How and why does space power develop over time? A factor-based qualitative and quantitative approach to understanding global space power development.

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Abstract

This paper answers the question of how and why space power developed over time. The analysis proceeds in three stages: 1) case studies, 2) factor-based regional analysis, and 3) quantitative analysis. Existing research on space power is typically compartmentalized by country or capability. This paper breaks from such compartmentalization to produce globally applicable conclusions. The paper's conclusions are relevant to the U.S. in two ways. First, the underlying motivations for space power development will inform U.S. efforts to lead in developing sustainable, globally accepted space policy. Second, the dual nature of space capabilities will likely destabilize the current balance of power. This paper provides critical context for how and why a particular region or country accessed outer space. This information will assist the U.S. in interacting with other nations in this newly unstable era.

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Introduction

The dawn of the space age made apparent the many potential uses for space technology beyond spaceflight. Despite the benefits of space technology for intelligence gathering, environmental monitoring, and global communications, most countries remain non-independently spacefaring. However, the number of spacefaring nations is rapidly increasing, according to Our World in Data (2023), as decreasing launch costs have made accessing space significantly cheaper (Roberts, 2020). This increased activity in space has two notable consequences. First, it calls for the development of global space policy that will be respected and endure. Second, it alters the current balance of power as more countries gain access to space technology, which can then be used for peaceful and non-peaceful purposes.

The reasons a country develops space power and how it attempts to do so are relevant considerations in crafting sustainable space policy and ensuring there is a peaceful balance of global space power. Space power is defined by the U.S. Space Force as, "...the totality of a nation's ability to exploit the space domain in pursuit of prosperity and security," (Dorian et al., 2020). Sustainable policy is designed from the outset to, "Achieve the goals that proponents set out to achieve and attract no criticism of any significance and/or is virtually universal." (McConnell, 2020, p. 351). Accomplishing universal acceptance requires the policymaker to identify, understand, interact with, and account for minority, dissenting, and absent voices. Overlooking inclusion in the policy environment invites political and social rifts, such as those which could emerge as non-spacefaring nations become active in outer space and inherit a policy framework to which they did not agree. It is therefore important to understand the historical context and trends driving how and why countries have, or have not, developed space capabilities. Historical trends clue decision-makers into the thought process behind another actor's behavior. In this approach, not only can the U.S. craft nuanced global policy that accounts for different space actors, but it will be aware of potential pitfalls and develop nuanced approaches to bilateral and multilateral interactions in space endeavors.

This paper examines 70 years of space history to investigate how and why each global region developed power in outer space. It uses qualitative case studies to identify regional trends and quantitative analysis to substantiate them. The trends are summarized and compared, producing results that demonstrate the factors that led each region to develop space power. The conclusion summarizes how these results can inform U.S. efforts to lead global space policy in a sustainable, globally accepted manner, and how the results can inform U.S. interactions with others in this newly unstable space age.

Qualitative Study

This study includes three distinct yet complementary parts: 1) case study collection, 2) regional analysis, 3) quantitative analysis. Case studies were completed on individual countries, followed by regional analyses using the information gathered. The regions and their countries are summarized below:

Africa: Kenya, Nigeria, Rwanda, South Africa

Asia: China, India, Japan, North Korea, Pakistan, South Korea

Europe: Finland, France, Italy, United Kingdom

Middle East: Egypt, Iran, Israel, Saudi Arabia, Turkey

Latin America: Argentina, Brazil, Mexico, Venezuela

U.S. and Allies: U.S., Canada, Australia

All countries chosen for case studies have a form of space programming, whether advanced or basic. Countries were divided regionally based on geography. Once the studies were completed, authors ranked each region on thirteen factors to determine salient factors for space power development in that region. The thirteen factors, which are derived from the substance of the case studies, are shown in Table 1. After ranking, authors compared the factors across the regions to draw conclusions about development and the future of development in that region.

The qualitative portion of this study reveals trends that map onto the quantitative results. Table 2 shows complete rankings for each region. The case studies and regional analysis show that Latin America and Africa have the least developed space programs. These regions are the most underdeveloped socioeconomically, have weaker militaries, and face more domestic unrest and less international (i.e., cross-border) turmoil than other regions. Latin America and Africa are rich in natural resources and have historically faced consistent extraction, and therefore might have a greater incentive to use space power for environmental monitoring and protection purposes (Amazonia: Uses and Applications, n.d.; Harding, 2013, p. 148; Behera, 2021; Ayman, 2021).

In other regions, a stable government, whether democratic or autocratic, is highly relevant to the initial and continued development of space power. The ease with which private actors can enter the space industry are also relevant factors. Such markets that are more likely to present complex regulatory schemes, have frequent government intervention, and consist of preferential treatment towards domestic industry tend to inhibit space power development and appear more often in countries with autocratic governments.

The analysis suggests that security concerns during the Cold War often drove early space programs. In contrast, new countries entering the space industry today are motivated primarily by environmental or economic concerns. These concerns include, for instance, ensuring a country's workforce has adequate communications infrastructure to perform essential duties and a desire to increase global standing and garner inter

Factor	Ranking (1 to 5)
Strong government driver	1: Private sector drove the initial development of space power 5: Government drove the initial development of space power
Strong civilian vision	1: Space power developed mainly for civilian applications (telecommunication, environmental monitoring) 5: Space power developed mainly for military purposes
Continued government driver	1: Private sector is driving most of the space power development today 5: Government is driving most space power development today
Conflict as main driver of development	1: Space power developed mainly as a response to a civilian desire for national modernization efforts 5: Space power developed mainly as a response to conflict to increase national security
Democratic form of government	1: The region is highly democratic 5: The region is highly autocratic
International partnerships	1: International partnerships were not important to the development of space power 5: International partnerships were critical to the development of space power
Domestic unrest (high government turnover, rebellions, civil wars, etc.)	1: The region faces little to no domestic unrest 5: The region faces constant domestic unrest
International conflict (regional unrest, foreign invasions/intervention, has clear enemies/allies, generally feels threatened, etc.)	1: The region faces little to no international unrest 5: The region faces constant international unrest
Environmental concerns (frequent natural disasters, significant illegal activity such as logging/poaching, rich in natural resources, etc.)	1: The region is not very concerned with the environment 5: The region is highly concerned with the environment
Socioeconomic development (GDP, poverty, education, health, etc.)	1: The region is significantly underdeveloped 5: The region is highly developed
Private enterprise	1: The region is closed to private enterprise (most enterprise is government driven) 5: The region is open to private enterprise (significant investment and innovation occurs in the private market)
Military	1: The region is the weakest militarily 5: The region is the strongest militarily
Nuclear and ballistic missile capabilities	1: The region has no nuclear or ballistic missile capabilities 5: The region has many countries with nuclear and/or ballistic missile capabilities

Table 1: Shows each factor on the left and contains the descriptor for the high/low ranking on the right. Each factor is contained in its own row.

national investment. Programs initiated primarily for military or security purposes tend to last longer given their directed, narrower, focus. Additionally, a strong military with nuclear and ballistic missile capabilities indicates greater space power, whereas the presence of natural resources does not necessarily indicate the same.

Finally, international partnerships are critical to most regions' space power development. Most countries could independently and rely on sharing expertise and importing technology regionally and internationally. Partnerships are particularly important in regions with fewer security threats and lower socioeconomic development.

Quantitative Study

The quantitative analysis explores factors that might affect the development of a country's space program. The first method employed for the quantitative analysis consisted of an ordinary least squares (OLS) model where the number of satellites was predicted using five factors. OLS is an effective statistical technique often used to determine the relationship between a dependent variable and one or more independent variables, assuming a linear relationship exists. We aim to predict the number of satellites based on the following quantitative economic and geographical factors:

GDP-PPP per capita: A country's economic output likely influences its ability to develop a space program.

Shoreline length: It is hypothesized that access to shorelines is beneficial for rocket testing and development which is important to developing a space program because launches occur most often on the coast.

Net Migration: Net migration intends to capture factors that make a country a favorable/unfavorable place to live, and whether it could be experiencing brain drain.

Percent of GDP spending on education: It is hypothesized that countries that prioritize education spending (especially in science and technology)

Factor	Africa	Asia	Latin Am.	Middle East	Eurasia	Europe	U.S., CAN, AUS
Strong government driver **1: Private sector drove initial development of space power** **5: Government drove initial development of space power**	5	4	5	5	4	3	5
Strong civilian vision **1: Space power developed mainly for civilian applications (telecommunication, environmental monitoring)** **5: Space power developed mainly for military purposes**	2	3	3	3	3	3	4
Continued government driver **1: Private sector drives most space development today** **5: Government drives most space development today**	4	4	4	3	3	3	3
Conflict as main driver of development **1: Space power developed mainly as a response to a civilian desire for national modernization efforts** **5: Space power developed mainly as a response to conflict to increase national security**	2	3	4	5	3	2	4
Democratic form of government **1: The region is highly democratic** **5: The region is highly autocratic**	4	3	3	5	2	1	1
International partnerships **1: International partnerships were not important to development of space power** **5: International partnerships were critical to development**	5	2	5	4	5	4	3
Domestic unrest **1: The region faces little to no domestic unrest** **5: The region faces constant domestic unrest**	5	2	4	5	2	1	1
International conflict **1: The region faces little to no international unrest** **5: The region faces constant international unrest**	1	5	2	5	3	2	3
Environmental concerns **1: The region is not very concerned with the environment** **5: The region is highly concerned with the environment**	5	5	5	4	2	5	3
Socioeconomic development **1: The region is significantly underdeveloped** **5: The region is highly developed**	1	3	2	3	3	5	5
Private enterprise **1: The region is closed to private enterprise** **5: The region is open to private enterprise**	2	4	2	4	2	5	5
Military **1: The region is the weakest militarily** **5: The region is the strongest militarily**	1	5	2	4	3	4	4
Nuclear and ballistic missile capabilities **1: No nuclear/ballistic capabilities** **5: Many countries with nuclear/ballistic capabilities**	1	5	1	5	2	4	4

Table 2: Shows each region's ranking for each factor on the 1 to 5 scale. The rows contain the factor description and the columns contain the regions.

will have an advantage in building space programs because there will be increased domestic population with the knowledge and skills to support a space program.

Gini Coefficient: Intended to measure the distribution of income inequality within a country.

The dataset used in the OLS analysis includes emerging space powers, defined as all countries operating at least one active satellite. This dataset excludes the U.S., China, and Russia because their dominance in the satellite industry dramatically skews the results. This analysis uses the Union of Concerned Scientists' (UCS) Satellite Database to estimate the number of satellites managed by each country. When multiple countries owned or operated a satellite, each country was credited for the satellite. The analysis excluded satellites managed by the European Space Agency because it is an organization and not an independent country. Military and non-military satellites were distinguished based on the "Users" listed by UCS. Satellites were classified as "military" where UCS listed multiple users including at least one military (i.e., "commercial/military"). The size of each country's military was compiled from The Military Balance, published by the International Institute for Strategic Studies, and included the total number of service members across all branches of a country's armed services. Averages were used when The Military Balance gave a range. The remaining data was sourced from the CIA World Factbook in May 2023.

The results of the first OLS model indicate that military size, GDP per capita, and shoreline length were statistically significant predictors of space power at the 0.05 level of significance. This model had an R-squared value of 0.4773, which suggests that the predictors included in the model can explain nearly 48 percent of the variance between countries. A second OLS model predicted the number of satellites controlled by each country's military. This model also used robust standard errors but showed no statistically significant predictors of the number of military satellites. However, this is likely because the sample size is too small to make an accurate prediction; of the 72 countries that operate at least one satellite, only 26 have military-controlled satellites.

The second type of model used in the quantitative analysis was a hurdle model. The hurdle model assumes two processes are behind the development of an initial satellite and subsequent satellites. Once a country clears the hurdle of establishing a first satellite, a different set of factors will likely influence how many satellites a country controls. This type of analysis is helpful in determining if there are any preliminary barriers to entering the space arena, which in turn is useful in monitoring country-level space activity to predict when a country might become independently space faring.

All countries, including the U.S., Russia, and China, were factored into the hurdle model analysis, regardless of the number of satellites. This decision reflects the nature of hurdle models, which are well suited for zero-inflated datasets. This dataset is zero-inflated because only 75 countries possessed active satellites at the time of this analysis, while the remaining countries possessed zero satellites. The results of this model demonstrate that GDP per capita and military size are the two statistically significant predictors of launching a country's first satellite (i.e., the first process of the hurdle model). Then, each variable, except net migration rate, are statistically significant predictors for the development of future satellites (i.e., the second process of the hurdle model).

The results of the OLS and hurdle model suggest a correlation exists between developing a country's space program and its economic and military strength. However, these results do not necessarily suggest that GDP per capita or military size has a causal relationship with space programs. The second stage of the hurdle model provides a more nuanced view of the factors that predict the development of additional satellites after establishing a country's space program.

Discussion

This paper presents preliminary findings on how and why countries develop space power. The results demonstrate that countries develop space power primarily through international partnerships. Two exceptions stand out: 1) early programs, such as the U.S. and Russia, which developed out of national necessity during the Cold War, and 2) programs in countries that are highly insular, such as China and North Korea. Those programs are primarily developed in-country and historically depend less on formal international partnerships. Apart from these exceptions, countries at all development levels rely on partnerships to advance their space programs. For example, Canada and Australia, two highly developed nations, rely on allies for technology sharing to develop space power cost-effectively, allowing wealthier countries to work out the technological issues before acquiring it themselves (OECD, 2022; UNDP, 2022, p. 298; Hanberg, 2017, p. 209). Additionally, European nations rely on the European Space Agency to build collective power rather than building their space capabilities alone. Underdeveloped countries, such as those in Latin America and Africa, must import technology from partners because domestic expertise has yet to develop.

Despite Russia's formidable nuclear arsenal and modern military, Russia lacks the economic and human resources to expand and improve upon their once powerful space program and instead relies on its critical partner China to foot the bill (Kramer and Myers, 2021). The U.S., China, and North Korea all leveraged technology and expertise from other countries to launch their space programs. The U.S. adapted German V2 rockets, Chinese space scientists gained their expertise through training in the U.S., Germany, Soviet Union, and Britain, and North Korea adapted Russian equipment for counterspace capabilities (Beardsley et al., 2016, p. 1; Uri, 2023; Harvey, 2019; Harrison et al., 2018). Thus, even in countries boasting strong, independent space programs, international partnerships have played a critical role in space power development.

The results show that wealth, including both monetary and human capital, and government ambition are two essential requirements that go hand in hand in space power development. Absent wealth, regions are less likely to develop independent space power, as Latin America and Africa demonstrate. These two regions imported most of their space power, albeit with some domestic contributions being made (Klinger, 2020; Oyewole, 2020; Froelhich et al., 2020). Wealth allows countries to import technology and typically indicates a more robust education system and scientific programming, which in turn allows countries to develop domestic space technology. Absent government ambition, even wealthy countries will fail to build space power, as demonstrated in Canada and Australia (Jones and Macken, 2019, p. 22; Godefroy, 2011, p. 68). Ambition motivates governments to spend on space, whether to initiate domestic programs or import technology and expertise and encourages governments to welcome private space industry. This ambition and investment fuels rapid space mobilization through public-private partnerships. Therefore, both wealth and government ambition are critical drivers of space power development.

Underlying security concerns can also explain how and why countries developed space power. First, most space technology has roots in late World War II weapons technology. The space age opened with the close of World War II, when missile and rocketry technology advanced enough to produce enough launching power to send equipment into the atmosphere (Beardsley et al., 2016, p. 1; Uri, 2023). The desire for long-range weapons systems, secure global communications infrastructure, and intelligence gathered at a safe distance drove nations to develop launch facilities, powerful rockets, and satellites. Without developments in military technology, space technology might not be what it is today. Second, space and military power have been intertwined since the early days of space. One only must look to the development of nuclear weapons and the need to build, launch, and defend them in the beginning of the space race. Alternatively, one could look to the need for intelligence on hostile neighbors that drove the rapid acquisition and development of space technology in the Middle East in the 1970s and 1980s (Harvey et al., 2010). Space remains critical to modern defenses, as ballistic and nuclear weapons are each launched using space technology while satellites provide crucial intelligence on crucial security targets like troop movements and military installations. Therefore, it is easy to see why many early space programs were initiated to bolster hard power in the latter half of the 20th century.

Through space programming, many countries still seek military power and other forms of soft power, such as the prestige that comes with being a spacefaring nation. Many newer programs, such as those started in Africa and revived in Latin America, are more focused on acquiring and implementing space technology for economic and environmental purposes. Regions that rely on natural resource extraction and sales, such as Latin America and Africa, seek to use space technology to monitor the environment for illegal activities and climate change-related disasters, hoping that they can reap economic benefits from such monitoring while bolstering their overall security and preparedness. In Brazil, for example, the Amazonia satellite program is used to detect and monitor Amazon rainforest deforestation to maximize profits and minimize illegal logging ("Amazonia: Uses and Applications," n.d.). Other regions see the space industry as an opportunity to boost the local economy by attracting foreign investment. For example, Australia recognized it was, "...failing to capture a significant share of a global space industry…" and has since worked to facilitate in-country investment in the private space industry (Dougherty, 2020; Blake and Lange, 2018). Still others see space to bring the country into the modern era, wanting to ensure that communication, internet, and broadcasting are reliable and accessible nationwide (Behera, 2021, pp. 52-53; Gottschalk, 2010, pp. 36-37). Typically, regions with little international conflict have the most peaceful space power applications, such as in Latin America and Europe. In contrast, countries and regions facing transnational threats, such as Asia and the Middle East, prioritize military applications.

Conclusion

The reasons behind space power development by any country are essential for the U.S. to understand for purposes of crafting foreign policy and engaging in international politics. The U.S. has significant space resources and expertise that it can leverage as bargaining power in interactions with other spacefaring countries. As a leader in outer space, the U.S. has a keen interest in influencing, if not shaping, global space policy through its hard and soft power. Suppose the U.S. desires a sustainable, rules-based order framework for global space regulation. If so, the U.S. must advocate for inclusive policy, whether they are major spacefaring nations or U.S. allies, and proactively involve all countries in space policy creation. Proactive inclusivity will further the chance of long-term global compliance and make the policy resistant to later undermining efforts. By understanding how and why regions and individual countries seek space power, the U.S. will bring a more sensitive and nuanced position to global policy issues.

Understanding the historical context of how and why space power developed across the globe will be important in deciphering the era to come. The nuclear era found balance in mutually assured destruction; the space era will ultimately balance in the same way. Although many states pursue space assets for peaceful purposes, whether economic or environmental, most space technology is dual use. This means that space technology is simultaneously useful for peaceful and non-peaceful purposes. With more and more states entering the space arena, more states will have access to the non-peaceful applications of space technology. This dual nature of space, and the increasingly crowded domain of space itself, will alter international politics. Having context for how and why a particular region or country accessed outer space in the first place will be critical to informing nations on how they should interact with one another in this new unstable era.

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