declined in recent decades.

Commercial space activities, such as satellite communications, were also part of the first Space Age, along with forecasts of space industrialization, manufacturing in space, solar power satellites and space tourism. However, space activities were driven by government spending, not private markets. In the 1990s, commercial space revenues grew steadily due to new information-based space applications such as remote sensing and the Global Positioning System (GPS), but more ambitious civil and commercial visions, such as space tourism and manufacturing, remained just visions. The cost and difficulty of going to and from space meant that moving information bits, rather than atoms or people, represented the only profitable commercial activities.

The second Space Age, or Space 2.0, seems to have arrived gradually and then suddenly in the past decade.[2] States remain central to government-driven scientific and defense activities in space, but the private sector has taken on significantly greater leadership roles in the innovative creation, financing, and conduct of space activities. Information-based space applications, particularly data analytics, have been enabled by new generations of lower cost satellites in proliferated constellations, which have in turn been made possible by lower cost, largely reusable, space launchers. Lower cost launchers have displaced earlier generations that relied on ICBM-based, expendable rockets as well as the retirement of government-subsidized reusable launchers (i.e., the Space Shuttle). With larger levels of demand, reusability has become the new standard for space launch vehicles. This is demonstrated not only by SpaceX, but by Chinese plans for Long March 9 and European concerns over its lack of a reusable vehicle for at least another decade.[3, 4]

Space 2.0 coincides with the democratization and globalization of space activity, in which many more private entities have space capabilities and many more countries, at all stages of development, are able to participate in space activities. Space-based capabilities, such as communications, navigation, and remote sensing, are central to multiple critical infrastructures on Earth, whether in advanced or developing countries. The accelerating growth of new commercial space activities also coincides with a hardening of geopolitical conflict between nations allied with the United States and China, Russia, North Korea and Iran. Although the Cold War may be over, the conflict between the Free World (sometimes known as “like-minded” nations) and authoritarian regimes, continues.

The growth of commercial space has prompted international calls for new space treaties and regulations to govern new space activities.[5] This includes current innovations such as the deployment and de-orbiting of mega-constellations as well as potential activities such as recovery of lunar and asteroid resources. Given the deterioration of relations with China and Russia and the diversity of space activities, it would seem a new, State-driven, agreement on space governance is unlikely. However, such an agreement cannot be ruled out as the first Space Age during the Cold War saw the creation of several new treaties for space, such as the 1967 Outer Space Treaty.

The growing importance of space to U.S. and allied security and economic interests poses a unique type of security dilemma. On one hand, access to and freedom of action within the space domain is a vital U.S. interest. On the other hand, the space domain today is not subject to U.S. sovereign control, either legally or practically. The United States could seek technical solutions to exercise hegemony over all space activities, but doing so would likely trigger an adversarial response that would not leave the United States or its allies in a better security position. So what else might the United States do to protect its vital interests in a domain it does not control – a domain even harsher and larger than the high seas? The United States could, in the alternative, persuade and, as necessary, deter other sovereign states from acting in ways that would harm U.S. vital interests. The hegemonic approach is essentially unilateral, although it may find support from close allies.[6] The latter is more multilateral, and extends beyond close allies, while not excluding the threat or use of military force. In either case, the scope and scale of future military and commercial space activities will determine what approaches to evolving security dilemmas are both necessary and feasible.

It is worth emphasizing the intensifying competition between the United States and China, which includes civil, commercial, and military competition in space. An essential difference is that the United States seeks to preserve its global leadership position and the established political and economic order and structures created in the wake of World War II, whereas China’s leaders view these structures and relationships as inimical to achieving the “China dream” of being at the center of global political, military and economic power. The Chinese Communist Party views space as another theater of competition for prestige, influence, as well as a potential resource to fuel economic growth and military power.[7] For example, a senior People’s Liberation Army official asserts that “The earth-moon space will be strategically important for the great rejuvenation of the Chinese nation.”[8] While not yet official policy, some Chinese officials also assert that the Moon and Mars are future territories that should belong to China.[9] This perspective raises serious questions about the willingness of the Chinese to work cooperatively with the United States and other nations on a wide variety of space topics.

China’s future path in space, or on Earth, is by no means determined. While Chinese Communist Party (CCP) General Secretary Xi Jinping clearly dominates political, economic, and military decision-making in China, there are numerous challenges facing the CCP leadership. China is facing significant economic contraction, as well as demographic aging, and other social challenges. While appealing to nationalistic tendencies, military operations against Taiwan and expanding China’s sphere of influence, while at the same time imposing ever tighter social and economic restrictions, could produce unintended consequences domestically and internationally. Slower economic growth, tighter restrictions on access to foreign technologies, and popular disaffection, may significantly impact China’s space programs even if open military conflict does not occur.

This paper seeks to look beyond immediate policy and programmatic debates over space activities and ask what global space activities might look like in the 2050s. What might civil, commercial, and national security activities look like in three decades? Given the growing importance of commercial and military space activities, how might these sectors impact each other?

2.0 Approaches to the Future

Making predictions about the future and crafting future scenarios is common to many fields, and space is no different. Some studies, such as the Global Trends reports by the U.S. National Intelligence Council are very broad in their inclusion of demographic, economic, and technological forces and their impact at societal, state, and international levels.[10] Others are also broad, but focused on the needs of a particular set of customers, such as the Global Futures report by the U.S. Air Force.[11] The Global Futures report also looks to the 2040 environment at the Global Trends report does, but focuses on possible future operating environments as they affect doctrinally-defined joint functions (e.g., Fires, Protection, Movement and Maneuver, Information, Intelligence, Command and Control, and Sustainment.) In these studies, space is an element of alternative scenarios, but not the focus.

Examples of space-focused forecasting studies would include work by the RAND Corporation for the United Kingdom, as well as internal strategic planning by private companies.[12] These studies reflect interest by a wide range of stakeholders in developing alternative futures, understanding their implications and the key forces that drive them, and the relative robustness of underlying assumptions. This paper is focused on potential space futures and largely from a U.S. perspective. It is also not a complete forecast of alternative futures, nor does it attempt to duplicate general economic, demographic, and technical forecasting studies, such as Global Trends, but does rely on them as foundational information.

There are many different approaches to forecasting the future, from extrapolating current trends and crowdsourcing expert opinions, to building complex mathematical models and scenarios of alternative futures. Each approach has its risks, from missing surprises through reliance on "conventional wisdom" to being overly deterministic and driven by hidden assumptions. Rather than trying to predict a likely or singular future, a more modest aim would be to understand what alternative futures are possible and indicators that a particular future is emerging. Positing a range of futures enables the bounding of uncertainty and mitigation of surprises. Identifying indicators of emerging futures allows the creation of strategies to exploit or hedge against events, without necessarily assuming a particular future will occur.[13]

Shell plc (formerly Royal Dutch Shell) is noted for its extensive use of future scenarios in developing corporate strategies.[14] Their approach is largely based on Peter Schwartz's work, "The Art of the Long View" in which alternative futures are imagined, indicators of those futures are sought, and strategies are developed should a particular future, or group of futures, emerge.[15] Unlike more consumer-driven forecasting (e.g., what fashions will be popular next season), developing alternative futures is a longer range, strategic exercise. The specific approach of Shell plc to forecasting is, understandably, corporate focused, in that it is seeking to anticipate the future in which Shell will operate but does not assume that it can dictate or drive that future.

Another scenario-driven approach, used by agencies with more potential to shape the future, is assumption-based planning (ABP) as developed by RAND.[16] In ABP, as in the Shell approach, scenarios are also developed along with indicators (also termed "sign posts") of alternative futures. ABP places a strong emphasis on identifying the most important assumptions leading to alternative futures and the vulnerability of those assumptions. ABP goes on to define shaping actions that can strengthen or weaken vulnerable assumptions, and finally, hedging strategies in the event an important assumption fails. Hedging in this context is distinct from a shaping strategy in that organizations are required to replan and function as if important assumptions fail (e.g., non-use of nuclear weapons in a conflict) not that such a failure has actually occurred.

In both the Shell and ABP approaches, analysts explore how to think about the future and can stop there. Both approaches also support the creation of top-level response strategies that move from "how to think" about the future to "what to do" about the future. While the difference may seem slight, the ABP approach aligns more closely with planning systems for organizations that have powers that can create different futures. Shell may invest in different technologies, reengineer supply chains, or enter new markets, but it does not have the ability to use military force or shift the global economy.

The identification of important assumptions and their vulnerabilities for particular scenarios can begin with extrapolation of current conditions and trends. Depending on the time horizon (in the present case, 30 years), various "shocks" may occur that change the course of future events. Exogenous events that could drive alternative space futures can be divided into "normal" changes and "radical" changes that affect supplies of labor, capital, and productivity. Examples of normal change, which can be foreseen and bound include: economic growth and shocks (e.g., recessions, inflation), budget deficits resulting in non-defense discretionary budget reductions, and education deficits resulting in skilled workforce shortages. Examples of radical changes, which are difficult to foresee and bound include a future Carrington event, Kessler syndrome, and catastrophic planetary impact, along a major realignment of the international political order, lethal pandemics, and national or global economic collapse.

The present article seeks to define the range of alternative futures for economic and military uses of space. What are key factors that would drive those futures? What are the national security implications of space commerce over the next 30 years? This examination does not say what the United States should do, but rather describes what is possible and what the drivers might be. As such, it is an exercise in how one might think about space futures rather than a prediction or set of recommendations. The next section briefly treats possible branch points among alternative space futures, some of which may result from "normal" developments while others would represent "radical" shocks.

3.0 Branch Points

Alternative space futures can be produced by changes in what space activities are seen as desirable, changes in what activities might be technically possible, and changes in affordability (e.g., due to lower transportation, manufacturing, or operating costs). In general, civil, commercial, and national security space activities are driven by the requirements of their mission, combined with opportunities presented by technological advancements. Requirements for scientific missions come from the priorities of particular scientific communities, such as astrophysics, planetary science, or Earth science, as expressed in reports for the National Academy of Sciences.[17] Commercial requirements are to make profitable returns for owners and investors. National security requirements are to deter conflict, and if deterrence fails, for the nation to win at an acceptable cost. In each of these cases, the space mission does not exist for its own sake but to accomplish larger scientific, commercial, security, or political objectives.

3.1 Human Spaceflight

Human spaceflight is the most visible and prestigious space activity, but with the least clearly definable requirements. President Kennedy's call to land a man on the Moon and return him safely to Earth "before this decade Is out" was a clear technical requirement, but the fundamental requirement was to restore and advance U.S. prestige during a global competition for influence. The race to the Moon arose from a geopolitical requirement, not a scientific, economic, or even a military one. This was not the only time geopolitics provided a rationale for human spaceflight, at least from the U.S. perspective. The Apollo-Soyuz mission in 1975 symbolized hopes for détente. The initial space station partnership of the United States, Canada, Europe, and Japan was meant, in part, to strengthen anti-Soviet alliances. The incorporation of the Russian Federation into what became the International Space Station was symbolic of hope for a post-Soviet relation with Russia. The centrality of international partnerships to the Artemis program reflects the importance that the United States attaches to international alliances in shaping governance of the space domain. During the Cold War, U.S. leadership in space was defined largely by what it could do alone. Today, U.S. leadership is also measured in its ability to attract others to common endeavors, such as Artemis.[18]

Looking beyond immediate U.S. plans to return to the lunar surface, a potential "breakout event" for commercial and national security space would be large numbers of humans living and working in space. While this is intensely desired by some, and viewed with skepticism by others, such an outcome would have impacts across a wide range of U.S. and international interests. Bohumil Doboš in his book "Geopolitics of the Outer Space" notes that current theorists of geopolitics consider the military, economic, demographic, and symbolic aspects of physical spaces in addition to their specific geography.[19] In the case of outer space, Doboš does not address demographic aspects as there are few people in space, but this could change in the future. If so, what might be the future of humans in space for purposes of geopolitical analysis? To answer that question, there are at least two sub-questions that serve as major branching points. Can humans support themselves using local resources or are they reliant on Earth? Can humans support themselves in space without relying on taxpayer support and subsidies? Which particular future arises is shown in Figure 1 below.[20]

If humans can use local resources and find economically self-sustaining activities, then some version of the science fiction of space settlements may occur. If government funding remains necessary, then humans in space may be a variant of McMurdo Station on Antarctica. If there are useful economic and scientific activities requiring humans, but long-term stays are not possible (e.g., due to biological reasons), then we may see space versions of deep-sea oil platforms. If reliance on Earth and Earth's taxpayers is necessary, then space can be a symbolic place, a place of adventure and science, but like Mount Everest, no one lives on it.

If government demand remains the dominant force in driving space commerce, then innovation can be expected to be slower and space activities more subject to government regulation as the government's economic power will be larger. If commercial demand becomes dominant, the commercial sector may grow more rapidly and organically, but policy problems will continue to arise – albeit in ways different from government dominated scenarios. Commercial providers can certainly be more efficient than governments, but there are some things only governments can do as they would otherwise make no economic sense.[21] The 2x2 matrix highlights the critical economic question for commercial space, whether its heavy reliance on government demand will continue. It is possible that by 2050 some well-funded and determined space companies may rival governments in terms of capabilities and, in some narrower ways, power and influence.

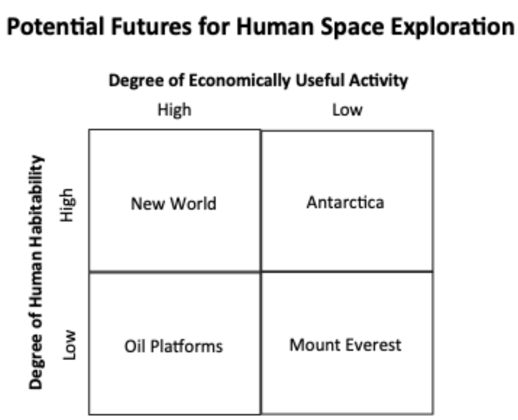

Figure 1

3.2 Potential Technical and Economic Developments

From a physics perspective, space capabilities depend on technologies that can manipulate matter, energy, and information. These technologies enable functions such as transportation, communications, navigation, power, etc. which can be used for various space-based and terrestrial missions. In terms of the Shell plc approach to forecasting, we could "scan the horizon" for technologies most relevant to the 2x2 matrix axes of "degree of human habitability" and "degree of economically useful activity." Large scale, exhaustive and horizon scans can require considerable time and effort, so this article is confined to the author's personal views.

Technology forecasting is inherently speculative. This is even more true when attempting to forecast which technologies will be economically competitive with sustainable applications. Getting new technology to work is hard, commercializing technology can be even harder. In terms of generating alternative space futures for 2050, we only need to identify technical capabilities that may find practical applications and what confidence we have in those judgments. Obviously, others may come to different assessments, but the basic methodology would remain the same – the sorting of identified capabilities in categories of high, medium, and low confidence for the target year. With those caveats, the most important technical and economic developments that could occur before 2050 include:

High confidence
- Reusable heavy-lift Starships work reliably and are economical to operate
- Additive manufacturing widely used in the space industry
- Sustained in-space maneuver capability for military payloads
- An interplanetary Internet using Delay Tolerant Networking
- Annual space tourism comparable to attempts to climb Mt. Everest (~800 persons)

Medium confidence
- In-situ and in-space resource utilization demonstrated and practical
- Space-to-space power beaming demonstrated at useful scales
- Small modular reactors are economically viable and used in space
- Artificial intelligence at human level is operationally useful
- Annual space tourism comparable to Antarctic tourism (~50,000 persons)

Low confidence
- Biotechnology allows for lifetime human habitation in space
- Manufacturing using molecular nanotechnology demonstrated

- Exploitation of in-space resources is commercially viable for terrestrial markets
- Space-based Solar Power is commercially attractive for terrestrial use

3.3 Events with Unknown Probabilities and Military Developments

Some potential natural and human-driven events may have unknown probabilities of occurring and thus there can only be low confidence in them occurring at all. Since they are possible, however, they should be taken into account when developing a range of possible (if not necessarily probable) future space scenarios. Unintentional events tend to be radical shocks.

Natural or Unintentional Events

- Carrington event impacts global infrastructure
- Kessler syndrome occur for some orbital altitudes and inclinations
- Catastrophic planetary impact

Many intentional developments can also have unknown probabilities, but like technical capabilities may be divided into high, medium, and low confidence levels. The most significant intentional developments are likely to be military space capabilities or events that shape the global environment for space activities. For example:

High

- Commercial assets in space targeted in conflict
- Space-based weapons for defensive counterspace (e.g., local self-defense)
- Norms of responsible behavior in space, observed by U.S. allies.

Medium

- Space-based ballistic missile defenses
- Space-based weapons for offensive counterspace space-to-space uses

Low

- Space “blockades” using space and ground-based weapons
- Space-based weapons for space-to-ground uses
- A new space-oriented arms control treaty

Detailed discussions of these military developments is beyond the scope of this paper. However, one example of commercial space capabilities creating a re-look at old military concepts concerns space-based ballistic missile defenses. The “Brilliant Pebbles" concept from the former Strategic Defense Initiative (SDI) utilized small kinetic interceptors in low Earth orbit to engage ICBMs in flight. In the 1980s, a constellation of 1,000 – 2,000 satellites with space-based interceptors seemed improbable and unaffordable. Today, constellations of that size, and larger, are being deployed in low Earth orbit for commercial communications and remote sensing. The same sort of large-volume satellite manufacturing could enable an affordable update of the “Brilliant Pebbles" concept – or so it might be argued. The technical issues involved are probably less difficult than the policy and strategy questions. Would the proliferation of space-based interceptors for missile defense improve or worse nuclear stability? Could such a system provide the capability to control access to space by other powers? In effect, could the system create a space blockade? If limited to self-defense of critical space assets (e.g., as a sort of space bodyguard), how could such a limitation be verified to reassure China or Russia that it did not threaten their nuclear deterrent or general space launch capabilities? Of course, the United States is not the only country capable of deploying “Brilliant Pebbles” today. How might the United States react if China would lead such a deployment?

It can be argued that a military space competition, if not an arms race, is already under way, driven by adversaries moving to exploit or defeat current U.S. space systems before the U.S. fields architectures with enhanced resilience and survivability.[22] There are major incentives for America’s adversaries to seek to exploit current U.S. vulnerabilities in space by rapidly developing and deploying a wide range of counterspace systems to deny, degrade or defeat space systems that support terrestrial military operations by the United States and its allies. This evidenced today with major efforts by Russia and China to develop, test and deploy such capabilities. In effect the United States, Russia, and China are facing a security dilemma in space where efforts to improve security for one triggers responses by the others. This cycle is made more intractable by arms control proposals that are both one-sided and unverifiable.[23]

It might be assumed that by 2050 both China and the United States will have adopted what they view as more resilient architectures (through proliferation, leveraging commercial space capabilities, alternative orbits, on-board defenses, etc.). At the same time, both sides may have also fielded both kinetic and non-kinetic counterspace systems in an attempt to gain a tactical warfighting advantage in space, which in turn makes the notion of resilience and security far more tenuous. In addition, both the United States and China could develop and possibly deploy anti-ballistic missile and anti-hypersonic strike system defenses in space. Hence, the "cat-and-mouse game" of both sides seeking to gain tactical military advantages in space will be an operational military concern, not just a theoretical one, by 2050.

Another potential "disruptor" could be one or both sides moving to deploy space-to-ground capabilities that could have a major impact on the early stages of a crisis or conflict. Such action could trigger a pre-emptive strike or an arms race qualitatively different than current military competitions. Finally, one might also consider a move by China to lay claim to large swaths of the Moon, its natural resources and associated mining rights, and possibly even LaGrange points or other pathways to the Moon or Mars, together with plans to actively defend such rights. An alternative future could occur if one side is unable or unwilling to participate in the competition, whether for economic or political reasons, as was the case for the end of the Soviet Union.

3.4 Common Factors Across Branch Points

There are some common factors that can be abstracted from the technical, economic, military, and diplomatic events that create alternative futures. The first is "Access" which means not only space launch capabilities, but in-space propulsion, power, communication, navigation, and logistical support. The second is "Security" which can include not just military security, but safety and sustainability as well. Examples might include efforts to mitigate the creation of orbital debris and potentially active measures to reduce the long-term probability of a Kessler syndrome – at least during peacetime. Finally, there is "Expansion" of actual and virtual human presence beyond the Earth for a multitude of reasons. If Access factors are supportive and Security is acceptable, then Expansion to the Moon and even Mars can occur. If done for reasons of scientific exploration and geopolitical prestige, human expansion beyond Earth will likely be slow due to dependence on government funding. If there are commercial motivations for human presence, then expansion could be faster.

More speculatively, at least within the 2050 time horizon, are the possible interactions of these factors. Greater access to space and human expansion could lead to new security requirements. For example, if the exploitation of in-space resources is commercially attractive and significant to the global economy, and the United States and its allies have a sufficiently large number of citizens routinely in space, a time may come when the United States will have vital national interests beyond the Earth. That time is certainly not today, but that day may come, along with new military and diplomatic challenges in protecting those vital interests. Such a situation may lead to a new, stable balance of power on Earth or it may lead to a more complex, multi-polar competitive and conflicted environment.

4.0 Context and Potential Shocks

It can be tempting to focus entirely on space-related factors in scenario development. Yet space developments do not, pardon the phrase, exist in a vacuum and assumptions about the context for scenarios are needed. Ideally, we should be explicit about what is known, unknown, and assumed regarding global political, economic, military, and technological conditions through 2050. Other forecasting efforts, such as the National Intelligence Council's periodic work on Global Trends, can be used rather than trying to duplicate their more rigorous efforts.[24]

The current (2022) estimate of the size of the global economy, about $100 trillion.[25] As might be expected, North America and Asia are the two largest economic regions, with the United States and China in first and second place respectively. China is projected to surpass the United States by 2030. The relatively small size of the Russian economy underscores that view that the world is once again moving into two competing blocks. On one side, the United States and its allies, and on the other, China. In between are a relatively smaller group of non-aligned countries. Even India, while remaining non-aligned, is a participant in an emerging Quad partnership with the United States, Japan, and Australia. The bi-modal, if not quite bi-polar, structure that has emerged in the last decade is one of authoritarian regimes on one side, such as China, Russia, Iran, North Korea, etc. and like-minded, if not always democratic, regimes on the other. The more confrontational approach of China coincides with the rise of Xi Jinping in 2012, and the deterioration of post-Cold War relations with Russia can be marked by Putin's invasion of Georgia in 2008, Crimea in 2014, and most seriously, the invasion of Ukraine in 2022. Both countries seek to restructure the international economic and political order established by the West in the aftermath of World War II.

In the past decade, China's economy and space capabilities have continued to grow. This includes not only PLA-led capabilities, but what looks to be an emerging commercial space sector. However, Xi Jinping's management of the economy has been at best uneven with signs of great economic stress –

both as a result of the Chinese zero-Covid policy and their own structural imbalances. How these economic stresses will affect the quasi-private space sector or China's civil and military government space efforts is unclear.

In contrast to China, the Russian economy has been structurally imbalanced for years, with a heavy reliance on oil, gas, and other natural resources for export earnings. Domestic consumer demand grew with the creation of a post-Cold War middle class as well as wealthy oligarchs. However, the consumer economy has been heavily dependent on imports and foreign technology. Russia has not developed a commercial space sector, or rather attempts at creating such a sector were crushed by Russian state enterprises. These enterprises in turn have been riddled with corruption and the loss of intellectual talent due to aging and emigration of talent. The result has been a Russian space sector in decline that does not have the ability to consistently innovate in space science and technology. Even traditional launch capabilities have shown increasing failures in the past decade. Various Western sanctions have eliminated space cooperation and commercial space trade with Russia, aside from the International Space Station.

Globally, and apart from the space sector, scientific and technical innovation continues at an impressive rate. The U.S. Department of Defense has identified several areas of science and technology for priority attention.[26] Artificial intelligence, quantum computing, and biotechnology have the potential for revolutionizing many economic sectors and create new dual-use challenges. Most recently, artificial intelligence has captured public attention with applications like ChatGPT. Continued improvements in advanced materials, microelectronics, cybersecurity, directed energy, and hypersonic technologies are also priority areas for research and it is easy to imagine space applications in all these areas. China is investing heavily in each of these areas as well as pilfering U.S technology on a massive scale. This makes it more difficult for the United States to sustain technical comparative advantages. At the same time, China's own innovation ecosystem has structural limitations that limit the exploitation of technical advances.[27]

Concurrent with scientific and technical innovation, national and global institutions are under increasing stress, resulting in a loss of trust in those institutions. The loss of trust is not merely the result of poor communications, but a reaction to incompetent performance and failures to meet the needs of large numbers of people. The loss of trust, and shortfalls in the capability or willingness of institutions to meet needs for which they were created will mean national and global collective action of all kinds will be increasingly difficult. It does not take much imagination to see growing gaps between space capabilities enabled by new technologies, and an inability to implement them due to government and corporate limitations. In addition, there can be an inability to manage potential harmful consequences of technical change due to institutions lacking necessary competency or legitimacy to be effective. For space activities, this may include orbital debris, radio frequency interference, and conflicts over the utilization of space resources.

One can look at the United States, Russia, China, and the rest of the world as conducting a kind of natural experiment on different relationships between space commerce and space security. The United States has an innovative private space sector and a large, experienced government space sector that seeks to exploit private sector capabilities, but struggles to keep up with technical change. Russia has a centrally-controlled government space sector that has prevented the emergence of a private space sector. Brain drain, corruption, lack of vision, and declining real budgets has resulted in a space sector that is neither innovative nor commercially competitive, albeit still militarily formidable. China's approach to civil-military fusion can be seen as an effort to foster innovation and competition while retaining central political control. China has invested considerable resources in creating a wide range of space capabilities, including human spaceflight, across state-owned and non-state enterprises. However, China's economy has major structural imbalance and Xi Jinping's assertion of greater political control over all areas of the economy. The commercial space sector is not immune from these broader economic forces.

For the rest of the world, small and medium powers are following paths similar to the United States. They are using limited amounts of government funding to foster their own space capabilities, some of which may produce revenue. These smaller and medium powers need to balance desires for full autonomy, which is expensive, with earning commercial returns through services using existing space infrastructures. Europe, for example, is studying whether to create an autonomous human spaceflight capacity in addition to unmanned science missions and space infrastructures (such as the Galileo and Copernicus programs). Japan is weighing how much effort it can and should place on building military space capabilities while fostering the growth of a more entrepreneurial space sector and maintaining its civil scientific program. Limited resources tend to result in the prioritization of dual-use capabilities (e.g., launch) consistent with broader hedging and shaping strategies, often with respect to the United States.

There are reasons for both optimism and pessimism when looking at alternative space futures. The technical capabilities for space exploration and utilization are better than ever. There has been a globalization and democratization of space activities that means there are many more opportunities for partnership and cooperation. There is broad global agreement on the desirability and attractiveness of space activity across diverse political cultures. At the same time, space continues to be hard and risky, both technically and economically. Many, many ambitious space visions over almost a century have failed to become reality. Moving forward, space activities face challenges to long-term sustainability against a backdrop of hostile great power competition not seen since the Cold War. The abilities of governments, transnational institutions, corporations, and other structures to meet challenges to space commerce and space security are in doubt.

As the two most capable space powers, the United States and China have the most potential to shape all sectors of space activity over the next three decades. There are several potential shocks the could change global space activity:

- Chinese invasion of Taiwan and military dominance in the Western Pacific
- Chinese hegemony in key technologies, e.g., artificial intelligence
- Chinese and U.S. competition for space resources, should those prove to be economically attractive
- Chinese economic and social unrest

China, and more specifically, the Chinese Communist Party, find space activities attractive for a variety of reasons. These include enhancing domestic prestige for the CCP, improving scientific and technical capabilities, creating options for foreign trade and influence, and of course, enhancing China's economic and military power. It is possible to imagine U.S.-Chinese cooperation on a wide variety of civil, scientific, and even commercial space activities, depending on the state of political relations (which are currently poor and likely to remain so). Thus a major branch point for alternative space futures, setting aside the four potential shocks noted above, is whether a military conflict, extending to space, occurs with China, and why. Alternatively, there could be nuclear and space-related arms control agreements that China would decide to observe. Or there could be a space arms ``stroll" if not a race in which both China and the United States develop offensive and defensive counterspace capabilities, but at a moderate pace with neither achieving a hegemonic position in space. A major uncertainty here would be how the Chinese leadership perceives space activity -- as a practical tool for specific military, economic, and diplomatic objectives, or in addition, as a larger political symbol for the destiny of the Chinese nation and the leading role of the CCP in the 21st Century?

5.0 Sample Scenarios

Given a general context and possible branch points, we can briefly describe at least four alternative space scenarios through 2050. These scenarios exclude catastrophic events such as general nuclear exchange or an asteroid impact. Not surprisingly, each future tends to have overlapping elements with others. More variants could be easily added.

China Remains – China continues its current plans for human spaceflight, completing and maintaining a space station. They orbit the Moon and conduct a human landing in the 2030s. The International Space Station was deorbited prior to 2030 as it became too difficult to maintain. Russia continues to claim it is working on its own Station but has not flown yet. Proposed commercial U.S. private platforms have not been able to find non-government customers or attract significant private funding. China is the only nation conducting human spaceflight, other than some suborbital U.S. tourism companies.

Artemis – China's plans for human spaceflight continue as described above. The United States lands on the Moon with an Artemis mission in 2028, years later than initially planned due to delays in qualifying the Starship-derived Human Landing System and the cost of the Space Launch System. The Lunar Gateway is operational and plans are for international partners to reach the Moon on Artemis V and beyond. Japan and Europe lack an autonomous human spaceflight capability. The International Space Station was deorbited in 2030. There is a small space tourism and manufacturing sector (mostly biological) to various crew-tended space platforms in low Earth orbit.

McMurdo Station – The Starship-derived Human Landing System is reliable and relatively low cost. The Space Launch System is retired after Artemis

VII with the last three core stages placed on display around the country. Starship cargo capacity allows the building out of a major base at Shackleton Create and sustainment of temporary campsites at various locations on the Moon. Lunar water is cracked into oxygen and hydrogen and transported to the Lunar Gateway, which serves as a fuel depot in high lunar orbit. The first human flyby of Mars and return occurs in the late 2030s with plans for a landing before 2050. Space is a critical domain for national security activities, but for the most part, all declared counterspace weapons are ground-based and not stationed in space.

For All Mankind – China has continued its human spaceflight plans as described earlier. The United States has been able to establish a sustainable presence on the Moon as described by "McMurdo Station." Concurrent with human missions to Mars, there is a space arms race between the United States and China. The United States has deployed bodyguard satellites around critical U.S. and allied space assets to defeat Chinese ground and space-based ASATs (and hedge against residual Russian, Iranian, and DPRK capabilities). China and Russia believe the bodyguard satellites to be space-based weapons that are precursors for a Brilliant Pebbles-like effort to undermine their strategic nuclear deterrents. Despite U.S. denials, China and Russia also argue that the U.S. satellites will create a hegemonic position in which the United States alone will decide who can have access to space. They declare this to be unacceptable and will not accept such systems becoming operational.

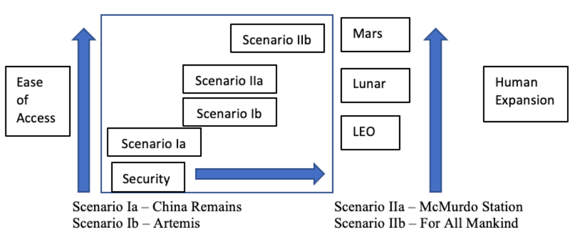

Figure 2 – Notional Scenarios

As shown in Figure 2, scenarios can be organized according to a few common factors. "Ease of Access" and "Human Expansion" closely track each other as humans tend to go where they can, if they can. The emphasis on "Security" specifically in the space domain can vary from the current status quo to a driving theme. In the case of the "For All Mankind" scenario, there is intense competition between the United States and China across civil, commercial, and military sectors. This involves developing the Moon, racing to Mars, and building space-based weapons systems to protect space, as well as terrestrial, interests.

In the case of the "China Remains" scenario, the United States largely stops its human spaceflight efforts while China continues with its current plans. Humans do seek to expand beyond the Earth, but they are not those of the United States and its allies. Space security is similarly a lower factor as the United States does not attach high importance to new activities beyond what it is currently doing.

In the case of the two middle scenarios, "Artemis" and "McMurdo Station," the focus is on the Moon. In the case of "Artemis" space activity remains scientifically focused and government funded. In the case of "McMurdo Station" commercial involvement is more extensive along with the exploitation of lunar resources in supporting a sustainable base – rather than just temporary, expeditionary camps similar to Apollo. In both scenarios, military attention remains focused on the Earth, where all U.S. vital interests reside. However, civil, commercial, and international partners in the "McMurdo Station" scenario create important dual-use capabilities in cis-lunar space. These capabilities for transportation, power, navigation, communication, and logistical support provide a potential hedge against future military needs. Needs that may not exist immediately, but could arise if U.S. vital interests were to extend beyond the Earth in the future.

6.0 Critical Assumptions and Branch Points

The common factors of "Access," "Expansion," and "Security" contain critical assumptions and branch points leading to multiple scenarios. A foundational critical assumption is that space activities themselves will be sustainable. This means that humans have the capability to access space and the space environment is permissive of doing so, i.e., no overwhelming catastrophe has occurred, such as:

- Nuclear war or lethal pandemic sufficient to stop the global economy
- Massive Carrington event that collapses global infrastructure
- Kessler syndrome is so severe as to block access to at least low Earth orbit.

For Access, technical capabilities are paramount, such as:

- Lower cost space launch, e.g., reusable heavy-lift

- Lower cost in-space transportation, e.g., reusable nuclear electric propulsion
- Reliable, proliferated in-space power, e.g., small modular reactors.

For Expansion, technical capabilities are necessary, but not sufficient. As noted in Figure 1, a particular future for humans in space depends on the ability to use local resources, the ability to engage in economically productive activities, and more subtly, the ability of humans to remain in space indefinitely. The latter is often overlooked as missions are conceived of as being a few years in length at most (e.g., a mission to Mars). However, it is unknown whether or how long humans can remain healthy on the Moon, Mars, or in free space. Even less is known about the ability of humans to reproduce or mature away from Earth.

For Security, both material and non-material factors are important. In contrast to Access and Expansion factors, the adversary gets a vote. That is, national ambitions and aspirations, in addition to the perception and reality of threats, drive how States see Security in future space scenarios. Key assumptions would necessarily include the behavior of adversaries, national interests and will, and material capabilities. For example:

- The world continues to be bi-block (if not multipolar) in which the United States supports a traditional, rules-based international order. Outside of that order are States and sub-national groups (e.g., terrorists) seeking to change that order.
- Vital national interests continue to be centered on the Earth. The space domain supports critical, national capabilities, but there are no space assets (e.g., a lunar settlement, Martian colony, asteroid mining operation) that are as vital as assets on Earth.
- Dual-use space capabilities driven by commercial interests are foundational to space security capabilities. Access to space, human expansion in space, and space security are neither affordable nor sustainable without a strong commercial (or at least revenue-producing) industrial base. This is true of all space-faring states, including China.

6.1 Critical Questions for Dual-Use Space Capabilities

The last point above about dual-use space capabilities is increasingly important and will be through 2050. Globally competitive, innovative firms tend to rely on global supply chains. U.S. space security capabilities are thus reliant on those supply chains. Several questions arise from linkages between commercial and defense industrial bases (which are largely indistinguishable), such as:

- Can reliance on China be effectively reduced in critical sectors and is relying more on domestic or at least like-minded sources feasible?
- In the global competition for technical talent, how can U.S. security interests compete with or align with commercial interests?
- In the global competition for markets, how can U.S. security interests align with commercial interests and where do they have to be distinct?
- How and what kind of intellectual capital does the space security community need to maintain? In particular, what capacities are needed within the U.S. government? What capacities can or should be outsourced?

While there are many technical and economic factors that can affect linkages between commercial and military activities, it is arguably social factors that will make the greatest difference among alternative space futures. This results from the fact that it's humans who give meaning and interpretation to material capabilities. Is something seen as a vital interest and worth sacrificing blood and treasure to gain? Are technologies used in a way that people find helpful and positive? Or do they find those same technologies objectionable and subject them to regulation, control, or even suppression? Where and when do non-government institutions and cultures matter to space, if at all, and why? As examples of social factor that could affect space activities, consider the following:

- Space tourism could, in principle, be a major new market for space activity, but it depends on demonstrating ambitious price/safety points. In particular, it depends on risk acceptance somewhere between climbing Mount Everest or taking an Antarctic cruise.
- Shifting the bulk of electrical power production to renewables does not appear economically possible. Even so, lower use of fossil fuels and greater electrical power use will still require major improvements in battery technology and grid management. The demand for rare earth elements may make future exploitation of near-Earth asteroids attractive.

- Regulatory and licensing decisions will have the greatest impact on the economic feasibility of small modular reactors, not technical readiness.
- Can large scale solar power satellites be economically competitive without government support and preferences? Should they be preferred? If so, why? What are the security risks of large, concentrated systems?
- As space-based information technologies, such as geospatial technologies, become more widely integrated into the economies of the developing world, do they lead to greater freedom and innovation or greater authoritarian social control and oppression?
- Under what conditions would the United States recognize vital national interests beyond the Earth?

7.0 Closing Observations

Returning to our initial questions, what is the range of alternative futures for greater economic and military uses of the space domain? What are the key factors that would drive those scenarios? What will be the relationship between national security and space commerce over the next 30 years? There are many uncertainties and specific outcomes that would enable or drive particular scenarios. Some uncertainties are technical, others are economic, and some are policy-based, dependent on the actions of sovereign states.

Perhaps the most important national security implication of space commerce is that there is and will be an increasing dependence of national security on space commerce. This is true generally in terms of the economic strength and innovation necessary to generate military power. Specifically for military space power, there cannot be a credible, government-driven space effort without a strong commercial space sector. This is a fundamental weakness of Russia and a reason for pessimism about their long-term prospects in space. It is also a reason for optimism about the United States, and uncertainty with regards to China in space.

Second, access to space and human expansion into space depend on lower cost, reliable technologies that enable greater autonomy from Earth. This autonomy needs to be physical, such as the use of local resources and the ability to live in space, as well as economic, in terms of becoming more self-supporting. Human space exploration will not cease if there are no viable economic opportunities for humans beyond low Earth orbit, but it will be a government-driven exploration and not a society-wide effort.

A third implication is that space commerce may or may not drive the creation of vital national interests beyond the Earth. A few scientific outposts on the Moon and Mars are not likely to be worth fighting over. A massive trade in rare Earth materials, vital to terrestrial economies, economical solar power satellites providing power to Earth, and self-sustaining settlements of U.S. and allied citizens would likely constitute vital interests – just as trade, colonies, and sea power were vital to the British Empire.

There can be secondary consequences for national security as a result of commercial space activities. For example, large numbers of satellites that are not carefully managed could pose risks to space sustainability by increasing the chances of orbital collisions. Any use of kinetically destructive anti-satellite weapons could make for a much more dangerous debris environment. At the same time, the dual-use utility of commercial satellites would make them military targets in a conflict that extended into space. The terrestrial manufacturing and data analytic capabilities enabled by mega-constellations could also support new, dedicated space-based weapons for a range of missions. Those missions could be purely defensive, such as bodyguard satellites around missile warning satellites. Or they could be used for offensive counterspace missions against space assets, ICBMs transiting space, or against ground-based targets. Space-to-space weapons, or space-to-ground weapons, could become more economically attractive based on new commercial satellite manufacturing lines. Likewise, military-focused, manned facilities may become feasible due to dramatically reduced launch costs. The United States, China, or both could deploy such systems.

What might be key signposts of different scenarios emerging? A loss of U.S. domestic political support for human space exploration would leave China the global leader by default. Successful demonstrations of a reusable heavy-lift capability and the Starship-based Human Landing System would make the Artemis scenario both feasible and likely. The demonstration of lunar-based hydrogen and oxygen production would make a McMurdo Station on the Moon more sustainable and more likely. An expansion of economic activity in space distinct from direct government subsidies could accelerate human expansion and could create vital national interests beyond the Earth. A new balance of power, with international agreement on responsible norms of behavior in space could herald greater peace and prosperity on Earth. In the alternative, continuing tensions with China on Earth could extend into space as well. This would be the For All Mankind scenario in which the 1960s space race never ended.[28]

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