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TECHNO-POLITICAL SPACE COOPERATION: A LONGITUDINAL ANALYSIS OF NASA'S BILATERAL AND MULTILATERAL AGREEMENTS

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ABSTRACT

National Aeronautics and Space Administration's (NASA) numerous and storied international projects form a foundation of space initiatives involving significant cooperation with both developed and developing states. To effectively explain lower-level patterns of cooperation, a cluster analysis of one key segment is utilized. In contrast to prior research projects focusing principally on case studies, this paper begins with a macro-level consideration of the more than two thousand agreements in NASA's International Agreement Database before proceeding to lower tier explanations. The lower-tier explanations provide insight into the regional and political influences on bilateral and multilateral cooperation and answer key questions concerning developing states. Developing states seeking to increase their indigenous space industry can leverage NASA's history of international space cooperation for important lessons and successful models of space cooperation. These historical cases of NASA cooperation include a large variety of both developed and developing space partners. Three previously identified variables underlie NASA's international cooperation efforts. These variables create a framework for explaining international cooperation behavior on a macro-level. International space cooperation builds on international institutions, costs borne, and technology readiness which together strongly influence both initial agreement formation and follow-on cooperation.

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INTRODUCTION[†]

"The administration (NASA), subject to the direction of the President and after consultations with the Secretary of State, shall make every effort to enlist the support and cooperation of appropriate scientists and engineers of other countries and international organizations."[‡]

Developing states with either low space industrial levels or merely a desire to start a space industry face numerous barriers to international cooperation with highly developed nation states. Yet, these barriers have been overcome in the past by designing appropriate agreements and managing sustained engagement with the fast moving space economies. NASA's extensive experience with international space cooperation provides an excellent foundation of cases to guide future space cooperation by developing states.

These historical cases of NASA cooperation include over 2550 agreements with a variety of both developed and developing space partners. Research into international space cooperation patterns in NASA's history suggests that international institutions, costs borne, and technology readiness strongly influence cooperation levels. The large size and breadth of NASA's experience helps overcome idiosyncratic and problematic findings of individual multilateral and bilateral projects. Indeed, three variables explain 60% of the temporal variations in

† The research for this paper was accomplished with support of a NASA Research Fellowship; however the contents of this paper are solely the opinion of the author and not official U.S. Government/NASA policy or position on international space cooperation.

‡ "National Aeronautics and Space Act of 1958, Public Law #85-568, 72 Stat., 426" (Washington, D. C.: National Archives and Records Administration; United States Senate, Eighty-fifth Congress, second session, 1958).

international agreement levels. NASA's International Agreement Database (IAD) of agreements includes over 888 agreements with developing states. Many of these developing states have grown into substantial space states and features of their transformation can successfully guide today's developing states.

To understand the influences underling NASA's international cooperation, this paper's research[1] combines the generic innovation process and characteristics of technology management with proven political science explanations for international relations theory. The empirical question becomes: What conditions explain the variations in the amount of NASA's international cooperation with its foreign partners from 1960 to 1995? The question is designed to respect the boundaries of available data regarding NASA's international cooperation.

NASA INTERNATIONAL AGREEMENTS

International cooperation as a dependent variable historically, in both the fields of political science and technology management, has been fraught with difficulties. Problems with "operationalizing" it in a non-subject-specific context or in using it in a broad statistical manner have limited the explanatory power of both international cooperation and international R&D hypotheses. This study compensates for the operationalization issue by counting the number of agreements over time and using this count rate as a measurement of cooperation. As for the statistical issue, this study will help future researchers and developing states by leveraging a set of cases which has a statistically significant size and a uniformly coded set of variables. Furthermore, this study resolves such issues as the small sample size and biased case selection by utilizing a database of all known NASA international agreements. Additionally, the cluster analysis approach in this study disaggregates the large number of cases into a more manageable yet statistically valid national groupings.

The IAD cases of international cooperation overwhelm or smooth the effects of any one prolifically documented project. For example, the database includes agreements with 103 different nations or foreign entities. Figure 1 shows the seventeen nations with greater than 1% of the total number of agreements.

The 'other' nation category combines all remaining eighty-six (86) nations with less than the 1% threshold into one category.[2] It is noteworthy that five partners -- France, United Kingdom, Germany, Canada, and Japan -- represent over 50% of all agreements signed by NASA. Concomitantly, NASA has signed over half of its international agreements with ninety-nine different partners. All together NASA partners represent 56% of the United Nations membership, evidence of the breadth of international cooperation. The preponderance of agreements with the five large partners explains why case-specific researchers of NASA's international cooperation often inaccurately estimate levels of this techno-political cooperation.

LONGITUDINAL ANALYSIS

Costs Borne by lead State

The first of three independent political variables concerns costs borne in an international cooperative agreement. Previous research indicates that relative costs borne by a leading nation, in this case the U.S. and represented by NASA, strongly influences cooperation through the expression of commitment perceived by partner nations.[3] Those agreements where costs borne by NASA are high should have produced more international cooperation. This increased cooperation should be reflected in an increased number of agreements signed by NASA and its partners. However, the costs borne by NASA and its foreign partners are not directly recorded in the IAD. This information can be derived using an alternate indication which is available in the IAD. Over the span of space-faring history, NASA has often been the largest space-faring nation, technologically and financially, the only exception being in the late 1950s and early 1960s when the USSR launched Sputnik and Yuri Gagarin. Thus, acknowledging the USSR's success in the 1970s with their space station programs, NASA's partners can be regarded as at or below parity to NASA's capabilities. That is, no political rival has a superior position relative to NASA's space-faring capabilities.

Historical tendencies suggest that relative costs borne by NASA are high when NASA's partner has a low space-faring industrial level.[4] Conversely, NASA's relative costs borne decrease as the space-faring industrial level of its foreign partner increases.[5] For example, in 1973, NASA signed an agreement with Belgium, a country with no space-faring capabilities, in which the Belgians were to build a space-manufacturing experiment to study the pore size and shape of the melted and solidified silver grids in a weightless environment. This experiment was flown on the U.S.-developed *Skylab* space station. The relative costs borne by NASA were high, with a ratio of approximately $ 2 million for Belgium to an excess of $1 billion for NASA.

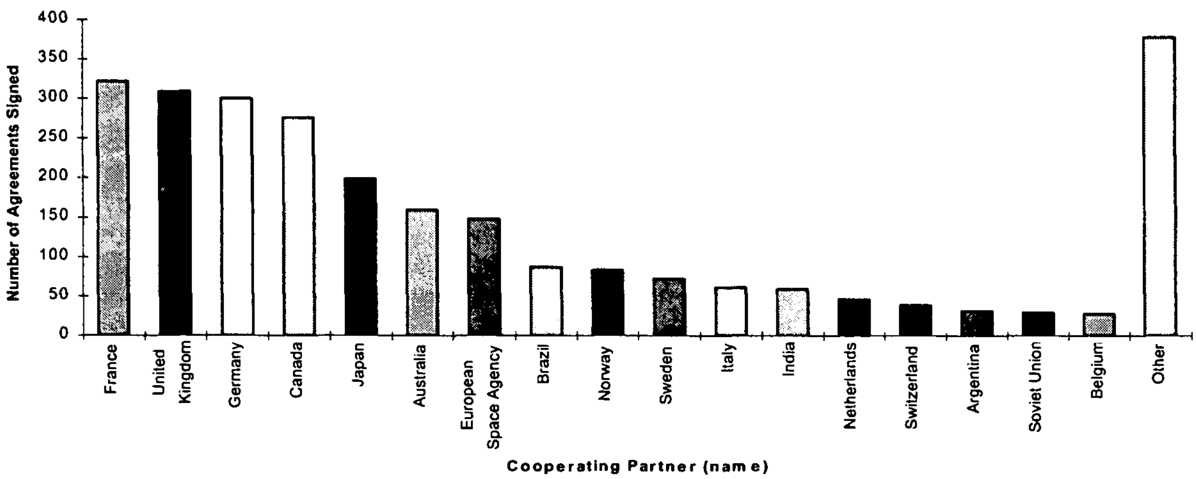

Figure 1 Agreements Signed per Int'l Partners

Another example of the U.S. costs borne in comparison to that of a nation with high space-faring capabilities, note the 1962 agreement between NASA and the USSR's Academy of Sciences which was formed to establish a dedicated direct communications link for the exchange of meteorological data. At that time, the USSR possibly exceeded, and certainly equaled NASA's space-faring industrial level, and was considered the only peer of NASA. The costs borne to implement this agreement were equally divided between the two partners.

An indirect measure of the costs borne variable is the relative space-faring industrial level (SIL), as indicative of the space-faring capability of NASA and its foreign partners. Partner nations' space-faring status can be determined from the IAD by classifying the partner nation's name, COUNTRY, as a nation with a high, median, or low space-faring industrial level. To operationalize this variable, each country or foreign partner's launch capability from 1959 to 1996 is assessed as high, medium, or low depending on their relative space-faring capabilities.[6] Nations are identified with high SIL if they possess the ability to launch humans into space and are labeled HUMAN. The USSR and the U.S. have met this standard.[§] Also, China has recently achieved the highest SIL level by successfully launching their first human into space. Nations possessing the ability to launch unpiloted satellites are labeled SATELLITE as indicative of a medium SIL. For example, India achieved a satellite launch capability in 1980 with the successful launch of the SLV-3 rocket.[7] Nations with no space-faring capabilities are labeled with NONE to indicate a low SIL. This status includes nations with only sub-orbital capabilities.

Involvement of International Institutions

An examination of the amount of individual bilateral agreement leads to twin observations concerning the distribution of agreements. First, the preponderance of agreements with individual nations are agreements with non-space-faring partners; 79% of NASA's agreements are historically with countries with little or no space launch capabilities. The remaining 20% of agreements are primarily with countries that have only satellite launch capabilities. Historically only 1% of the agreements with individual nations are with the USSR which was the only other nation capable of launching humans into space between 1960 and 1995.

A second observation is a central tendency towards engineering agreements. In all three SIL

[§] For instance, before 1985 only two spacefaring nations existed: the Soviet Union and the United States. So, prior to 1985 non-Soviet partners with low spacefaring capabilities are assumed to have low costs borne by the United States to implement their agreements. Yet after 1985, European spacefaring autonomy in space, recognized by a 1985 European Space Agency (ESA) Council resolution, accurately marks a change in costs borne by U.S. agreements, e.g., Joan Johnson-Freese and Roger Handberg, *The Prestige Trap: A Comparative Study of the U.S., European and Japanese Space Programs* (Dubuque, IA: Kendall-Hunt Publishing, 1994).

subgroups, engineering has 44% to 71% of the agreements. In the Human SIL group of agreements, this percentage increases to 57% of the aggregate assessment. This tendency for "non-space-faring engineering" agreements represents one finding of this research. In the category of international institutions, 72% of European Space Agency (ESA) agreements were signed during its non-space-faring phase of SIL. Furthermore, when the international institution does not have space-faring capabilities, the majority of IAD agreements focus on engineering objectives indicating a dominance of technology projects. Once the international institution obtains satellite launch capability, this concentration on technology agreements disappears. An analysis of both the agreements with individual nations and agreements with an international institution indicates a similar concentration toward agreements with non-space-faring entities. Likewise, there is a similar central tendency toward technology agreements. However, this tendency is stronger when NASA's partner is a non-space-faring international institution. The comparison also indicates that entities with satellite launch capabilities, either individual nations or international institutions, generally do not have a pronounced tendency toward any particular type of agreement (science, technology, or innovation).

Technology Readiness Levels

There are three categories of TRL: science, technology and innovation. The TRL of any agreement is important because it directly affects both the estimation of effort and cost to implement that agreement and the dynamic behavior within the R&D systems dynamic model.[8] Scientific projects typically involve 20 or fewer researchers, whereas technology projects (for instance, the ESA's Spacelab) can involve hundreds of workers, and innovation projects often involve thousands of people. A project with a lower TRL should lead to more cooperation by simplifying the R&D process. Such a project is more likely to succeed because the coordination and uncertainty demands are fewer. These successful projects should create a positive, cooperative atmosphere which, in turn, should lead to repeated or legacy agreements. Conversely, large expensive technology and innovation programs often require years to complete and force R&D system dynamics to be repeated within each budget cycle. This repetitive cycling, when perpetuated through the budget cycles of multiple nations, leads to interruptions of available resources as well as uncertainties concerning the level of commitment of each partner nation. These conditions can often create non-cooperative behaviors which, in turn, lead to delayed completion or premature termination. Also, intervening national elections can further contribute to program uncertainty. These expensive programs, however, may motivate nations to seek more international cooperation by inviting additional partners to share cost. The additional partners, however, further complicate the system development, leading to further delays. This mitigating effect is a case where politicians seek more international cooperation while technology management seeks simpler relationships.

Figure 2 shows the breakdown of the coded TRL measure by the three categories, science, technology, and innovation across the agreements. Technology agreements represent 48% of the IAD cases, scientific agreements represent 34% of the IAD cases, and innovation agreements represent the smallest percentage of cases at 18%.

This distribution indicates a slight central tendency towards "technology" TRL agreements; however, these levels are influenced by the limitations on NASA's mission, which encourages commercial enterprise to handle applications of technology. That is, after a technology is proven, the commercial sector adopts the innovation component, thus skewing the distribution.

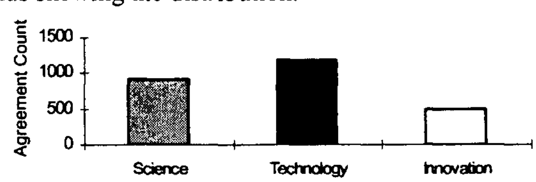

Figure 2 Technology Readiness Level Distribution

It is possible to find individual cases of innovation (TRL = 3) during the early phase of the technology life cycle of the field. However, as a group, innovation (TRL = 3) agreements tend to concentrate toward the end of the technology life cycle. The same can be said for science or engineering cases outside the appropriate phase of the life cycle. One way to induce such an accelerated distribution of products and services during the first phase of the technology life cycle is the involvement of politicians keen on sharing the benefits of space technology through issue linkage to garner often non-space related foreign policy objectives. This was the case for NASA's prolific document exchange program in the 1960s in which NASA distributed to over 100 nations the knowledge it had gained in the 1st half decade of Apollo program accomplishments. However, this type of cooperation is difficult to sustain because it runs counter to the natural match between TRL and the technology life cycle.

LESSONS FROM NASA'S EXPERIENCE

To effectively explain the patterns of cooperation that NASA has experienced, this study uses two approaches for analyzing the data: aggregate assessments of all agreements and a cluster (disaggregation) analysis of one key segment. Much of the prior research into NASA's international cooperation considers individual cases first, and then generalizes to macro explanations. This study, in contrast, begins by considering all agreements together in order to explain as much as possible, at the macro level, before proceeding to lower tier explanations. These lower tier assessments are important to understanding regional and political influences. So, to accomplish this lower tier analysis, the data must be partitioned into logical groupings to enable an analysis of the IAD and to answer the central research question. First an aggregate analysis helps to explain many important patterns of NASA's international cooperation.

Annual Agreement Rate

The annual quantity of international agreements, labeled AAR for Annual Agreement Rate, captures a dimension of cooperation unrelated to unique features such as leadership or economic benefits of any individual agreement.

Over the entire IAD, the mean average of agreements signed per year is 50.7 over thirty-seven years. However, the range between the maximum and minimum variation is nearly twice the mean at 99 and the standard deviation is 27.7. The median average of annual agreements signed is 45 with a mode of only 26 agreements. This 26, 45, 50.7 progression of the mode, median, and mean averages indicates an initial upward trend of the AAR. However, this growth trend changes during the late 1980s and turns downward as seen in Figure 3. Furthermore, the annual quantity of international cooperation as represented by the AAR is increasingly volatile after 1976.

One interesting finding emerges, shown in Figure 3, from a third-order polynomial trend analysis of the AAR measure. International cooperation at NASA peaked in 1980 and generally fell for the subsequent sixteen years. Previously, many aerospace experts identified the *Challenger* disaster of 1986 as the watershed event for U.S. civilian aerospace.[9] Some experts claimed that the agency recovered from that disastrous event[**], but this analysis indicates that international cooperation has not recovered and continues to decline. Another interesting feature of the data is the pronounced drop in number of agreements signed in 1974, 1983, 1988, and 1992. Overall, the non-linear trend of AAR over time is matched by the increasing variability of AAR as NASA moves toward the millennia.

This study suggests that the AAR trend line in Figure 3 is simply of the first derivative of the technology life-cycle S-curve of the aerospace field and explains much of NASA's international cooperation. The peak and subsequent decline in the distribution of AAR empirically suggests that the aerospace field has reached its maximum level of R&D activity. The variation in AAR levels over NASA's history reveals the underlying maturation of aerospace as a field. NASA initially achieved small amounts of international cooperation which gave way to a phase of rapid advancement of the aerospace field. Yet today's slow progress as measured by AAR indicates the final phase of NASA's first space age. This is an important finding for policy makers in that, despite current political attempts to foster NASA's international cooperation, leaders are fighting technological forces, making it difficult to recreate previous levels of cooperation. Without a new breakthrough in space technology, today's trend may point towards a more productive venue for international cooperation in the commercial sector, where a trend analysis might yield different patterns.

Repeat Agreement Level

Another macro-level lesson from a different perspective involves repeated agreements. The incidences of repeat or legacy agreements are detectable in the IAD. Thus, through repeated and second-generation agreements, an estimation of the underlying R&D cooperation as a measure of the dependent variable is possible. This measure, RAL, is defined as the number of repeated, extended, or second-generation agreements associated with each IAD case. RAL measures the extent of international cooperation hidden within the database.

Conceptually, RAL measures cooperation differently than AAR since the objective of RAL is to understand R&D cooperation along a different perspective. RAL measures the technical relationship between agreements through their description as opposed to their signatory date. So, for example, the successful Applications Explorer Missions, e.g., CEC0003, has a sequence of twelve associated follow-on agreements with different partners; thus its RAL is 13. In other words, this agreement has 12 other agreements in the IAD which are related to it by a content analysis of the program description, PROGNAME. Like AAR, RAL measures the

[**] Johnson-Freese, 1990, p. 24.

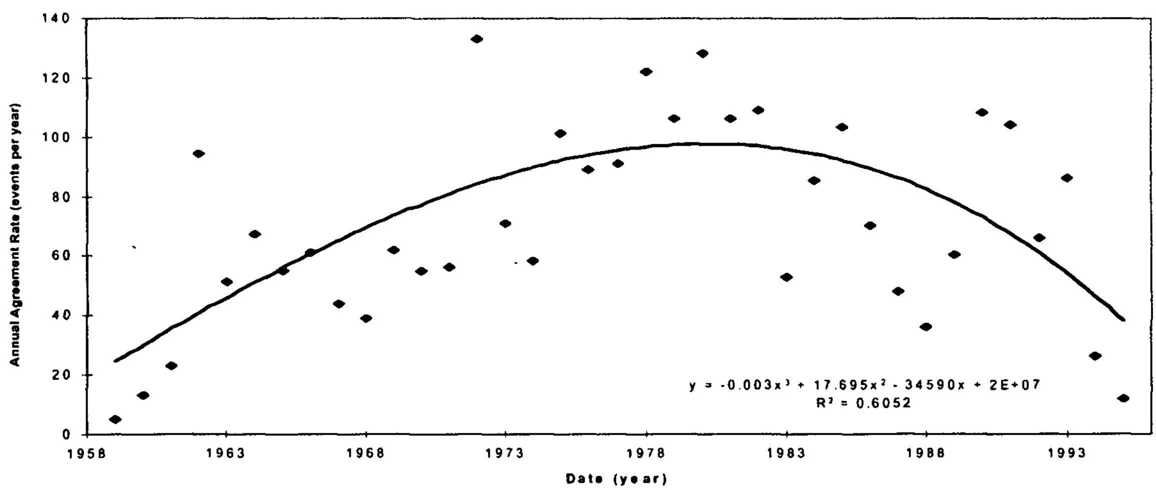

Figure 3 1959 to 1995 Annual Agreement Rate Trend

amount of international cooperation indirectly. It is a proxy measure of the dependent variable, the amount of NASA's international cooperation. RAL assumes that there is a positive correlation between the amount of international cooperation necessary to accomplish a series of space projects and the number of related agreements. The procedure for determining an RAL for each individual agreement involves comparing an agreement's description characteristics to all 2550 agreements.

Years with high average RALs indicate periods of high collective-goods cooperation because space, as collective-goods, requires international cooperation to both justify R&D costs and capture benefits. A high RAL indicates a broad distribution of a specific technology across international partners. Yet, NASA's scope and mission are limited to non-commercial R&D, and this truncation of scope creates a distorted RAL behavior. An examination of this RAL reveals two observations about these NASA agreements. First, *science* RAL sequences begin slowly until 1968, when the average sequence length grows dramatically, peaking in 1971, and subsequently shows a exponential decay down to an average of 7.[††]

The late 1960s to early 1980s represented a period in NASA's history in which far-reaching international cooperation occurred, particularly with non-space-faring nations. It was a phase of the distribution of space technology benefits as global collective-goods to many nations. From the mid-1980s to 1995, NASA appears to be conducting its international cooperation predominantly with large, space-faring nations. For example, the *International Space Station* organized the leading space-faring nations but lacks possible contributions from developing states. In keeping with NASA's founding legislation, this U.S. agency could again consider broadening the scope of its international cooperation toward the developing world so as to distribute the full benefits of collective-goods.

This research indicates that NASA, just after the *Apollo* program, successfully shared the benefits of space exploration, as demonstrated by the RAL. The once impressive fifteen year infusion of NASA space technology into people's lives has disappeared in the last decade. Although the *ISS* is being constructed by the space-faring community of the world, its utilization could and should be broadened to include the non-space-faring majority of nations.

[††] The skewed (decay) portion of the science RAL behavior is distorted by NASA's limited scope and mission. NASA performs space R&D which often requires international agreements to test, access, or demonstrate a R&D concept. Successful NASA concepts like satellite telecommunications and remote-sensing have been transferred to the commercial sector. The companies in these aerospace sectors are typically global and continue the international cooperation started by NASA though international contracts. The NASA RAL level, however, does not measure these related agreements, so it declines dramatically. The actual "concept RAL" level may continue at high levels for years. This transition effect is a good area for future research.

ANALYSIS OF AGREEMENTS WITH DEVELOPING STATES

RAL patterns and role of Developing States

An important regional cluster of NASA cooperation includes all *other* agreements remaining after the disaggregation of the IAD into USSR, ESA, and Japanese clusters. In this combination of nations which individually hold less than 1% of NASA's IAD agreements, it is the second largest cluster of agreements with a total of 888 agreements representing 35% of NASA's international cooperation. As with the other clusters, *technology* agreements are most common with a 40% share of the agreements. These *other* foreign partners vary across the political and technical spectrum from space-faring nations like China to city-states like the Vatican. This cluster shows two AAR peaks, in 1962 and 1972, which may result from developing states geographic location and collectives-goods effects.

The *other* cluster represents NASA's international cooperation with over 100 foreign nations or entities. They represent people, real-estate, and property which encircle the globe and include Asia, Africa, North America, South America, Europe, and Australia. It is this global reality which enables over one third of NASA's international cooperation. For example, NASA's *Apollo* program faced a situation in which a radio transmission from the moon could only be continuously received if there existed an array of antennas covering the globe.[10] Figure 4 shows the 1998 global distribution of launch sites, which inherently have space infrastructure due to their SIL and thus provide automatic ground stations.[11] But most of the *Apollo* antennas and their ground-stations necessary for continuous coverage require international agreements with unlikely foreign partners such as Chile, Botswana, Australia, and Thailand. Thus, many of the agreements in this cluster show the influence of the developing states's broad global distribution. In short, some of NASA's international cooperation is caused by mere latitude and longitude of a foreign nation. The only requirement for this type of cooperation is an appropriate global position. In this case, space transcends political boundaries because earth-orbiting satellites know no borders, only Kepler's law.[12]

Space as Collective Goods

What are the conditions that influence the amount of NASA's international cooperation with *other*, often developing states or partners? A partial answer of this question requires an examination of the nature of the benefits of space science, *technology* and innovation. Space products and service (*innovations*), like space-based weather maps or direct-to-home television news, are collective goods by their political nature. They theoretically benefit, through their global perspective, all nations and all peoples.

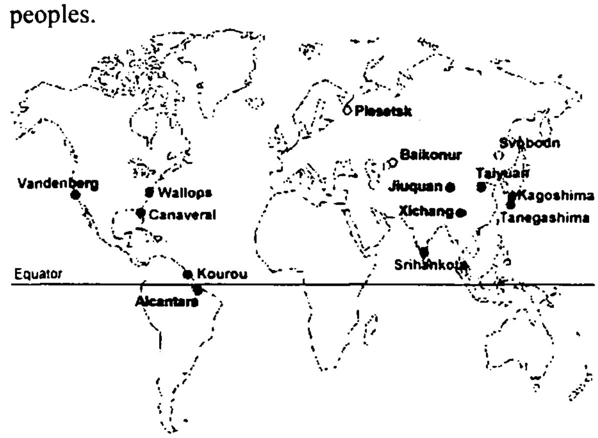

Figure 4 Geography of Global Space Launch Site

That is, to be fully appreciated, space benefits cannot be limited by national borders. As collective goods, they must be distributed among a broad set of customers or users. Even though this important type of cooperation is difficult to measure, the RAL provides a mechanism for just such a measurement.

Recall, the RAL measures the extent of IAD agreements to-other-agreement relationships. Some agreements have been repeated or extended in an effort to maintain international cooperation which, in some cases, is propagated for collective-goods considerations. For example, as *Landsat*, a space-based mapping system required a broad set of user terminals to globally distribute remote-sensing information. The basic *Landsat* agreement was repeated with numerous international partners, and its repetition indirectly measures its collective-goods condition. Thus, examining the behavior of RAL can help explain some of NASA's international cooperation.

NASA/Europe Model for Developing States

NASA-European space cooperation encompasses a long standing string of agreements with numerous European nations as well as with European Space Agency (ESA). NASA's international cooperation is historically Eurocentric with 63% of the IAD agreements being with either individual European member-states or ESA. As seen earlier in Figure 1, the preponderance of European agreements are between NASA and France, the UK, or Germany, each with approximately 300 individual agreements over the thirty-seven year history.

In the 1960s and 1970s, Europe was limited in the scale and variety of aerospace projects of which it was capable of undertaking because no single individual European member-state had a high enough space industrial level (SIL). The fragmented nature of European space industry was recognized as a problem by both NASA and Europe and, subsequently, ESA was formed to correct the problem as well as to create a balance with NASA's SIL. Individual European member-states have a pattern of cooperation that is distinctive from the NASA-ESA agreement pattern. The IAD contains agreements with European nations both before and after the formation of ESA and therefore provides an empirical foundation for understanding the effects of SIL and TRL as well as ESA on NASA-European cooperation.

This study distinguishes two forms of NASA-European cooperation: agreements with the European Space Agency (ESA) and agreements with individual European member-states. 148 ESA agreements with NASA were signed from 1964 to 1994. Included in this group of agreements are the European Launch Development Organization and European Space Research Organization (ESRO/ELDO), which were the precursor international organizations, formed by Europe to conduct aerospace R&D. In 1973 in Brussels, a stronger space organization (ESA) began from the merger of smaller ESRO and ELDO.

NASA signed its first ESRO/ELDO agreement in 1964. The AAR level for the next 10 years averaged two agreements per year. In 1973, with the establishment of ESA, the number of agreements signed with this newly formed European collective space agency increased AAR levels 100% from the previous year. The AAR level for subsequent years ranges from a low of 2 agreements in 1985 to a high of 10 agreements in 1991 with an average of 6 agreements per year, a three-fold increase from the period before the formation of ESA. Of the 148, 62% are categorized by TRL as technology agreements. Innovation agreements represent 20% of the total and science agreements represent the smallest proportion at 18%.

While ESA has yet to possess human launch capability, ESA's satellite launch capability debuted in 1979 with its first Ariane rocket launch. However, this European space-faring advance does not signal a change in the amount of NASA cooperation with Europe as there is no dramatic variation in the number of agreements.

The distribution of NASA's 1450 bilateral agreements with various European nations concentrates in thirteen states: Austria, Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom. This European cluster has the largest number of agreements out of the four regional groups and, as in the aggregate assessment, the tendency toward technology agreements remains, yet at a diminished level of 47%.

NASA signed its first agreement with a European nation in 1959; in that year a total of three agreements were signed with European nations. The number of agreements grew rapidly over the next five years to a level of 36 agreements per year by 1964, representing a twelve-fold increase in five years. The number of agreements between NASA and European nations remained steady until 1972, the year prior to the establishment of ESA, when the AAR went to 67. This new and higher level was generally maintained throughout the 1970s with a peak occurring in 1980 with 77 agreements signed during the year after the first Ariane launch. In the 1980s, the AARs began a volatile phase, ranging from a low of 18 in 1988 to a high of 63 in 1991. From a TRL perspective, technology agreements represent 47% of the 1450 agreements signed. Science agreements represent 38% while innovation agreements are the fewest with 15%.

Changes in two measures of independent variables underlying NASA's international cooperation with Europe are pivotal in the explanation of variation patterns in the amount of cooperation as measured by the AAR. The first change, a political milestone, was the establishment of ESA in 1973 representing a maturing of intra-European international cooperation in its own right. Indeed, Europe's approval of ESA in Brussels was accomplished, in that, after, "ten years, Europe had finally acquired the framework it had been looking for in order to coordinate, and possibly later integrate, all its common and national space programs."‡‡ The formation and establishment of ESA is a measure which has influenced the amount of cooperation possible with NASA. As a political measure ESA's formation introduces international institutional forces between NASA and European-states.

The second change, a technical achievement, was the first successful launch of the Ariane rocket from French Guinea in 1979, representing a higher level of technical quality for Europe. Studies of the performance of joint alliances, similar to NASA-Europe cooperation, find that, "what produces enhanced economic performance is thus a satisfactory level of technical quality combined with

‡‡ Bonnet, Roger, and Vittorio Manno. International Cooperation in Space: The Example of the European Space Agency. Cambridge: Harvard University Press, 1994, p. 20.

the choice of an adequate organization."[§§] Thus, this technical achievement represents a new level of SIL capability in Europe which influenced the amount of NASA cooperation by enabling new kinds of joint programs and balancing the space-faring industrial gap between NASA and its European partners.

Comparing ESA and its member-state agreements helps explain some patterns of NASA international cooperation. A relative assessment of the TRL distribution that ESA has 18% science agreements, 62% technology agreements, and 20% innovation agreements with NASA. However, European states have a different mixture of agreements with NASA: 38% science agreements, 47% technology agreements, and 15% innovation agreements. The fact that European bilateral agreements have a significantly higher number of science agreements suggests that NASA can encourage more international cooperation through formulating and proposing science projects to individual European member-states rather than to ESA, and conversely, large technology and innovation projects should encourage more ESA cooperation. Another empirical test of this tendency is found in the comparison of the average number of bilateral science agreements per nation, at 43, with the number of science agreements signed by ESA, at 27. The number of bilateral agreements exceeds ESA's number by 60%, indicating a strong preference towards European bilateral science agreements.

CONCLUSION

This paper seeks to explain some of the techno-political conditions contributing to the amount of cooperation experienced and recorded in NASA's International Agreement Database. The two aggregate assessments offered are empirically based descriptions of NASA's entire history of international cooperation unblemished by selection bias; they explain over 60% of NASA's international cooperation. By utilizing a cluster analysis approach, NASA's international cooperation can be understood along both aggregate and regional perspectives. Each of these views suggests explanations for some of the variations in NASA's international cooperation levels. Future research into this subject should clarify several potential causal relationships which seem to explain the amount and type of international cooperation needed for future human exploration programs. The scale of future international programs may rival the size of NASA's aggregate history of agreements. The conclusions and implications of this research may help NASA and other space agencies to better formulate and establish the international agreements necessary for a large scale programs such as those required for Mars exploration.

Future practitioners interested in international space cooperation should consider studying the formation of Europe's Galileo Program or how NASA's Exploration procurements structure international participation. The post "9-11" security aspects of space power and the transnational qualities of many multinational aerospace corporations should have strong influences on the amount and type of space agreements signed with both the developed and developing states.

Developing states seeking to form international space cooperation agreements with NASA should carefully consider leveraging international-institutions to raise their collective SIL and selecting projects with the right technology-readiness levels. A new era of international cooperation in space seems to be starting; the implementation of the United States Space Exploration Vision expressly calls for international involvement.[13] As new technology develops from government projects, new opportunities open for developing and developed states seeking to invest in space exploration technologies.

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[5] See Finding 3, "U.S.-Russian Cooperation in Space," (Washington, D.C.: Office of Technology Assessment: Congress of the United States, 1995), p. 2, 13.
[6] 0=None, 1=Satellite and 2=Human Spacefaring Industrial Levels.
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