An Economic Goods Analysis of U.S. Space Situational Awareness (SSA) Policy

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Executive Summary

At the simplest level, space situational awareness (SSA) is about understanding the current and future locations of space objects, communicating that information to stakeholders, and ensuring the continued safety of spaceflight. On April 16, 2018, U.S. Vice President Mike Pence announced that the National Space Council had developed a new U.S. policy to address SSA. While he did not provide much detail, Pence did state that the Council had directed the Department of Commerce "to provide a basic level of space situational awareness for public and private use, based on the space catalog compiled by the Department of Defense, so that our military leaders can focus on protecting and defending our national security assets in space."[1] This announcement highlights a fundamental question for the U.S . government in its approach to SSA– what role should the U.S. government play in SSA?

An economic goods analysis of SSA can be a crucial step towards answering this challenging question about the role of the U.S. government. An economic goods analysis of SSA is useful because it can clarify the core government functions in SSA, identify the privately provided elements of SSA, and make explicit the policy decisions that are currently shaping the economic and technological environment of SSA.

In this paper, I conducted an economic goods analysis by expanding the conversation around SSA in two ways. First, I tried to disaggregate the concept of SSA from a single economic good into its component pieces and then treat each of these pieces as its own good. Second, I used an expanded definition of economic goods to find variation in the level and type of exclusion among goods. Following these two expansions, I conducted an economic analysis of the SSA components using these tools.

By conducting this analysis, I concluded that when SSA is considered as a single good it is a public good because it provides benefits such as national security, free enterprise, and space sustainability to all Americans. However, delivering this public good involves a more sophisticated approach than simply providing each element of SSA through the U.S. government. This analysis reveals that in order for the U.S. government to deliver the larger public good of SSA, the U.S. government will have to use different strategies to address each type of good represented within SSA.

These conclusions have several implications for policymakers thinking about SSA. First, the U.S. government should focus its investment in SSA capabilities and technologies in the areas of SSA that are core government functions. Second, the U.S. government should develop a strategy for providing oversight for the SSA services that are currently provided by the private sector. Third, the U.S. government should ensure adaptability by developing a system for regularly reviewing U.S. policy decisions that are already shaping the SSA environment. Third, the U.S. government should plan to continue to deliver the economic goods that it is currently choosing to make completely non-excludable. Finally, the U.S. government should begin planning now for an environment where the goods that it currently provides but makes partially exclusive are mainly provided by the private sector and overseen by the U.S. government.

[1] "Remarks by Vice President Pence at the 34th Space Symposium," White House, April 16, 2018, accessed May 1, 2018, https://www.whitehouse.gov/briefings-statements/remarks-vice-president-pence-34th-space-symposium-colorado-springs-co/.

Introduction

Over the last half century, satellites have revolutionized life on earth. Global navigation, weather tracking, and enhanced communications all at our fingertips are just a few examples of the ways that satellites orbiting the earth are improving life on the ground. However, the near Earth orbits that are primarily used by these satellites are rapidly becoming congested with both active satellites and large amounts of space debris. Satellites in low-Earth orbit (or LEO) move incredibly fast, and there are hundreds of thousands of objects orbiting the earth that are capable of damaging these key satellites. In fact, in 2009, a collision between an active American satellite and a defunct Russia satellite resulted in an additional 3,000 pieces of debris. In order to operate in this congested arena, stakeholders require information about this environment. The activity known as space situational awareness (SSA) generally consists of understanding where space objects are located, communicating this information to relevant stakeholders, and ensuring a safe operating environment.[2] While not the only actor, the United States Department of Defense has played a major role in providing data on the location of more than 23,000 of these objects to public and private satellite operators in order to prevent dangerous collisions. However, several major trends in the last decade are forcing the United States to rework its approach to SSA. Increasing commercial space activity, increasing international space activity, and increasing threats to space assets are three key factors that are driving changes in the space environment. These trends have not gone unnoticed – they have sparked responses in the private sector. Private companies are

[2] Emily Nightingale, Bhavya Lal, Brian Weeden, Alyssa Picard, and Anita Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," Institute for Defense Analysis, August 2016, iv, accessed May 1, 2018, https://www.ida.org/idamedia/Corporate/Files/Publications/STPIPubs/.../P-8038.ashx.

becoming increasingly involved in SSA and are now offering commercially available products and services to satellite operators that were previously only available through the government.

Due to these trends, the U.S. government has realized that it must change its approach to SSA. On April 16, 2018, U.S. Vice President Mike Pence announced that the National Space Council had developed a new policy to address SSA. While he did not provide much detail in his remarks at the 34th Space Symposium, Pence did state that the Council had directed the Department of Commerce "to provide a basic level of space situational awareness for public and private use, based on the space catalog compiled by the Department of Defense, so that our military leaders can focus on protecting and defending our national security assets in space."[3] This decision highlights a fundamental question for the U.S . government in its approach to SSA– what role should the U.S. government play in SSA?

Conducting an economic goods analysis of SSA allowed me to begin to address this question by identifying (1) the core governmental functions involved in SSA, (2) the privately provided elements of SSA, and (3) the policy decisions that are currently shaping the SSA economic and technological environment. Conducting an economic goods analysis of SSA is important for four key reasons. First, in order for the U.S. government to initiate a new policy on SSA, policymakers must determine the proper role of the U.S. government in the context of SSA. An analysis of the economic goods of SSA can help provide a framework for thinking about the role of the U.S. government in this area. Second, an economic goods analysis of SSA can help identify and make explicit the policy decisions that are currently shaping the SSA economic environment. These policy decisions are critical because they determine winners and losers, stifle

[3] "Remarks by Vice President Pence at the 34th Space Symposium," White House, April 16, 2018, accessed May 1, 2018, https://www.whitehouse.gov/briefings-statements/remarks-vice-president-pence-34th-space-symposium-colorado-springs-co/.

and cultivate innovation, and help and harm national security. Third, making these policy decisions explicit highlights the existing policy tools and levers that can be used to create a new U.S. government approach to SSA. Finally, making these policy decisions explicit also marks the places where the U.S. government will need to be prepared to adapt to future technological and economic changes in the space environment.

Application of Conceptual Framework and Method of Analysis

The discussion around SSA often comes back to questions of public vs private goods. A key element of the theory of public goods involves the incentive structures that typically lead to the under-provision of public goods. Understanding these incentive structures can provide policy solutions for problems related to public goods. Traditionally the economic incentive structure of public goods is tied back to their two distinguishing features: non-excludability and non-rivalry. This study attempts to move past the simple question of whether SSA is a public or private good in order to provide the U.S. government with a more nuanced framework for approaching questions related to SSA. This approach was inspired by the expanded typology of economic goods provided by economists Kaul and Mendoza.[4] Kaul and Mendoza, and others before them, identify that varying the degree of excludability and rivalry can produce various mixed forms of impure public goods.[5] Kaul and Mendoza also provide an important distinction between the intrinsic properties of a good and the properties that a good possesses due to policy or social choices. This distinction is particularly relevant when evaluating a good's level of exclusiveness. For example,

[4] Inge Kaul and Ronald Mendoza, "Advancing the Concept of Public Goods," in *Providing Global Public Goods*, ed. Inge Kaul, Pedro Conceicao, Katell Le Goulven, and Ronald U. Mendoza, (New York: Oxford University Press, 2013), 80.

[5] Kaul and Mendoza, "Advancing the Concept of Public Goods," in Kaul et al., 81.

with a classic public good such as national defense, it is very difficult to prevent anyone in the society from enjoying the benefits of this good. This property of non-excludability is intrinsic to national defense. However, for other goods, such as a road, policy choices may determine the exclusivity of the good. A policy decision could determine if the road was a toll road, and exclusive, or open to all, and non-exclusive. Finding the decisive policy decisions within an issue can provide policymakers with levers to modify the characteristics of these goods and allow for approaches to policy that are adaptable to future changes in technology and the operating environment.

This important insight gave me the tool to make useful distinctions between different types of SSA goods. However, this was only the first step in achieving a new framework for analyzing SSA. Making these distinctions required breaking the larger concept of "SSA" down into individual economic goods, and then evaluating those goods across Kaul and Mendoza's typology of economic goods. The result is a hopefully useful categorization of the goods contained within the broader SSA enterprise. This analysis also provides the framework for several policy recommendations that flow from this analysis.

What exactly is SSA and how is it currently provided?

In the U.S., the 1957 launch of Sputnik triggered the desire for knowledge about what was happening in outer space. Following the 1958 National Aeronautics and Space Act, the U.S. began distributing an early form of SSA around the world by mailing data to other countries using the postal system. Now, using sensors that were originally designed for ballistic missile warning, the U.S. government continues to track the location of as many objects in space as possible. In 2009, a collision between the Iridium 33 and Cosmos 2251 satellites was a major catalyst that triggered

key changes to the U.S. approach to SSA and resulted in the current system.

Prior to Pence's announcement in April 2018, the United States Strategic Command (USSTRATCOM) has had the lead responsibility for conducting the U.S. SSA mission. Within USSTRATCOM, the Joint Space Operations Center (JSpOC) has been the primary organization fulfilling this mission. Originally tasked with warning of close approaches between U.S. government satellites and space objects, JSpOC's mission was expanded in 2010 to include all active satellites and space objects.[6] Prior to Pence's 2018 announcement, JSpOC's website stated that its SSA role was to maintain the "catalog of all artificial Earth-orbiting objects, [chart] preset positions for orbital flight safety, and [predict] objects reentering the Earth's atmosphere."[7] JSpOC conducts this mission using the Space Surveillance Network (SSN), which is a network of radars, sensors and telescopes. JSpOC takes around 400,000 observations per day using these telescopes in order to create its satellite catalog. JSpOC projects future locations of space objects and spot checks them periodically rather than tracking them continually because of the technical limits of the SSN. Since JSpOC is authorized by U.S. law to provide SSA data and information to "domestic, international, and commercial satellite owner/operators on a voluntary basis," JSpOC shares some of its information with operators via its Space-Track.org website and its SSA Sharing Agreements.[8] In addition to tracking space objects, JSpOC regularly conducts conjunction assessment for all active spacecraft. This involves projecting a range of paths for active spacecraft

[6] Warren Ferster, "JSPOC Conjunction Alerts Could Be Improved, Group Says," Space News, March 9, 2012, accessed May 1, 2018, http://spacenews.com/jspoc-conjunction-alerts-could-be-improved-group-says/.

[7] "Joint Functional Component Command for Space," Vandenberg Air Force Base, March 5, 2013, accessed May 1, 2018, http://www.vandenberg.af.mil/About-Us/Fact-Sheets/Display/Article/338339/joint-functional-component-command-for-space/.

[8] Space situational awareness services and information: provision to non-United States Government entities, US Code 10, § 2274, accessed May 1, 2018, https://www.gpo.gov/fdsys/granule/USCODE-2014-title10/USCODE-2014-title10-subtitleA-partIV-chap135-sec2274.

and then comparing these flights paths to JSpOC's catalog of space objects. If there is potential for a close approach, JSpOC can warn the operator of the spacecraft.[9]

JSpOC and USSTRATCOM interact with operators though Space-Track.org and the SSA Sharing Program, and they provide stakeholders with three levels of service –emergency, basic, and advanced. The emergency level, which JSpOC provides to all satellite operators, includes basic conjunction assessment and collision avoidance support. The basic level of service, which is free to all who register with an account, provides information about the location of space objects via Space-Track.org. Finally, USSTRATCOM also offers advanced SSA services to all members of the space community who sign an SSA sharing agreement with USSTRATCOM.[10] As of April 2017, USSTRATCOM had signed SSA sharing agreements with more than 60 commercial companies.[11]

The U.S. government also provides SSA services through the Department of Commerce's National Oceanic and Atmospheric Agency (NOAA). NOAA's Space Weather Prediction Center (SWPC) provides space weather alerts, warnings, watches, and forecasts to a wide range of stakeholders who need to know about space weather. Due to the negative impact that unexpected solar weather can have on space launches, satellite operations, and human spaceflight, this group

[9] "Joint Functional Component Command for Space," Vandenberg Air Force Base, March 5, 2013, accessed May 1, 2018, http://www.vandenberg.af.mil/About-Us/Fact-Sheets/Display/Article/338339/joint-functional-component-command-for-space/.

[10] "Documentation - SSA Sharing & Orbital Data Requests," Space-Track, accessed May 1, 2018, https://www.space-track.org/documentation#/odr.

[11] USSTRATCOM Public Affairs, "U.S. Strategic Command, Norway sign agreement to share space services, data," STRATCOM, April 5, 2017, accessed May 1, 2018, http://www.stratcom.mil/Media/News/News-Article-View/Article/1142970/us-strategic-command-norway-sign-agreement-to-share-space-services-data/.

includes both public and private stakeholders in the space industry.[12] The National Aeronautics and Space Administration (NASA) also works closely with the JSpOC to both provide SSA services and ensure that its missions have access to reliable SSA data.[13]

What has changed in the space environment?

Over the last several years, there have been three main trends in the space domain that have mandated a change in the U.S. government's approach to SSA. The private sector has also responded to these trends by beginning to provide its own forms of SSA. One of these trends is the significant increase in the amount of commercial space activity. Another trend is the increasing amount of international actors involved in space. Finally, threats to U.S. and allied space assets have also increased, particularly threats from China and Russia. Together these trends make SSA an increasingly vital mission.

Increased commercial space activity

According to the Union of Concerned Scientists, over 450 commercially operated satellites have been launched since 2012. By comparison, from 2000 through 2011, roughly 230 commercially operated satellites were launched.[14] This explosion in commercial satellite numbers is only expected to increase considering that commercial companies filed for licenses for more

[12] "Subscription Services," Space and Weather Prediction Center – NOAA, accessed May 1, 2018, https://www.swpc.noaa.gov/content/subscription-services.

[13] Nightingale, Lal, Weeden, Picard, and Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," 24.

[14] "UCS Satellite Database," Union of Concerned Scientists, November 7, 2017, accessed May 1, 2018, https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database?_ga=2.107602818.1049944222.1523461777-1048549875.1523318888#.Ws4vamFFWT9.

than 8,500 communications satellites in 2016 alone.[15] All of this commercial activity in space makes JSpOC's job of tracking space objects and warning of potential conjunctions increasingly difficult.

Increased international space activity

Increased international space activity is another important trend in the space environment over the last decade. According to the Union of Concerned Scientists' 2017 data, there are now sixty different countries independently operating satellites. That is an increase of more than ninety percent from the thirty-two countries that were operating in 2009.[16] While USSTRATCOM has sought to sign SSA sharing agreements with many of these countries (Norway became the thirteenth country to sign such an agreement in 2017), this large number of new countries operating in space brings challenges for SSA provision.[17] At the simplest level, these new actors mean more space objects, less coordination among actors, and less certainty about the intentions of these actors.

Increased threat environment

Developments in dual-use space technology have spurred an increased need within the U.S. national security community for information about the characteristics, location, capabilities, and

[15] "UCS Satellite Database," Union of Concerned Scientists, November 7, 2017, accessed May 1, 2018, https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database?_ga=2.107602818.1049944222.1523461777-1048549875.1523318888#.Ws4vamFFWT9.

[16] "UCS Satellite Database," Union of Concerned Scientists, November 7, 2017, accessed May 1, 2018, https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database?_ga=2.107602818.1049944222.1523461777-1048549875.1523318888#.Ws4vamFFWT9.

[17] USSTRATCOM Public Affairs, "U.S. Strategic Command, Norway sign agreement to share space services, data," STRATCOM, April 5, 2017, accessed May 1, 2018, http://www.stratcom.mil/Media/News/News-Article-View/Article/1142970/us-strategic-command-norway-sign-agreement-to-share-space-services-data/.

limitations of foreign satellites. In his 2017 testimony before Congress, Director of National Intelligence (DNI) Dan Coats stated that "Russia and China continue to conduct sophisticated on-orbit satellite activities, such as rendezvous and proximity operations, at least some of which are likely intended to test dual-use technologies with inherent counterspace functionality."[18] Coats also mentioned that "space robotic technology research for satellite servicing and debris-removal might be used to damage satellites."[19] This public statement by the DNI highlights the changing nature of the space domain and the U.S. need for improved SSA services to identify an characterize space to objects to determine which may represent potential threats to U.S. space assets.

Private sector provision of SSA services

The private sector has reacted to these trends in the space environment by beginning to develop its own entities for providing SSA data and services. Gaps in the SSA services provided by the U.S. government have also encouraged commercial companies to begin providing their own SSA services. In fact, an extensive study of the commercial SSA marketplace conducted by the Institute for Defense Analysis (IDA) in 2016 found that private sector nongovernmental entities were "already providing SSA data, software, and services to private and governmental customers, and [were] on a trajectory to match, and perhaps even surpass, government capabilities for providing conjunction assessments in the near future."[20]

[18] Dan Coates, "Worldwide Threat Assessment of the US Intelligence Community," Director of National Intelligence, May 11, 2017, 9, accessed May 1, 2018, https://www.dni.gov/files/documents/Newsroom/Testimonies/SSCI%20Unclassified%20SFR%20-%20Final.pdf.

[19] Coates, "Worldwide Threat Assessment of the US Intelligence Community," 9.

[20] Nightingale, Lal, Weeden, Picard, and Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," iii.

Gaps in the Market for SSA

While the data provided by the U.S. military is free, there has been a growing dissatisfaction with that information. As early as 2012, one problem identified by some operators was the existence of too many false alarms in the warnings provided to operators.[21] Interviews with commercial satellites operators conducted in 2016 by IDA also identified these challenges with the JSpOC warnings. Based on these interviews, IDA concluded that even though "no public data exist to prove the validity/accuracy of the existing conjunction assessment warnings provided by DOD to commercial and civil users…some stakeholders have performed analyses not publicly available that have raised questions about rates of false positives and false negatives."[22] In addition, the IDA market analysis found that the current SSA information services provided by JSpOC are limited due to problems such as "[lack of] product timeliness, poor representation and visualization, lack of transparency on data accuracy, lack of actionable data, and limited assistance by JSpOC in reviewing conjunction warnings."[23]

Rise of Commercial SSA Sector

Paul Welsh, vice-president of business development at Analytical Graphics Inc. (AGI), a commercial company and defense contractor providing SSA services, says that the expansion of military space activity, the rapid growth of commercial satellite industry, and the increasingly pressing problem of space debris represents a "confluence of opportunity" for commercial

[21] Warren Ferster, "JSPOC Conjunction Alerts Could Be Improved, Group Says," Space News, March 9, 2012, accessed May 1, 2018, http://spacenews.com/jspoc-conjunction-alerts-could-be-improved-group-says/.

[22] Nightingale, Lal, Weeden, Picard, and Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," iii.

[23] Nightingale, Lal, Weeden, Picard, and Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," 22.

companies.[24] Indeed, a number of commercial SSA service providers are attempting to fill these gaps in the SSA market. Improvements in technology have also helped make better SSA data and services a reality. IDA's 2016 research found that these private companies are able to provide supplementary data, software components, and SSA services that are "increasingly comparable to, or according to some companies interviewed, even superior to DOD's."[25]

For example, in March 2014, AGI opened its Commercial Space Operations Center (ComSpOC), which it claims provides the "world's most accurate Space Situational Awareness (SSA)" via its own space catalog called SpaceBook.[26] ComSpOC data relies on observations from its non-DOD network of sensors around the world. ComSpOC purchases much of its data from outside contractors that run these observation sites. In 2015, AGI reported that ComSpOC was tracking all of the main objects in geo-stationary orbit (or GEO). As of May 2018, ComSpOC was tracking more than 9,000 objects in space, and its website offered services including "accurate orbit data, maneuver detection, characterization, conjunction assessment, and other analysis to ensure safety of flight and mission."[27]

Those demanding these services include U.S. government agencies, both civilian and military, foreign governments, and commercial satellites operators. Perhaps tellingly, even though the U.S. Air Force maintains the SSN and is the largest provider of SSA data, U.S. government agencies are considered the biggest market for SSA data. In particular, NASA, NOAA, and the

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[24] Ilima Loomis, "Private firms spy a market in spotting space junk," Nature, September 23, 2015, accessed May 1, 2018, https://www.nature.com/news/private-firms-spy-a-market-in-spotting-space-junk-1.18425.

[25] Nightingale, Lal, Weeden, Picard, and Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," 47.

[26] "COMSPOC," AGI, accessed May 1, 2018, http://www.agi.com/comspoc.

[27] "COMSPOC," AGI, accessed May 1, 2018, http://www.agi.com/comspoc.

FAA are important targets for SSA providers.[28] However, commercial SSA providers also hope to market their products to non-government satellite operators. Clinton Clark, vice-president of sales at ExoAnalytic Solutions, stated that even if "there were no government buyers at all, it would still be a very viable, meaningful business."[29] One of ExoAnalytic Solutions' main activities is selling satellite-observation data to AGI's ComSpOC.

While pioneers of sorts, these companies are not outliers. Other companies involved in the commercial SSA sector include LeoLabs, Omnitron, Numerica, NorthStar, Applied Defense Solutions, SRI International, Orbital ATK, Rincon, Launchspace Technologies, Ball Aerospace & Technologies Corp., Cosmic Advanced, Engineering Solutions, and Astra LLC.[30] In addition to these commercial examples, there is also at least one example of a private non-profit association pooling the resources and information of a number of satellite operators in order to create a SSA database and provide SSA services. The Space Data Association (SDA) is an organization that includes the world's four largest commercial satellite operators. Operators pay a membership fee and share their data in exchange for access to SDA's Space Data Center (SDC) and services that include conjunction assessment, radio frequency interference and geo-location support, and authoritative contact information for space objects.[31] In March 2017, AGI announced a joint

[28] Ilima Loomis, "Private firms spy a market in spotting space junk," Nature, September 23, 2015, accessed May 1, 2018, https://www.nature.com/news/private-firms-spy-a-market-in-spotting-space-junk-1.18425.

[29] Ilima Loomis, "Private firms spy a market in spotting space junk," Nature, September 23, 2015, accessed May 1, 2018, https://www.nature.com/news/private-firms-spy-a-market-in-spotting-space-junk-1.18425.

[30] This information was collected from the services advertised on these companies' public websites, news reports, and IDA's study.

[31] "Why Join?' The Space Data Association, accessed May 1, 2018, http://www.space-data.org/sda/why-join-2/.

partnership with SDA to launch an updated SDC Space Traffic Management service that will provide satellite tracking, radio frequency spectrum management, and conjunction warning services to companies.[32]

Economic Goods Analysis

Clearly this changing environment mandates a change in the way the U.S. government approaches SSA. However, given that SSA does not appear to fit neatly into either the traditional public or private good model, how should the U.S. approach SSA? This public/private good dichotomy is too narrow a choice for an issue as complex as SSA. In order to find a more appropriate approach, the U.S. government should expand its perspective in two ways. First, a new approach to SSA requires an expanded view of SSA. Rather than considering SSA as one monolithic economic good, it is useful to disaggregate SSA into its component parts and assess each of them as unique economic goods. A cursory economic goods analysis of SSA demonstrates why this is necessary. For example, a general description of the benefits provided by the economic good of SSA would include U.S. national security, promotion of free enterprise, and sustainable space orbits, all of which are clearly non-rival and non-exclusive public goods. However, specific activities within this broad concept of SSA also provide direct benefits to users that are not so clearly non-rival and non-exclusive. Since the U.S. government has a responsibility to ensure U.S. national security, promote free enterprise, and at least contribute, if not lead, on an international public good like sustainable space orbits, how can these two realities be reconciled? Breaking SSA down into its component parts and assessing the characteristics and direct benefits of each specific

[32] Phillip Swarts, "Space Data Assn., AGI working to improve commercial space traffic center," SpaceNews, March 10, 2017, accessed May 1, 2018, http://spacenews.com/space-data-association-agi-working-to-improve-commercial-space-traffic-center/

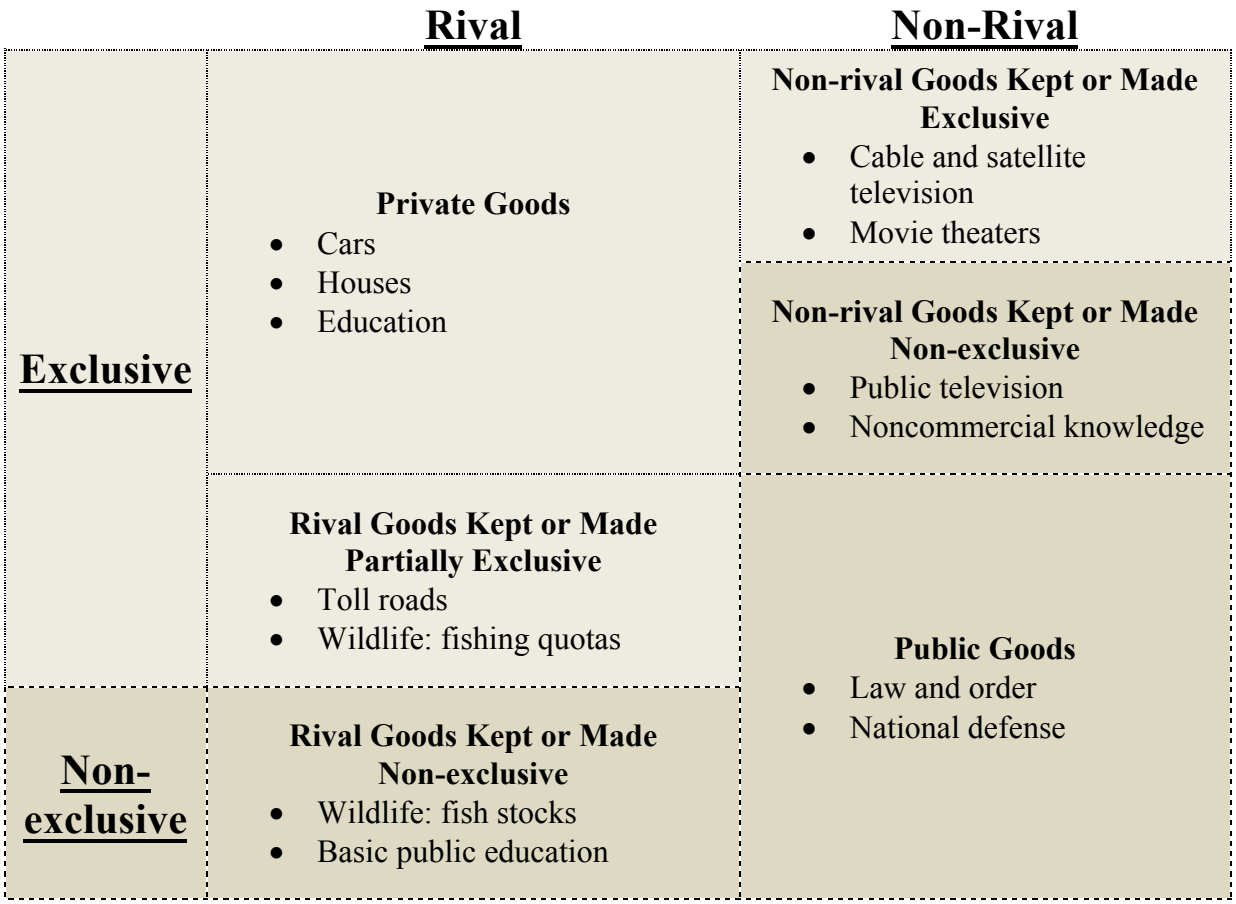
economic good allows policymakers to determine which pieces of SSA are public, which are private, and which are blurred. These distinctions then allow policymakers to determine where effective policy decisions are required to ensure that the high level public goods of national security, free enterprise, and space sustainability are provided.

Drawing these distinctions requires a broader view of economic goods in general. Here Kaul and Mendoza's concept of "social constructs" in the classification of economic goods is helpful. Conventionally, economic goods can be evaluated to determine if they are rival or non-rival and if they are excludable or non-excludable. Based on this evaluation, economic goods can be classified as one of four categories: private, common stock, club, or public. However, as Kaul and Mendoza point out, policy decisions can be critical in shaping whether a good is considered public or private. This recognition replaces the categories of common stock (rival, but non-exclusive) and club (nonrival but exclusive) with four new categories of blurred goods: (1) Rival goods that are made exclusive or partially exclusive; (2) Rival goods that are kept or made public; (3) Nonrival goods made exclusive; and (4) Nonrival goods that are kept or made non-exclusive. When combined together, these two expansions of the convention thinking on SSA provide a powerful tool for analyzing the U.S. government's role in SSA.

Figure 1: Conventional Types of Economic Goods

	Rival	**Non-Rival**
Exclusive	**Private Goods** • Cars • Houses • Education	**Club Goods** • Movie theaters • Noncommercial knowledge • Television signals
Non-exclusive	**Common Stock** • Natural resources • Wildlife: fish stocks	**Public Goods** • Law and order • National defense

Figure 2: Expanded Types of Economic Goods



Identification of Economic Goods

To conduct this analysis, I needed to identify the specific economic goods within SSA. In my view, I saw several fundamental goods that all of SSA is built upon. These are metric data, characteristic data, descriptive data, space weather data, and the observation and analytical tools required to collect and analyze these data inputs. These fundamental economic goods are then used to create the products and services that make up SSA. In this analysis I have chosen to focus on analyzing this second level of goods –the SSA products and services.

Method of Analysis

I identified a list of ten economic goods involved in SSA. These are (1) national security SSA applications; (2) a space catalog/historical data; (3) launch and early orbit support; (4) on-orbit close approach warning; (5) on-orbit collision risk assessment and maneuver planning; (6) end-of-life verification; (7) de-orbit and re-entry support; (8) space weather warnings; (9) U.S. compliance with international obligations; and (10) radio frequency interference notifications. I have developed a framework of questions in order to analyze these economic goods.[33] This framework is loosely informed by Richard Thaler and Cass Sunstein's concept of "Who uses? Who chooses? Who pays? Who loses?" in their book *Nudge.*[34]

Methodology – Explanation of Framework for Analysis		
Description	What is the economic good?	Define the good and provide a brief explanation of the activities involved.
	Who uses this good?	Identify the actors who use this good.
	How this good being provided and by whom?	Describe the main actors involved in the provision of this good as well as the process or processes by which the good is currently provided.

[33] Due to my own lack of technical expertise, I did not feel comfortable analyzing the economic good of radiofrequency interference (RFI) notifications. This is unfortunate, however, I hope that this framework could also be applied to RFI notifications as well.

[34] Richard Thaler and Cass Sunstein, *Nudge: Improving Decisions about Health, Wealth, and Happiness,* (USA: Penguin University Press, 2008), 85.

	What does this enable? What are the benefits? What are the externalities?	Describe the benefits of this economic good to those who acquire the good. Describe potential externalities. I have attempted to remain narrowly focused on the immediate benefits of the specific good in question.
	Who ultimately pays for this good?	Determine who bears the economic cost of this good. Typically either the end users pay for it or the government pays for it or some combination of both.
Characteristics	Is consumption of this good rival?	A rival good is a type of good that may only be possessed or consumed by a single user. Using a rival good prevents its use by other possible users. Again, here I have tried to remain narrowly focused on the immediate benefits of this specific good to the user who has acquired it.
	Is consumption of this good non-excludable?	A good or service can be considered non-excludable if it is impossible to prevent consumers who have not paid for it from having access to it.[35]
	Has this good been made or kept exclusive? Has this good been made or kept non-excludable? What were the key policy decisions and/or technologies involved?	This is where I attempt to distinguish between goods that are intrinsically exclusive and those that have been made or kept exclusive by a policy decision. Then I try to identify that policy decision.
Market Role	Is this good being adequately provided?	Assess the provision of this good based on the satisfaction of stakeholders and the apparent demand for additional providers or services.
	Could this good be adequately provided by the private sector? What could be the implications?	Assess the potential for the private sector to adequately provide this good given current market incentives and technological capabilities. Consider the consequences of this change in supply on the quantity and nature of the service provided.

[35] It is important to note that sustainable space orbits (or national security, or free enterprise) could be identified as a benefit of every single one of the goods discussed here. This would make all of these goods non-excludable. I try to focus on the immediate benefits of each good since that is the purpose of disaggregating SSA.

Determination	In which category does this good belong?	Based on the above analysis, place this good into one of the six economic goods categories that I have identified: (1) Rival goods that are made exclusive or partially exclusive; (2) Rival goods that are kept or made public; (3) Nonrival goods made exclusive or partially non-exclusive; and (4) Nonrival goods that are kept or made non-exclusive; (5) Public goods; and (6) Private goods.

Assessment of Economic Goods

Economic Good #1: National security SSA applications		
Description	What is the economic good?	Threats to space assets are increasing. A crucial component of SSA for the U.S. government centers around locating, identifying, and characterizing space objects to ensure that threats to U.S. national security space assets are mitigated.
	Who uses this good?	The U.S. military and intelligence community uses this good.
	How this good being provided and by whom?	The National Space Defense Center (NSDC), a joint effort between the DOD and the U.S. Intelligence Community previously known as the JICSpOC, is the "24/7/365 operations center focused on protecting and defending the space domain… [and it] immediately expands [U.S] space situational awareness and bolsters [U.S.] readiness."[36] While there is not much public detail about the NSDC, it appears that the NSDC also works closely with the JSpOC, since the JSpOC still has responsibility for tracking space objects.
	What does this enable? What are the benefits? What are the externalities?	U.S. national security space assets are critical to ensuring the success of broader U.S. national security objectives. Linking the safety of national security space assets to general national defense means that the benefits from this good are extensive.

[36] Shellie-Anne Espinosa, "National Space Defense Center transitions to 24/7 operations," Air Force Space Command, January 26, 2018, accessed May 1, 2018, http://www.afspc.af.mil/News/Article-Display/Article/1423932/national-space-defense-center-transitions-to-247-operations/.

	Who ultimately pays for this good?	The U.S. government pays for this good.
Characteristics	Is consumption of this good rival?	National defense is a non-rival good. If an additional American enjoys the benefits of national defense, it does not limit the ability of another American to enjoy those same benefits.
	Is consumption of this good non-excludable?	The benefits of national defense are not exclusive. Generally, the U.S. cannot exclude any American from enjoying the benefits of national defense.
	Has this good been made or kept excludable? Has this good been made or kept non-excludable? What were the key policy decisions and/or technologies involved?	National defense is by nature non-excludable.
Market Role	Is this good being adequately provided?	While it is difficult to know from open source material, it appears that U.S. national security space assets are currently safe enough from threats, and it is clear that the U.S. military continues to work to mitigate threats to these assets.
	Could this good be adequately provided by the private sector? What could be the implications?	National defense is a classic public good. If the U.S. government did not provide this good, it would likely be under-provided by the market.
Determination	In which category does this good belong?	Public good

Economic Good #2: Space catalog/historical data		
Description	What is the economic good?	A space catalog provides a list of identified space objects as well as varying levels of metric, characterization, and descriptive data about the space objects. I have included historical data in this category as well because historical data about space objects' locations can be included in a space catalog.
	Who uses this good?	All satellite operators use this good.
	How this good being provided and by whom?	Currently, DOD provides the most comprehensive publicly available space catalog in the form of Space-Track.org. This data is freely available as long users make an account on the website. Space-Track includes some historical data as well. Commercial SSA providers also offer subscription space catalogs, however, they are currently not as extensive as Space-Track.[37] Some commercial SSA providers offer access to their historical databases for a fee.[38]
	What are the benefits? What does this enable? What are the externalities?	An accurate space catalog provides the foundation for many of the other services that are considered to be a part of SSA. This includes conjunction warnings and analysis, safe space launches, and de-orbit and re-entry capabilities. Reliable space object metric data is necessary for predictions about where objects will be in the future. A space catalog can also include contact information for satellite operators.
	Who ultimately pays for this good?	The U.S. government pays for this good. However, commercial companies also offer similar services, and in those cases, the operators pay for the good.
Characterist.	Is consumption of this good rival?	A space catalog is non-rival because multiple users can benefit from the data without inhibiting the other users' ability to benefit from the data.

[37] For example, AGI's COMSPOC currently tracks 9,000 objects compared to JSpOC's 23,000.

[38] For example, Exo-Analytic Solutions offers access to its complete historical observation database to commercial operators for $185,000 per month. See "Commercial SSA Pricing," Exo-Analytic Solutions, accessed May 1, 2018, https://exoanalytic.com/commercial-price-list/#espoc-observation-database-access.

	Is consumption of this good non-excludable?	It is possible to exclude users from using a space catalog.
	Has this good been made or kept excludable? Has this good been made or kept non-excludable? What were the key policy decisions and/or technologies involved?	This good has been made non-exclusive in the form of Space-Track.org. However, DOD does not provide all of the information that it collects nor does it provide the data in its rawest form, which would be the most useful for integrating into other systems. COMSPOC makes its space catalog available to the public as well, but charges a subscription fee for more extensive services. Historical data has similarly been made non-exclusive when provided by the government and exclusive when provided by commercial companies.
Market Role	Is this good being adequately provided?	There is a demand for alternatives and supplements to Space-Track. Part of this also stems from the fact that the U.S. government does not include the location of some of its classified spacecraft in its public catalog.
	Could this good be adequately provided by the private sector? What could be the implications?	Based on the current conditions, it seems likely that the private sector could provide this capability in some capacity. However, this would likely raise the costs of operating satellites, which could potentially limit the ability of new companies to enter the market, reduce competition, and reduce innovation.
Determination	In which category does this good belong?	Non-rival good made non-exclusive (government) Non-rival good kept exclusive (commercial)

Economic Good #3: Launch and early orbit support		
Description	What is the economic good?	When a new spacecraft is planning to enter orbit, its operator needs to conduct pre-launch collision avoidance analysis to ensure that the spacecraft will not collide with any other objects. Additionally, operators must verify the launch successfully placed the spacecraft into the correct orbit.

	Who uses this good?	Spacecraft operators use this good during launch and early orbit.
	How this good being provided and by whom?	DOD provides several services to stakeholders to ensure safe space launches. These include launch conjunction assessment, launch early orbit determination, and early orbit conjunction assessment. These services are available to all entities who sign an SSA Sharing Agreement with USSTRATCOM.[39] Commercial entities also offer similar services, however, it is unclear how commercial services compare to STRATCOM's and how commonly these commercial services are procured by operators.[40]
	What are the benefits? What does this enable? What are the externalities?	Space launch support allows satellite operators to get their spacecraft into space without fear of collision. The U.S. government also benefits because it uses this opportunity to begin tracking the new space object and to impose requirements on satellite operators.
	Who ultimately pays for this good?	The U.S. government pays for this good. If operators procure additional commercial services, then they also pay for this good.
Characteristics	Is consumption of this good rival?	These benefits are rival because both USSTRATCOM and commercial providers can only provide this good to a finite number of launchers at any one time.
	Is consumption of this good non-excludable?	It is possible to exclude users from this good.

[39] "Documentation - SSA Sharing & Orbital Data Requests," Space-Track, accessed May 1, 2018, https://www.space-track.org/documentation#/odr.

[40] IDA's report is particularly skeptical about the capability of commercial services to provide early orbit determination due to the technical requirements. (Nightingale, Lal, Weeden, Picard, and Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," 43.)

	Has this good been made or kept exclusive? Has this good been made or kept non-exclusive? What were the key policy decisions and/or technologies involved?	The U.S. government has actually made launch support partially non-exclusive by making these services free. However, this good is still only partially non-exclusive because users still must sign an agreement with USSTRATCOM. Similar commercial services are exclusive.
Market Role	Is this good being adequately provided?	There is some level of demand for these services beyond what is available via USSTRATCOM. Private sector sources of safe launch services are growing to meet the demand.
	Could this good be adequately provided by the private sector? What could be the implications?	While there are commercial companies that advertise pre-launch collision avoidance and launch verification services, IDA's review of commercial services is skeptical that these services could be fully provided by the private sector in the near future.[41]
Determination	In which category does this good belong?	Rival good, made non-exclusive by policy decision and technological limitations of private sector

Economic Good #4: On-orbit close approach warning		
Description	What is the economic good?	A close approach notification is a warning to a satellite operator that the operator's satellite is projected to pass within a certain distance from another space object.
	Who uses this good?	All satellite operators use this good.
	How this good being provided and by whom?	The U.S. government provides both basic and advanced conjunction assessments using its space catalog. It provides close approach warnings via Conjunction

[41] Nightingale, Lal, Weeden, Picard, and Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," 43.

		Summary Messages (CSM) from the JSpOC.[42] However, non-government entities, such as those described in this paper, have also begun providing similar services.
	What are the benefits? What does this enable? What are the externalities?	Close approach notifications allow satellite operators to conduct their missions in space without fear of collisions. They also provide impetus for collision avoidance maneuvers.
	Who ultimately pays for this good?	The U.S. government pays for this good. However, operators also pay for this good when they procure additional commercial services.
Characteristics	Is consumption of this good rival?	Basic close approach notifications are largely nonrival because the marginal cost of providing an automated warning to an additional operator is close to zero. The marginal costs of advanced close approach notifications are higher, making them rival goods.[43]
	Is consumption of this good non-excludable?	It is possible, though unlikely, to exclude some operators from accessing this good. However, in practicality, the basic service is not truly excludable because there would eventually be a possible collision between an operator that receives warnings and one that does not.
	Has this good been made or kept excludable? Has this good been made or kept non-excludable? What were the key policy decisions and/or technologies involved?	As currently provided, these benefits are not exclusive because the U.S. government essentially provides the basic service to all operators for free. The advanced services are provided for free, however, they are partially exclusive since operators must have signed SSA sharing agreements with USSTRATCOM to access these services. Commercial services are also exclusive.

[42] According to Space-Track's "Conjunction Message Guide," a CSM is a "fixed format ASCII formatted message which contains information about a conjunction between a high-interest space object and another resident space object."

[43] For more details on Space-Track's policies see JFCC Space, "Spaceflight Safety Handbook For Satellite Operators," Space-Track, January 2017, 10, accessed May 1, 2018, https://www.space-track.org/documents/JSpOC_Spaceflight_Safety_Handbook_For_Operators.pdf.

Market Role	Is this good being adequately provided?	IDA's study of commercial SSA companies indicates that there is significant dissatisfaction with the current provision of this good. False alarms have been one of the concerns raised by satellite operators. Additionally, the JSpOC's legacy computer systems have had difficulty keeping up with the trends in the space environment.[44]
	Could this good be adequately provided by the private sector? What could be the implications?	If the U.S. government stopped providing basic on orbit close approach warnings today, close approach notifications would likely be underprovided. This seems unlikely to happen since the negative consequences of a collision of any two space objects are so potentially harmful. However, every satellite operator does need this information in order to safely operate their satellite. Based on the growth in commercial SSA services, it would be possible for the private sector to provide this service, however, it would have to address the issues of free-riding and excessive risk-taking.
Determination	In which category does this good belong?	Basic Warning: Non-rival good kept non-exclusive by policy decision Advanced Warning: Rival good made partially non-exclusive by policy decision Commercial Warning: Rival good made exclusive

Economic Good #5: On-orbit collision risk assessment and maneuver planning		
Description	What is the economic good?	This activity involves analyzing the potential for a close approach to result in a collision and assessing options for maneuvers to minimize or eliminate that potential.
	Who uses this good?	Satellite operators use this good.

[44] Nightingale, Lal, Weeden, Picard, and Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," 23.

	How this good being provided and by whom?	USSTRATCOM offers both basic collision avoidance and advanced collision avoidance via its Space-Track website. Both options are freely available, however, in order to receive the basic assistance, the user must have registered with Space-Track, and to receive the advanced assistance, the user must have signed an SSA sharing agreement with USSTRATCOM.[45] USSTATCOM is able to do this because it can compare the projected flight trajectory of any object against its entire space catalog to determine the potential for a collision. Several commercial companies now also offer on-orbit collision risk assessment and maneuver planning.
	What are the benefits? What does this enable? What are the externalities?	The main benefits of this good are avoiding collisions and unnecessary maneuvers.
	Who ultimately pays for this good?	The U.S. government pays for the services that it provides. Operators pay for the commercial services that they procure.
Characteristics	Is consumption of this good rival?	Consumption of this good is rival and is enjoyed by the satellite operators directly involved. This activity also requires JSpOC or commercial resources to be dedicated to this task.
	Is consumption of this good non-excludable?	Consumption of this good is excludable since both the JSpOC and the commercial companies have the ability to decide to which users they provide this service.
	Has this good been made or kept exclusive? Has this good been made or kept non-exclusive? What were the key policy decisions and/or technologies involved?	This good has been made non-excludable by USSTRATCOM in the form of Space-Track and its sharing agreements. However, it is still partially excludable since users have to provide the JSpOC with limited information. Commercial companies provide this good in an excludable form.

[45] "Documentation - SSA Sharing & Orbital Data Requests," Space-Track, accessed May 1, 2018, https://www.space-track.org/documentation#/odr.

Market Role	Is this good being adequately provided?	Due to the emergence of commercial versions of this service, it appears that there is demand for this good that is not being met by the U.S. government.
	Could this good be adequately provided by the private sector? What could be the implications?	Commercial providers are already providing this service, however, the JSpOC's main advantage, other than being free, is its existing space catalog. Some companies hope to rival that catalog soon, but currently the private sector does not appear to have the capability to provide the full coverage of space objects that is provided by Space-Track.org. The biggest challenge here is risk. The U.S. government is likely not comfortable with the level of risk that commercial satellite operators may be willing to take for the sake of lowering costs. This is important because a collision has costs for all space operators.
Determination	In which category does this good belong?	Basic Service: Rival good made non-excludable by policy decision Advanced Service: Rival good made partially non-excludable by policy decision Commercial Service: Rival good kept exclusive

Economic Good #6: End-of-life support		
Description	What is the economic good?	End-of-life support is provided when a satellite operator plans to move its spacecraft to a less-populated orbit at the end of its mission. This activity requires verification of success and collision avoidance analysis.
	Who uses this good?	Operators use this good when performing end-of-life operations.
	How this good being provided and by whom?	This good is provided by the U.S. government through Space-Track.org. If an operator asks the JSpOC for assistance and provides the JSpOC with a plan, the JSpOC will provide either basic or advanced support.[46]

[46] "Documentation - SSA Sharing & Orbital Data Requests," Space-Track, accessed May 1, 2018, https://www.space-track.org/documentation#/odr.

	What are the benefits? What does this enable? What are the externalities?	One benefit of this good is that it provides a way for operators to prove that they have complied with their pre-mission orbital debris mitigation plan. These services also limit the risk of collision during these operations.
	Who ultimately pays for this good?	The U.S. government pays for this good.
Characteristics	Is consumption of this good rival?	Consumption of this good is rival because the JSpOC can only handle so many of these requests at one time.
	Is consumption of this good non-excludable?	Consumption of this good is excludable because the JSpOC can choose which users will receive this service.
	Has this good been made or kept exclusive? Has this good been made or kept non-exclusive? What were the key policy decisions and/or technologies involved?	Currently, this good has been made partially non-exclusive because the JSpOC offers these services for free if users sign an SSA sharing agreement.
Market Role	Is this good being adequately provided?	This good appears to be adequately provided.
	Could this good be adequately provided by the private sector? What could be the implications?	I did not find much evidence of commercial companies offering this particular service. However, it is possible to imagine this good being provided by commercial companies, particularly if regulations regarding end-of-life procedures were stricter and commercial companies had to certify their compliance with these regulations.
Determination	In which category does this good belong?	Rival good made partially non-exclusive by policy decision

Economic Good #7: De-orbit and reentry support		
Description	What is the economic good?	A de-orbit is the "controlled reentry of a satellite into the earth's atmosphere."[47] This is done as a form of debris mitigation. Conjunction assessment is necessary for these operations.
	Who uses this good?	Operators use this good when performing reentry.
	How this good being provided and by whom?	If a satellite owner/operator decides to perform the controlled deorbit of a satellite or rocket stage and provides relevant on-orbit information, the JSpOC will provide related conjunction assessment and collision avoidance support as well as confirmation of reentry after the owner/operator's deorbit procedures are performed. USSTRATCOM offers this service to satellite operators at no cost if the operators have signed an SSA sharing agreement. USSTRATCOM does this using its already existing catalog of space objects and SSA data. Some commercial providers also advertise this capability, however, it is unclear how their services compare with STRATCOM's or how commonly they provide these services.
	What are the benefits? What does this enable? What are the externalities?	Proper de-orbit and reentry verification provide operators with proof of their compliance with debris mitigation guidelines. They also minimize the risks of collision and the amount of new orbital debris in space.
	Who ultimately pays for this good?	The U.S. government pays for this good. Operators also pay for this good if procured commercially.

[47] JFCC Space, "Spaceflight Safety Handbook For Satellite Operators," Space-Track, January 2017, 10, accessed May 1, 2018, https://www.space-track.org/documents/JSpOC_Spaceflight_Safety_Handbook_For_Operators.pdf.

Characteristics	Is consumption of this good rival?	Consumption of this good is rival since a limited number of operators can consume the immediate benefits of de-orbit and reentry services at one time.
	Is consumption of this good non-excludable?	Consumption of this good is excludable because both the government and commercial providers can limit which operators can access this good.
	Has this good been made or kept exclusive? Has this good been made or kept non-exclusive? What were the key policy decisions and/or technologies involved?	This good has been made or kept partially non-exclusive because USSTRATCOM provides these services to operators for free as long as they are willing to sign an agreement with USSTRATCOM. This good is exclusive in its commercially provided form.
Market Role	Is this good being adequately provided?	Since private companies have begun advertising these services, there seems to be a demand for these services beyond what is provided by USSTRATCOM.
	Could this good be adequately provided by the private sector? What could be the implications?	As of right now, the private sector is not capable of adequately providing these services on its own. According to IDA, the technology required to do proper verification of reentry does not exist outside the U.S. military, and will not in the near future.[48]
Determination	In which category does this good belong?	Rival good that is kept or made partially non-exclusive

Economic Good #8: Space weather warnings		
Description	What is the economic good?	Space weather describes the variations in the space environment between the sun and Earth. Space weather warnings are alerts that this environment is likely to change in a way that could affect spacecraft operations.

[48] Nightingale, Lal, Weeden, Picard, and Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," 41.

	Who uses this good	All satellite operators use this good.
	How this good being provided and by whom?	Currently, the U.S. government, through NOAA's Space Weather Prediction Center (SWPC), provides a range of alerts, warning, predictions, and forecasts through its SWPC subscription service. These services are free once a user registers on NOAA's website.
	What are the benefits? What does this enable? What are the externalities?	Space weather can have significant effects on the operations of satellites and other spacecraft, particularly those operating in LEO. Understanding the projected effects of space weather on a satellite at any given time is necessary to prevent damage and continue operations.
	Who ultimately pays for this good?	The U.S. government pays for this good.
Characteristics	Is consumption of this good rival?	Space weather warnings are not rival because one user can benefit from these warnings without affecting another user's ability to also benefit from these warnings.
	Is consumption of this good non-excludable?	This good is excludable because these services can be provided to a limited number of users.
	Has this good been made or kept excludable? Has this good been made or kept non-excludable? What were the key policy decisions and/or technologies involved?	As currently provided, this good is not exclusive because the U.S. government essentially provides this service to all operators for free. In theory, space weather notifications could be made exclusive. NOAA could decide to only share this information with certain satellite operators for a fee.
Market Role	Is this good being adequately provided?	Space weather warnings do appear to be adequately provided. While there are other organizations tracking space weather in addition to NOAA, there does not appear to be the same sort of commercial competition that has arisen in other parts of the SSA market.

	Could this good be adequately provided by the private sector? What could be the implications?	If the U.S. government stopped providing this service today, space weather warnings would likely be underprovided. While there would be incentives for companies to work together to provide this service, free-riding and the temptation of large existing companies to collude to keep new companies out could be huge.
Determination	In which category does this good belong?	Non-rival good made non-exclusive by policy decision

Economic Good #10: U.S. compliance with international obligations		
Description	What is the economic good?	The United States has several international obligations regarding space activities. The most prominent are included in the 1967 Outer Space Treaty (OST). Remaining in compliance with these obligations is an economic good with benefits for the United States.
	Who uses this good?	The U.S. government and the American people benefit from being in compliance with international space obligations.
	How this good being provided and by whom?	Article VI of the OST states that the "activities of non-governmental entities in outer space… shall require authorization and continuing supervision by the appropriate State Party to the Treaty."[49] In order to remain in compliance with this treaty, the U.S. government needs to authorize and supervise governmental and non-governmental U.S. space activities. Currently, the U.S. provides this oversight through a variety of regulatory agencies, though this seems likely to change under the new policy.
	What are the benefits? What does this enable? What are the externalities?	The U.S. government and the American people benefit from the United States being in compliance with international space obligations because this provides the U.S. with legitimacy on these issues and it strengthens international norms that are in line with U.S. interests.

[49] United Nations Treaties and Principles on Outer Space," United Nations, 2002, 5, accessed May 1, 2018, http://www.unoosa.org/pdf/publications/STSPACE11E.pdf.

	Who ultimately pays for this good?	The U.S government pays for this good.
Characteristics	Is consumption of this good rival?	This good is not rival because all Americans can benefit from the United States remaining in compliance with its international obligations.
	Is consumption of this good non-excludable?	The United States as a whole is either in compliance or it is not. Therefore the good is not exclusive because one American cannot be denied the benefits while the others get to enjoy the benefits.
	Has this good been made or kept exclusive? Has this good been made or kept non-exclusive? What were the key policy decisions and/or technologies involved?	This good is naturally non-exclusive.
Market Role	Is this good being adequately provided?	U.S. compliance with international space obligations is likely not being adequately provided at present. Several companies have put forth proposals for space activities that fall outside of the current U.S. regulatory system with the purpose of proving that the current system needs to change.
	Could this good be adequately provided by the private sector? What could be the implications?	While it is possible that the private sector could organize itself to achieve international compliance, it seems unlikely that this could be done without U.S. government involvement.
Determination	In which category does this good belong?	Public good

Limitations of Analysis

While I believe the strengths of an economic goods analysis of SSA is clear, there were several limitations to this particular analysis. The most important of these is my own lack of

technical knowledge and first-hand experience with SSA technology, systems, and processes. For example, this lack of technical knowledge prevented me from assessing the economic good of radiofrequency interference notifications and services. Second, another challenge lies in accurately projecting the demand for SSA goods and services. Since many of those services have been provided for free in the past, it is hard to gauge the market value of these services and how much various operators would be willing to pay for them. Third, it can be difficult to accurately assess the technical capabilities of commercial SSA providers without actually using their services. These providers have every incentive to tout the prowess of their systems, but it was difficult for me to validate these claims or know how many customers these companies have. This limitation required me to rely heavily on IDA's 2016 survey of commercial SSA providers. Finally, the list of economic goods that I identified within SSA may not be exhaustive. Despite these challenges, my goal was to provide an economic goods framework for analyzing SSA, and I believe that this paper takes steps towards doing that.

Conclusions

Through conducting this analysis, I concluded that, when considered as a single good, SSA is a public good because it provides benefits such as national security, free enterprise, and space sustainability to all Americans. However, delivering this public good involves a more sophisticated approach than simply providing each element of SSA through the U.S. government. This analysis reveals that for the U.S. government to deliver the larger public good of SSA, the U.S. government will have to use different strategies to address each type of good represented within SSA.

Types of goods within SSA

Conducting this economic goods analysis of SSA allowed me identify the core governmental functions involved in SSA, the private elements of SSA, and the policy decisions that are currently shaping the SSA economic and technological environment.

First, there are at least two SSA goods that should be considered classic public goods. These are the national security SSA applications and U.S. compliance with international obligations. The specifics of how best to provide both of these goods are topics that are currently open to debate, however, I think that it is clear that the U.S. government should play the primary role and bear most of the cost of providing these goods.

Second, there are a number of SSA goods that are currently being provided by the private sector. These include launch and early orbit support; on-orbit collision risk assessment and maneuver planning; and de-orbit and reentry support. However, all of these services are currently provided as additional capabilities that augment the services provided by the U.S. government.

Third, this analysis highlights several U.S. government policy decisions that are shaping the SSA economic goods environment. First, the U.S. government has chosen to make some potentially excludable goods completely non-exclusive. These goods include: (1) a space catalog; (2) space weather data; (3) basic on-orbit close approach warning; and (4) basic on-orbit collision risk assessment services. Second, the U.S government has chosen to make some potentially excludable goods partially exclusive through SSA sharing agreements. These goods include: (1) launch and early orbit support; (2) advanced on-orbit close approach warning; (3) advanced on-orbit collision risk assessment and maneuver planning; (4) end-of-life support; and (5) de-orbit and reentry support. The chart below provides a reference for these classifications.

Figure 3: Expanded Types of Economic Goods Applied to SSA

<table>
<tr><th></th><th>Rival</th><th>Non-Rival</th></tr>
<tr><td rowspan="2">Exclusive</td><td rowspan="2">Private Goods
Commercial launch and early orbit support
Commercial on-orbit close approach warning
Commercial on-orbit collision risk assessment and maneuver planning
Commercial de-orbit and reentry support</td><td>Non-rival Goods Kept or Made Exclusive
Space catalog/historical data (commercial)</td></tr>
<tr><td>Non-rival Goods Kept or Made Non-exclusive
Space weather warnings
Space catalog/historical data (public)
Basic on-orbit close approach warning</td></tr>
<tr><td></td><td>Rival Goods Kept or Made Partially Exclusive
Launch and early orbit support
Advanced on-orbit close approach warning
Advanced on-orbit collision risk assessment and maneuver planning
End-of-life support
De-orbit and reentry support</td><td rowspan="2">Public Goods
National security SSA applications
U.S. compliance with international obligations</td></tr>
<tr><td>Non-exclusive</td><td>Rival Goods Kept or Made Non-exclusive
Basic on-orbit collision risk assessment and maneuver planning</td></tr>
</table>

Additional conclusions and future research

In addition to these conclusions about the types of goods involved in SSA, this economic goods analysis also highlighted three more areas in need of further research– (1) risk management strategies, (2) impacts on innovation, and (3) the global nature of SSA. Each of the economic goods in the category of rival good made partially non-exclusive by policy decision deserves an

in-depth study of different ways that the good could be provided, how risk could be managed, and the impact of these choices on innovation and the global SSA environment.

Commercial provision of any of these SSA goods is accompanied by challenges surrounding different levels of risk tolerance. Space stakeholders all have different levels of investment in space and different levels of tolerance for risk. Any time that a non-exclusive good is made exclusive, the cost to the user increases. Regardless of the level of cost, there will be some users who no longer prefer the good at that cost. On their own, these users will not procure the good or service. For example, if the U.S. government stopped freely providing its advanced collision risk assessment and maneuver planning services, the private sector would surely increase its services to help meet the demand. However, the new cost of this service would be too high for some potential satellite operators. Depending on their level of risk tolerance, some of these users may still decide to operate their satellites anyway. Two avenues for addressing risk are regulation and insurance, and both of these strategies require more in-depth analysis.

While both of these approaches might be effective in improving safety of spaceflight, they could also prevent start-ups and other smaller operators from entering the market at all. This reduced competition could hurt innovation in the space industry and cement some of the current market dynamics in the space industry. The potential economic effects of different regulatory approaches should be an area of future research.

Finally, the global nature of SSA services must also be considered in these analyses. I have discussed all of these issues in the U.S. context, however, there are many non-U.S. actors operating in space, many of whom rely on JSpOC and Space-Track.org. In my opinion, this is yet another reason why focusing on the economic incentives in SSA is useful for the U.S. government as it begins to change its approach to SSA policy. While regulatory changes do only have a limited

direct impact on users outside of the U.S., strategically affecting the economic incentives and conditions of the SSA environment can significantly influence the behavior of space operators all around the world.

Implications for Policymakers

These conclusions have several implications for policymakers thinking about SSA.

1. The U.S. government should continue to directly invest in the SSA systems, technologies, and capabilities necessary to deliver the clear public goods associated with SSA, namely national security and compliance with international obligations.
2. The Department of Commerce should develop a strategy for providing oversight to the SSA service sectors that are currently provided by the private sector.
3. The U.S. government should plan to continue to deliver the economic goods that it is currently choosing to make completely non-excludable, namely space weather warnings, basic emergency on-orbit close approach warning, and basic on-orbit collision risk avoidance and maneuver planning.
4. The Department of Commerce should establish a system for regularly reviewing the policy decisions shaping the exclusivity of specific SSA goods to ensure adaptability of U.S. policies.
5. The U.S. government should begin planning now for an environment where the goods that it currently provides but makes partially exclusive (specifically, launch and early orbit support; advanced on-orbit close approach warning; advanced on-orbit collision risk assessment and maneuver planning; end-of-life support; and de-orbit and reentry support) are mainly provided by the private sector and overseen by the U.S. government.

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