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BUILDING TECHNOLOGICAL CAPABILITY WITHIN SATELLITE PROGRAMS IN DEVELOPING COUNTRIES

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This paper explores the process of building technological capability in new satellite programs within developing countries. Specifically, the article focuses on the strategy used by many developing countries to facilitate local technological learning via international collaboration. Two important, global realities motivate the study. The first reality is that satellite services – remote sensing, communication and navigation – are increasingly valuable to address needs in developing countries. For example, remote sensing satellites can provide imagery and scientific data that is useful to manage disasters, monitor crops, facilitate urban planning, and spur industry. The second global reality is that a growing number of countries are moving from passive consumption of satellites services to active participation in space activities. New countries on every continent are creating or strengthening local satellite programs. Countries such as South Africa, Nigeria, Mexico, Malaysia, and the United Arab Emirates are joining more established countries such as India, China, Brazil, Argentina and South Korea. Previous research by the authors considered the evolution of technological capabilities for eight countries in Africa, Asia and Latin America. A key result from this past analysis is that many countries use foreign partnerships to gain new capability in satellite technology. This paper shows how literature on technological learning provides insight into these collaborative satellite projects. Ample work has been done in this body of literature to analyze capability building for technologies outside of the space context. Very little work has applied their ideas to satellite technologies, as done in this paper. The results are valuable to policy makers in countries throughout the world. For countries with young space programs, it provides a new lens through which to view the process of technological capability building. For countries with more established space programs, the discussion provides insight about technology transfer policy and the potential of international cooperation with new partners.

I. INTRODUCTION

Many countries in the regions of Africa, Latin America, the Middle East and Asia are often informally denoted as "developing countries". The majority of countries in these regions are pursuing a long process of socio-economic advancement. They are gradually building their local infrastructure to provide better physical, social, health and education services to their people. They are progressively refining their systems of government as they move forward from colonization, civil strife or dictatorship. Developing countries face many challenges. Many of their citizens struggle to meet their basic needs. One common feature of developing countries is a lack of access to – or mastery of – the latest technology. In the midst of these realities, there exists an important connection between developing countries and one of the most advanced areas of technology – space satellites. This paper explores that connection with particular emphasis on examples of developing countries that are consciously building local technological capability in the field of satellites.

The study considers issues faced by leaders in developing countries as they initiate new national satellite programs. The focus is specifically on issues encountered as part of establishing a new workforce of experts with an understanding of how to design, manufacture and operate satellites. The main argument is that there are lessons to be learned from beyond the field of space technology that may provide useful guidance for such satellite programs. These lessons must be applied cautiously, however, because of unique features of the satellite programs.

The following discussion has four main sections. The first section provides background and context. It more fully introduces the potential benefits that developing countries can gain by accessing satellites services. The second section includes a discussion of motivations, strategies and historical models for satellite programs in developing countries. The third section considers key concepts and frameworks from literature on technological learning that are relevant to satellite programs in developing countries. These concepts derive from case studies in other technological fields. The fourth section considers how to appropriately apply lessons from these other technology fields to satellite programs. The paper closes with concluding remarks and a preview of future research plans.

II. SATELLITE SERVICES FOR DEVELOPING COUNTRIES

Satellites are essentially information tools that can facilitate the creation, transformation or transmission of data. That data may include a scientific measurement of sea surface temperature; it may be a digital packet of information that is part of a phone call; or it could be a reference location that allows a ship to calculate its position.

The many applications of satellites can be divided into three broad categories: Remote sensing, communication and navigation. Remote sensing includes all the activities in which the satellite measures something from a distance. The earth-centric remote sensing services include observing meteorological patterns, taking optical images with cameras, and using scientific instruments to measure phenomena in the land, sea or atmosphere. Satellites are used for communication anytime they transmit a signal from one location to another. This signal can be a phone call, radio broadcast, television program, internet query, text message or data stream. Satellites are used to enhance navigation when they are part of broader systems that create a positioning reference. Through Global Navigation Satellite Systems (GNSS) – such as the U.S. Global Positioning System – users can receive signals from satellites that enable them to identify their own position and plan a route.

The capabilities provided by satellite remote sensing, communication and navigation are highly relevant to needs in developing countries. In general, developing countries face challenges in areas such as obtaining timely information about the state of their environment, maintaining a complete communication infrastructure and managing safe transportation. Many developing countries are also located in a geographic region – near the equator – that experiences a disproportionately large amount of natural disasters. Even as these countries are working to build a new national system after years of colonialism or civil unrest, they are threatened in their progress by destruction from tsunamis, earth quakes, floods, fires and famine. Another challenge for these countries is to manage the health of their populations. They struggle against both tropical diseases such as malaria and new menaces like AIDS.

Satellite remote sensing can be very valuable in developing countries, specifically by providing information about the state of the environment. Satellite data can provide policy makers with useful information about the health of crops, the changes in land use by people and animals, the management of water resources, pollution in the atmosphere and the risk of disease vectors. Researchers can use such data to determine if there are conflicts between the resources available to the population and the resources required – in areas such as agriculture, health and water. By passing such information to policy makers, this research can help mitigate these conflicts. In times of sudden disasters, satellite imagery can be very crucial. It can show locations of fires, the extent of damage from floods, earthquakes and landslides. Satellites are also a key tool in providing warning for hurricanes and typhoons.

Satellites currently play an important role in the communication infrastructure of developing countries. They are frequently used to broadcast television and radio to homes and businesses. This is the most commercially successful application. They can be helpful for long distance phone and internet connections, although there is an inconvenient delay when the satellite is located in a geostationary orbit. Two key social applications in which satellites can contribute are tele-medicine and tele-education. The quality of medical care and education is a challenge in many developing countries – particularly in rural areas. Tele-medicine can help by connecting local health care workers with support from information and personnel in other areas. Through tele-education, students can connect with teachers, curricula and course assignments from a distance.

Satellite navigation can be very useful in developing countries where logistics and transportation are constant challenges. In some developing countries, there are poor systems of maps and references, such as formal addresses for buildings. Countries may also struggle with installing the standard, ground-based technology to support transportation. An example of this standard technology is RADAR-based air traffic control systems for rural airports. In such situations, the infrastructure provided by Global Navigation Satellite Systems can provide useful short term and long term service. GNSS can improve the safe operations of cars, trains, planes and ships. During disasters, GNSS can be used to help recovery workers find problem areas. GNSS has also been used in areas such as wildlife management. Tiny sensors can be placed in endangered species to help scientists understand their movements.

This section has outlined some of the many applications through which satellites can provide valuable services in developing countries. It must be added that, with all of the capabilities of satellite services, the benefits cannot be achieved by simply operating the satellites. The satellite service must be part of a larger, functional system that integrates the information or communication services of the satellites and delivers useful end results for citizens. This facet of satellites services is often highly challenging in developing countries.

Most developing countries do have access to satellite services and have some systems in place to take advantage of them. Most countries in Asia, Africa, the Middle East and Latin America do not own satellites domestically. Instead they gain access to satellite services and data through interactions with foreign governments or companies. A

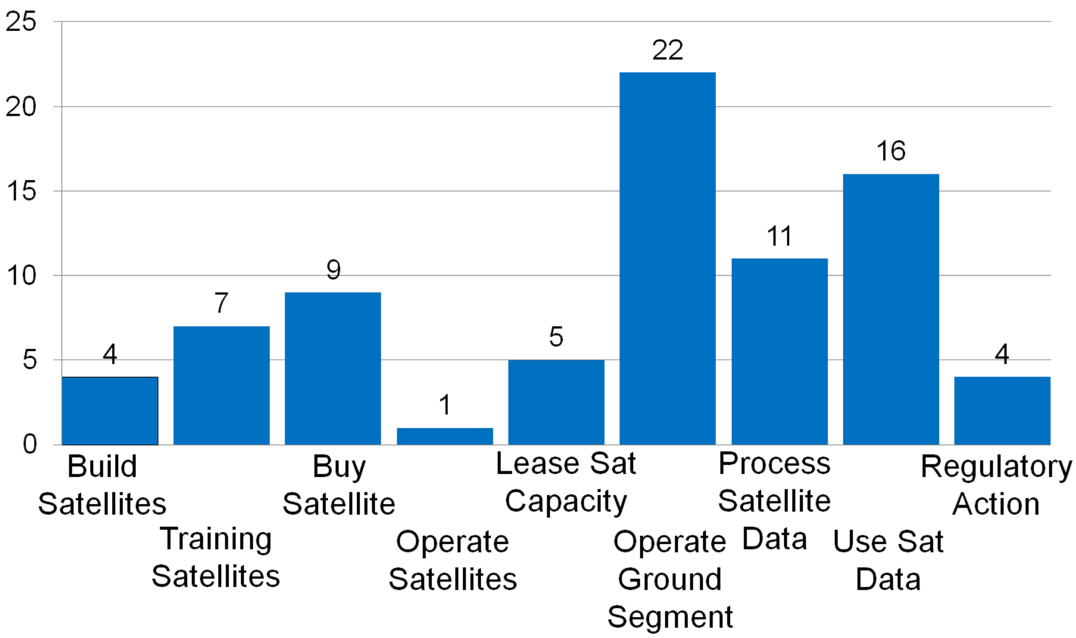

Figure 1: This chart shows the break down for 9 different types of satellite projects from Africa. Most countries in Africa access satellite services in-directly via second-hand data or ground-based technology.

previous study by the authors considered models of satellite projects in the African context. The research reviews eighty examples of satellite-enabled activities done for the benefit of Africa. These eighty case studies are divided into nine categories based on how the African consumer interacted with the satellite technology. In each case, the African player is accessing a service in satellite remote sensing, communication or navigation. They often do so indirectly, however, by sharing or buy data or communication service from a foreign source. Figure 1 shows the results of this classification for the African satellite projects. In eleven special cases, shown in two categories on the far left, an African government works directly with the satellite. They buy and operate a domestically owned satellite and involve local engineers in the manufacturing of the satellite – as trainees or engineers. This points to a trend that is the focus of the next section. More and more, developing countries are investing in their own national satellite systems rather than relying exclusively on foreign satellite owners. [1]

III. SATELLITE PROGRAMS IN DEVELOPING COUNTRIES

As mentioned above, one global reality that motivates this study is that a growing number of countries are moving from passive consumption of satellites services to active participation in space activities[2]. New countries on every inhabited continent are creating or strengthening local space programs. Countries such as South Africa, Nigeria, Mexico, Malaysia, and the United Arab Emirates are building up local capabilities in satellite technology within young space agencies. They join more established countries such as India, China, Brazil, Argentina and South Korea who have already achieved indigenous capability to build and operate satellites. India and China have their own proven launch capability, while Brazil and South Korea are pursuing this goal. In the early years of the space era, only a few countries had access to the technology required to independently build and operate satellites or launch vehicles. This is changing, particularly in the area of satellites, as the technology matures and business models in the satellite industry evolve. Traditional aerospace companies in the United States and Europe specialize in selling large scale satellites that required a huge initial investment. Many firms and governments from developing countries find their prices and technical options out of reach. Smaller companies in the aerospace industry – especially Surrey Satellite Technology Ltd (SSTL) in England – are providing new options for developing countries. SSTL offers lower cost, smaller satellite products that more countries can afford. The company spun out of a university lab whose mission was to lower the cost of satellite technology by using satellite components that were designed for ground operation instead of components designed especially for space. SSTL also provides training for their customers; they facilitate the inauguration of new satellite programs and firms. Some of SSTL's former clients are now competitors in the small satellite market. One example is a team from South Korea that now operates the company known as SaTReC Initiative.

This section considers issues arising from the creation of satellite programs in developing countries. It first considers motivations for developing countries to pursue domestic satellite programs. It also analyses the strategic decisions that are central to all satellite programs and considers various historical models for program implementation.

III.1 Why do developing countries have satellite programs?

People often wonder whether developing countries should invest in owning and operating national satellites. Some argue that there is enough remote sensing data available on the international market to meet the needs of developing countries. They conclude that developing countries should not invest in satellite hardware, but should buy or share data from other sources. With this approach, the developing country is focusing resources on utilization of the data for local needs rather than production of the data. This is often a reasonable approach. Most developing countries are currently in this situation. Their efforts to use satellite remote sensing data are facilitated by many international initiatives such as the project of Group on Earth Observations to gradually establish a Global Earth Observation System of Systems[3]. During disasters, developing countries can activate the International Charter: Space and Major Disasters, with the help of the United Nations[4]. This charter is an agreement among many countries that own satellites. They freely share satellite imagery to support efforts in disaster response.

In the area of satellite communication, one can make a similar argument. There are many commercial companies that own and operate communication satellites for a profit. They provide service throughout the developing world. Doesn't their presence supersede the need for national governments to operate communication satellites? The argument seems even clearer in the area of satellite navigation. The United States currently operates the Global Positioning System. It is a constellation of at least 24 navigation satellites that freely broadcast their location. Users can triangulate from multiple GPS satellites and calculate their own location. Several other GNSS projects are currently underway.[5] Russia is revitalizing their GLONASS constellation; Europe is preparing to launch the Galileo constellation; and countries such as India, China and Japan are planning to operate regional or global satellite navigation systems.[6] If at least one of the global systems offers a free signal, it can serve all developing countries. It seems very likely that during the next few decades, the freely available navigation services will only increase for developing countries.

All of these facts seem to lead to the conclusion that developing countries do not need to own and operate their own satellites. There are subtle realities, however, that challenge this conclusion. In the area of remote sensing, it is true that there are many government programs through which data collected by the international community can be shared with countries that do not own satellites. There are also commercial providers such as Digital Globe, GeoEye and SpotImage that sell high resolution satellite imagery. The problem remains, however, that developing countries cannot always get the data they need when they need it. This may be because the data collected by other countries does not account for the technical requirements of a particular user in a developing country. Such requirements can include temporal frequency, spatial resolution, spectral frequency or geographic coverage. Also, the global political infrastructure of data sharing policies is not yet complete. Organizations from developing countries that wish to share international data may be obliged to work hard on establishing bilateral agreements with each data producer and keep those agreements up to date in order to ensure access. This can be a laborious process. Meanwhile, high resolution data, which is particularly useful for projects in urban planning, is still very expensive and main available from commercial providers. It can be cost prohibitive for developing country governments to buy high resolution imagery regularly.

In the area of communication, one could argue that the need for this service is provided by commercial vendors. It is common economic wisdom that a company in a competitive market can offer a consumer service more efficiently than a government can. This seems to imply that governments should open their doors to allow competition among communication providers and not be involved as a service provider. This economic prescription may not meet social goals, however. There is room to consider government involvement to ensure that the poorest and most needy communities benefit from satellite communication service, if needed.

In the area of satellite navigation and positioning, developing countries do not need to invest in their own satellite constellations. The opportunities offered by the GPS, Galileo and GLONASS satellites are great. There are limitations, however. The free signals from this publicly available infrastructure do not have high enough resolution for many applications. They are adequate for consumer use in driving and walking. They are not precise or consistent enough for the so-called "safety of life" applications, such as landing plane. Also, for applications such as precision agriculture and urban planning, highly detailed information may be needed. For these reasons, in the area of satellite navigation, developing countries cannot be passive consumers in the long term. They need to seek out systems to augment and improve the navigation signals they receive. There are both ground based and space based augmentation systems.

Given all of this discussion, the framework in Figure 2 is helpful for organizing the issues regarding motivations for developing countries to pursue satellite programs. The framework considers separately the short term versus the long term motivations for a country's actions. It also divides national investments into three areas: satellites services, satellite hardware and satellite expertise. In the short term, a country can rationally pursue satellite services because they meet time sensitive needs for information. In the long term, these services from satellites can facilitate improved infrastructure and better informed regional planning. Satellite service can also improve the functioning of commercial activity over time, in areas such as mineral exploitation, real estate development and logistics. In the short term, a developing country government may choose to own domestic satellite hardware because they are not getting a particular type of needed data or service from the international market. In the long term, having a national satellite or set of satellites can influence the country's relationships with foreign technology sources. There may be geo-political or economic reasons that a given country prefers to not depend on foreign sources for their satellite services in the long term.

	Satellite Service	Satellite Hardware	Satellite Expertise
Short Term	Address time sensitive national needs	Help meet specific, local requirements for information	Develop knowledge to be an informed consumer of satellite services
Long Term	Enable informed regional planning; enhance infrastructure	Decrease dependence on foreign technology sources	Inspire young scholars; enhance educational opportunities

Figure 2: Framework for potential motivations for rational investment in satellite service, hardware or expertise within a developing country

A separate consideration is whether a country chooses to invest in satellite expertise in the short and long term, as the framework shows. Such an investment in space expertise can take many forms, such as university programs, government research projects, training for civil servants or founding new companies related to satellite technology. Of course, a country can choose to buy a national satellite by procuring a turn-key system from a foreign company. This can be done with little knowledge about how satellites are designed, manufactured or operated. At times, it is rational for a developing country to buy a turn-key system and forego any foray into understanding satellite technology. However, there are also rational reasons to invest in establishing satellite expertise at some level within developing countries. In the short term, such expertise can help make that country an informed, savvy consumer. Buying a satellite is complex; each satellite is custom designed to perform a specific mission for the customer. It is not a commodity product. A technically savvy customer will be much more able to specify what kind of system they need to solve local problems. In the long term, it is beneficial for developing countries to invest in building local technological capability about satellites because it is good for the overall scientific system in the country. Such experience can inspire young scholars to study in new areas and help pave the way for other scientific activities. This paper will later look at examples of countries that have chosen to invest in local capability in satellite technology. Later sections will show the models they are employing to move forward in this area.

Finally, there is another class of arguments about satellite programs in developing countries. Some worry that these projects are done only based on national pride or a desire to place one's country in the "elite" club of space-faring countries. There is plenty of evidence, from both more developed and less developed countries, that national pride and politics do play a key role in decisions about whether and how to invest in space. There may certainly be motivations to boost a country's image both internally and externally. The authors contend, however, that such motivation can exist simultaneously with the practical rationale described above. There need be no conflict between wanting a national satellite because it will inspire youth to see their country a regional technology leader and because it will allow the government to have better forecasts about the next famine.

III.2 Common, Strategic Decisions for Satellite Programs

Once a country chooses to invest in having a national satellite program, there are several challenging decisions that must be made about the scope and implementation of the program.[7] These decisions can be categorized into three key areas. As shown in Figure 3**,** these areas encompass progressively broadening levels. First, there are more narrow decisions about the technical capabilities to which the country aspires. This includes the human resources they want to develop and the types of technical facilities to procure and operate. Within this category are questions that the country can answer in numerous ways. Do they wish to own their own satellites? What types of satellites do they need? How will they procure the satellites? Will they develop any of the technology using local personnel – for the satellite or for the instrument? Will they develop the technology using local facilities? Each of these decisions involves complex trade-offs and potentially large investments of resources.

At the second level are decisions about how the satellite program fits into the domestic context. The new program will have some relationship with existing entities in government, academic and industry. Stakeholders from each of these areas will seek to influence the program as well. Questions at this level include the following: How will existing organizations in research, administration and industry be involved in the new satellite program? Will the government seek to foster specific local industries via the program? Should the satellite program be executed directly by a government entity, a commercial entity or a combination of both? Decisions at this second level are highly driven by the local economic and technology context.

At the third and broadest level, the satellite program will be defined by how it relates to the international context. Many satellite programs involve relationships with foreign governments or firms. Governments who begin new satellite programs have to make strategic decisions about how and when to work with foreign players. A political partnership with a foreign government can be useful, especially when it fulfils a political objective and meets needs for both sides. It can often appear to save resources, especially if both partners contribute to the satellite costs. There are hidden expenses to consider, however, due to the costs of coordination, travel, political delay and potential language or cultural barriers. A commercial relationship with a foreign firm is often used by developing country governments as part of their satellite program. They may buy a full satellite or specific services from the firm. A commercial relationship has the advantage of putting control in the hands of the customer. This can be more flexible than a political partnership. Commercial relationships can be limited as well, however, due to the needs of the firm to control their intellectual property and make a profit.

All developing countries face these three strategic decisions if they choose to implement their national satellite program. There are also important relationships between the decisions made at the three levels. This paper considers how the international partnerships influence program capabilities. The following section considers some historical models for developing country satellite programs.

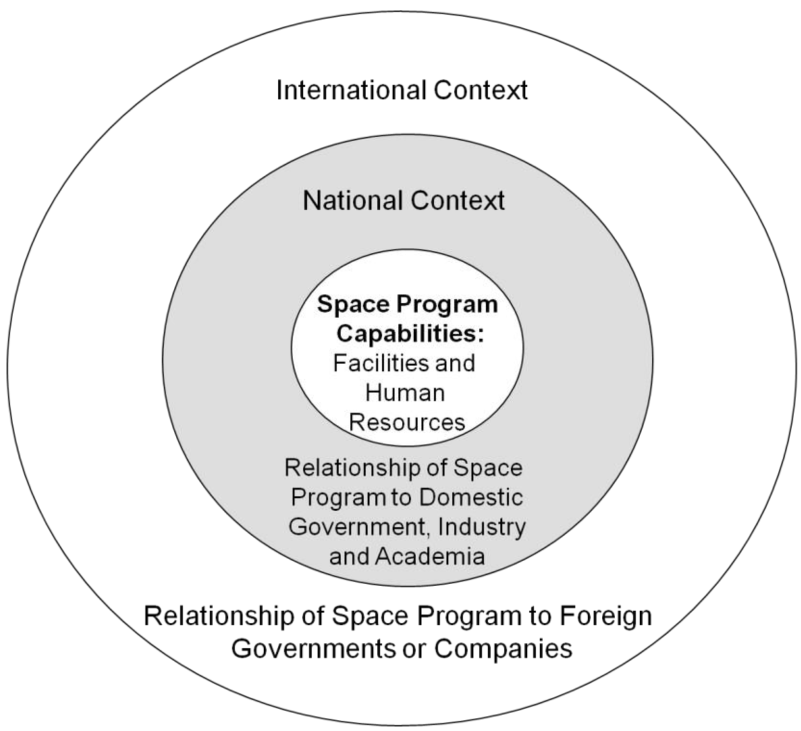

Figure 3: National satellite programs in developing countries face strategic decision in these three areas

III.3 Historical Models for Satellite Programs

Previous research by the authors examines the experiences of eight countries that established national satellite programs as part of their development process.[8] The countries included in the study are Argentina, Algeria, Brazil, Egypt, India, Malaysia, Nigeria and South Korea. The study compares the pathways of these countries in achieving key milestones along an idealized ladder of technical autonomy called the Space Technology Ladder. This ladder is shown in Figure 4. It outlines a variety of implementation approaches in four areas, namely: 1) Establishing a national space office; 2) Owning and operating a low earth orbit (LEO) Satellites; 3) Owning and operating a geostationary (GEO) satellite; and 4) Launching satellites. Within each area, there is a vertical progression of increasing technical autonomy. For example, Level 3 to 7 all show methods for owning and operating a LEO satellite. At Level 3, however, the country buys the satellite from a foreign partner and at Level 7 they are able to execute the project independently in their own local facilities.

The Space Technology Ladder	
13	Launch Capability: Satellite to GEO
12	Launch Capability: Satellite to LEO
11	GEO Satellite: Build Locally
10	GEO Satellite: Build through Mutual International Collaboration
9	GEO Satellite: Build Locally with Outside Assistance
8	GEO Satellite: Procure
7	LEO Satellite: Build Locally
6	LEO Satellite: Build Through Mutual International Collaboration
5	LEO Satellite: Build Locally with Outside Assistance
4	LEO Satellite: Build with Support in Partner's Facility
3	LEO Satellite: Procure with Training Services
2	Space Agency: Establish Current Agency
1	Space Agency: Establish First National Space Office

Figure 4: The Space Technology Ladder shows potential milestones for countries developing local space technology capability

One key result from the study is the diversity of approaches among the countries. They all found unique ways to answer the strategic questions defined above and move along the Space Technology Ladder. For example, Argentina tended to partner primarily with foreign governments via political agreements in their early LEO satellite projects in the 1990s. They also contracted with an existing technology firm to do local manufacturing of the satellite buses. In contrast, Malaysia's more recent efforts in LEO satellite programs built heavily on commercial relationships with foreign firms in the United Kingdom and South Korea. They also created a new commercial firm within Malaysia to manage the projects. This is just one example of the contrasts among the historical approaches to satellite programs. The major milestones of several Asian countries are shown in Figure 5 below. As can be seen, countries do not move linearly along the Space Technology Ladder, they bounce around it and find their own unique path to technological capability.

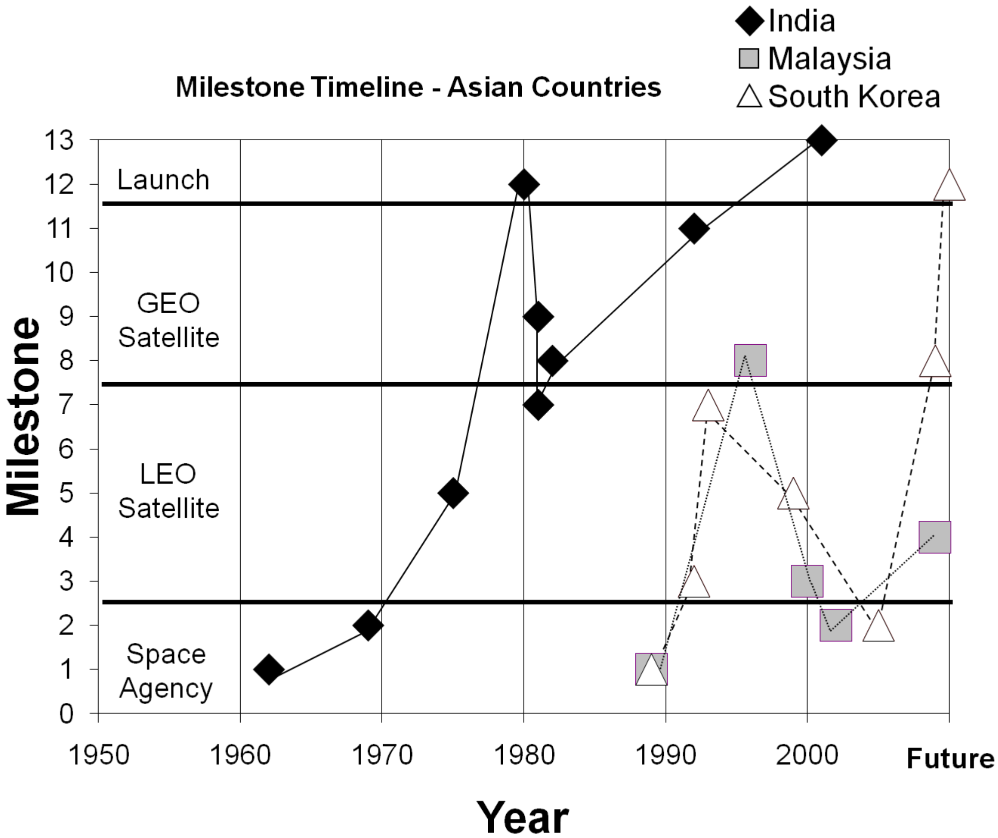

Figure 5: This charts shows the progress of three Asian countries through the milestones from the Space Technology Ladder

A second key result from the historical models of satellite programs is the importance of international collaboration as part of the process of building technological capability. As countries progress up the Space Technology Ladder, they are increasing their local level of technical expertise in the area of satellites. When developing country governments begin new satellite programs, they often have limited domestic resources to help establish a technical workforce in satellites or start up satellite manufacturing facilities. The local universities may not have specialties in satellite engineering and the local industry does not yet have experience. In these cases they typically turn to foreign firms or government partnerships for technical assistance. Thus, the foreign intervention in these satellite programs is arguably a vital part of the process of technological capability building. History shows that many countries in the past have depended on foreign partnerships to grow their capabilities in satellite technology. It is likely that many countries in the future will choose a similar course of action.

An international technology partnership does not guarantee successful capability building, however. There are a number of challenges that can decrease the effectiveness of capability building via international partnership. The next few sections explore and expand this idea by considering concepts from literature and history in other technical fields.

IV. LESSONS FROM STUDIES ON TECHNOLOGICAL CAPABILITY BUILDING

Space is not the only technical area in which developing countries use international partnerships as a key strategy of their process of technological capability building. This scenario has been common in a variety of technological areas since the post-World War II era. Starting in that period, many developing countries were gaining independence from colonial leaders, especially in Asia and Africa. They sought to establish new industries as part of their process of economic development. Some countries wanted to be able to locally manufacture the modern appliances and tools that they were importing from more developed countries. Some countries sought to build their economy by manufacturing exports that could be sold in the wealthy markets of the US and Europe. In both cases, there was an effort to bring into the country a technological capability that had previously not existed. Often, countries used political or commercial partnerships with foreigners to build local capability. Since World War II, a number of experiments in technological capability building have been executed throughout the developing world.[9] Many scholars have examined and synthesized the experiences of these countries. These scholars come from fields such as economics, political economy, management, international development and urban planning. The commentary of these scholars is diverse; there is not a unified interpretation among them. Rather there is spirited debate about what has happened and what it means. Some focus on these episodes as examples of technology transfer[10]. They write about actions that a more developed country can take while sharing technology with a less developed country. Another community of scholars focuses on technological learning. They seek to understand what actions a less developed country can take to improve their chances of successful technological capability building when working with partners from a more advanced country.

This paper draws specifically from the second community of scholars that focuses on technological learning. This literature is dominated by a close-knit community of scholars, many of whom know each other and collaborate on research projects. Some of the prolific members of this community are Giovanni Dosi,[11] Alice Amsden,[12] Paulo Figueriedo,[13] Sanjaya Lall[14] and Linsu Kim.[15] They build on foundational concepts including Schumpeter's Entrepreneur,[16] Senge's Organizational Learning,[17] and Nelson & Winter's Evolutionary Economics.[18] The scholars who contribute to this community use both theory and empirical evidence to craft prescriptions describing how firms or organizations in developing countries can increase their level of technological capability. The present abbreviated literature review explores some of the concepts and frameworks that have been proposed by the technological learning literature regarding the process of building capability via international partnerships.

A series of important relationships and definitions springs forth from the technological learning literature. At the core is the concept of national development. In this research, borrowing from this community of scholars, development is about the process by which countries become more advanced in their use of technology for productive activities. As Amsden[19] writes, development is the "process of moving from a set of assets based on primary products, exploited by unskilled labour, to a set of assets based on knowledge, exploited by skilled labor." Amsden is not alone in asserting the connection between technology and national development; she is joined by other voices such as Nelson and Druker. Nelson's[20] work on National Innovation Systems describes how the interactions of the many players that are involved in science and technology come together to support national development. Druker[21] describes how the global economic system has changed since the Industrial Revolution, such that the application of knowledge is becoming more important than capital and labour as factors of production. Druker describes the global transition from the "Industrial Revolution" to the "Productivity Revolution" to the "Management Revolution." Developing countries have not fully participated or benefitted from these transitions, which is why they are considered less developed than other regions. Thus, a country becomes more developed as it makes better use of knowledge based assets. This phrase is another way of describing technology. Bozeman[22] writes that technology is made up of the "knowledge-based assets that are applied to create value." In the context of this research, technology includes products, processes and knowledge – both the tangible and the intangible. The term technological capability, used so frequently here, means the "ability to make effective use of technology."[23] Technological learning, then, is the process of increasing in technological capability. It is a very active word that describes a conscious effort on the part of the learning individual or organization. In the context of this research, it is an effort on the part of the national satellite program.

Some may argue that technological learning is not important for developing countries. Perhaps they should leave the advanced technology to other countries and focus instead on exploiting their local competitive advantage such as ample labour or abundant natural resources. To this, authors such as Grieve[24] offer resounding disagreement. Although development strategies may include such resources as part of the portfolio, Grieve urges developing countries to also "achieve a firm grasp of modern technology, learn from it, and on this basis, seek to develop innovation and technological capabilities." Thus, firms and other organizations are advised to learn from the state of the art technology that is used in more advanced countries. In the parlance of this literature, developing countries are "latecomers," meaning that they are working behind the technological frontier.[25] They are also isolated from the centers of technology production, such as excellent universities and research laboratories.[26] The experience of technological learning for latecomers is not necessarily a repeat of the experience of the more developed countries as they discovered or invented today's technologies. Kim[27] builds on work by Utterback[28] that shows how latecomers may move through an innovation cycle. Utterback's seminal work shows how inventions are created and go through a period of high product innovation until standards set in and innovation declines. Next, there is a period of active process innovation until a new product takes becomes dominant. Utterback's model applies to advanced countries working at the technological frontier. Kim proposes that developing countries – as latecomers – may follow a reversed technology trajectory. They enter when a product is already mature and learn from outside sources how to manufacture it. Gradually, they may be able to do process innovations and product innovations. They work toward generating new technologies in that field, after enhancing their skills by working on the mature technology. For the case of satellite technology, such an experience could apply to a latecomer's work in the area of solar panels, for example. It is a technology that is somewhat mature, but there is also room for innovation to improve the efficiency of their performance. An organization from a developing country may learn the well established techniques for manufacturing solar panels from an outside source. They may then continue to work with those methods over time and start to make small improvements in the manufacturing. Eventually, they may experiment with slightly different materials and do tests to improve the performance of the panels. Ultimately, their hands-on efforts may lead them to propose a new alloy for the solar panels. Such a transition could take decades; it may be longer if the organization does not have a solid understanding of the physics underlying the operation of the solar panels. Figure 6 provides a graphical description of the ideas of Utterback and Kim, building on the example of the solar panel manufacturer.

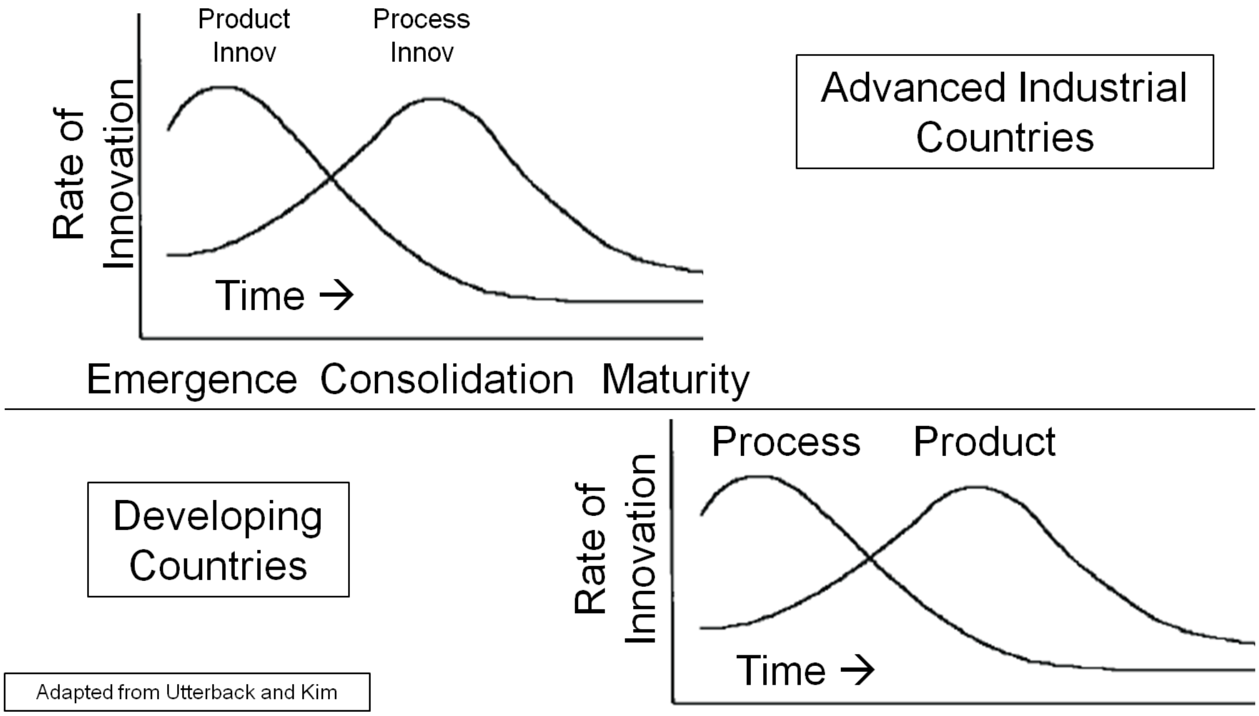

Figure 6: This graphic builds on work by Utterback and Abernathy and by Kim. It shows how technology trajectories differ between developed and developing countries

What allows a latecomer organization in a developing country to successfully move through the phases from manufacturer to process innovator to product innovator for a particular class of technology? Some argue that it depends largely on the organization's "absorptive capacity." This concept refers to the organization's ability to take in and act on the new information about the technology they are learning. Building on Cohen and Levinthal,[29] originators of the concept, Kim argues that absorptive capacity for an organization depends on prior knowledge and the intensity of effort applied to understanding the technology. In other words, an organization can better absorb and work with a new technology if they have more relevant prior knowledge and if they work hard to learn about it. These concepts place a great deal of responsibility on the shoulders of the technological learners.

What are the sources of technological information for latecomer organizations in developing countries? Kim[30] provides a useful framework for dividing such sources. Generally, they represent different kinds of relationships with outside organizations or information. There are one-sided scenarios in which a latecomer organization pursues knowledge independently via reverse engineering, literature, conferences, etc. There are formal relationships with well defined contracts, such as licensing technology from foreign firms, buying turn-key products and hiring technical consultants. In some less formal interactions, organizations can learn when they buy from or sell to a more advanced organization. Kim's work considers only commercial relationships of this nature, but in the space arena, such relationships might also be between governments. Figure 7 shows Kim's framework for technology sources, but it is slightly adapted.

	Role of Foreign Technology Sources	
	Active	*Passive*
Market Mediated	Quadrant 1 • Foreign licensing • Turn-key purchase • Technical consultancy • Special-order capital	Quadrant 2 • Sale of standard capital good
Non-market Mediated	Quadrant 3 • Technical assistance from technology vendors • Political partnerships	Quadrant 4 • Imitation • Reverse engineering • Observation • Journals • Meetings

Figure 7: Kim's framework on foreign sources of technology

The discussion thus far has addressed the meaning of development, the role of technology in development, the process of building technological capability via learning, the reversal of the traditional technology trajectory for latecomers, the importance of absorptive capacity and potential sources of technology. What remains is to drill even deeper into the practical issues surrounding technological learning. Such learning can happen along various dimensions, but it ultimately begins with an individual learning something new. This literature emphasizes the fact that technological knowledge can be tacit or explicit. Knowledge is tacit when it is not well codified.[31] This may be because the knowledge is wrapped up in a routine done by a skilled person. This person knows how to do the routine, but they cannot easily explain it to someone else.[32] It is difficult to convey tacit knowledge from one person to another. When tacit knowledge is made explicit – for example – by writing it down, learning can happen. If much of the knowledge required to do a certain technological task is tacit, it will be much harder for individuals working independently to learn about the technology. Thus, approaches like those in Quadrants 2 and 4 above will be less effective **(see** Figure 7**)**. In these cases, it is very important for representatives from the developing country to learn directly from people who are skilled in the technology. This can enable individual learning, but that may not be enough.

Some technological activities, including many satellite projects, require intensive group coordination. Individuals must understand how to achieve their own role, and the group must understand how to work together to achieve the overall goal. This requires organizational learning. Thus, organizational learning can also be an important part of technological progress for a latecomer institution in a developing country. Organizational learning is not automatic, nor is it well understood. Figuerido[33] proposes that it comes through socialization within the organization and a conscious effort to make tacit knowledge explicit. Edmonson[34] adds that when small groups work together on a complex task over time, they can naturally go through a process of organizational learning. They gradually develop a mutual understanding of how their individual contributions combine.

The theoretical frameworks introduced here were largely developed via inductive analysis from case studies of technological capability building. Kim, for example, writes specifically about Korea and highlights sterling successes in areas such as ship building, car manufacturing and steel production. Figuerido compares the learning experiences of two steel plants in Brazil over decades of operations. Amsden considers the learning efforts of electronics firms in Taiwan and many others. Edmonson writes about the experiences of hospital staff in the United States adopting a new, complex surgical procedure. These are just a few examples, but they motivate the following question: In what ways are the principles drawn from these case studies relevant to satellite projects in developing countries? The next section explores this issue.

V. ANALYSIS: APPLYING THE LITERATURE TO SATELLITE PROJECTS

As discussed above, developing countries that start satellite programs often seek support from foreign sources for technological capability building. One particular model of project stands out. It has been used by Nigeria, Malaysia, the United Arab Emirate, South Korea, Turkey, Algeria and Egypt - among others. The project model is summarized in Figure 8**.** An organization from a developing country hires a foreign firm to build a satellite. The foreign firm is responsible both for implementation of the satellite and for training local engineers from the developing country. The project thus has both short term technology goals and long term capability building goals. This section considers some of the ways that advice from the technological learning literature applies to this project model.

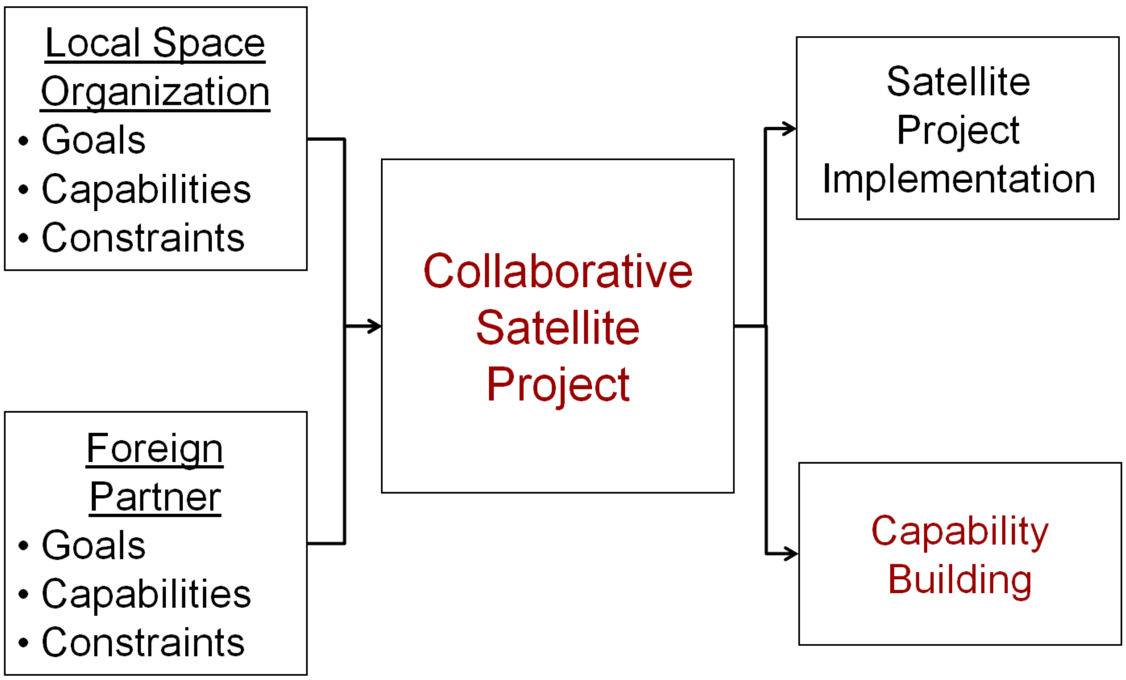

Figure 8: This model describes the archetypal project that is at the center of this research. Many developing countries have pursued projects of this type.

Before making such an application, a few words of caution are in order. The conclusions and prescriptions from the technological learning may not always apply directly to the satellite context. Recall that the ideas were developed from research about other types of technology. A first major difference between the satellite context and the case studies from technological learning is the nature of the players. The literature on learning focuses almost entirely on commercial firms. Satellite projects may be executed by commercial firms from developing countries, by government agencies or by a combination of the two. The incentive structure for a firm is driven largely by a desire for profit. This may be different in a government context. Such a difference may influence the learning dynamics. Without the pressure of maintaining a profit, how will incentives for learning in a government be different?

Also note that the research cited above is especially relevant to commodity products that are mass produced or continuous flow products such as steel. In these cases, the latecomer firm in a developing country can separate their learning about the manufacturing process from learning about the actual product. A manufacturing plant can produce a product without the operators understanding how to design or improve the product. Additionally, for commodity products, there is little variation on the design across customers. These factors can be quite different in satellite projects. The requirements are unique for each customer and each mission. Each product is built over a long time period, without frequent repetition that would enable learning by experience. Also, the manufacturing process is closely linked with the design, testing and verification process. It would be difficult for an organization to build a satellite without an understanding of how it works. These aspects illustrate some differences between the satellite context and that of others in the technological learning literature.

Given these caveats, here are three areas of application from the technological learning literature for satellite projects that involve international collaboration and technological capability building. First, the technological learning literature highlights the efforts supplied by the learner. When Figure 7 shows potential sources of technological knowledge, it does not just include other organizations. It also accounts for local effort to study, research and read. Such effort enhances the absorptive capacity of the organization. The higher the absorptive capacity, the more effective the capability building efforts will be during the project. Such effort can be made by individuals and whole organizations.

Second, the technological learning literature emphases the importance of both individual and organizational learning. Satellite projects require high levels of coordination among teams. It is certainly an example of a technology in which individual learning is not sufficient. Satellite projects involve work at the individual, small group and large organization levels. The literature encourages a conscious effort to communicate the results of learning across those levels via codification and socialization.

A final important issue in satellite engineering is the level of tacit knowledge. The technological learning literature stresses the need to communicate tacit knowledge in order for effective learning to occur. Many aspects of satellite design are not well codified, but require engineering judgment. This is important during early steps in the satellite design process. Here the team considers high level architectures for the mission and uses heuristics to choose among the options. Throughout the design process, engineers for satellite subsystems need to make judgements based on experience about how much they should optimize their individual system relative to constraints such as time, money and risk. Project managers and system engineers need to choose how and when to introduce new technology into satellite projects. In all of these areas, tacit knowledge, built up over years of experience, can help a satellite engineer make a sound decision. Such knowledge is not easily communicated to someone who is training in satellite engineering. Such knowledge, in fact, may take years to develop. Consequently, leadership in developing countries must take into account the realities of tacit knowledge.

VI. SUMMARY AND FUTURE WORK

This paper has pursued two major goals. The first is to provide a background about satellite programs in developing countries. The early sections show that satellites provide key services in developing countries, especially in remote sensing, communication and navigation. These services are accessed through a variety of technical models. Most developing countries have only indirect access to the satellite and little control over the services. A growing number of developing countries are pursuing national satellite programs that will allow them to have more control over the satellite services they access. The paper explores potential motivations for developing countries to have national satellite programs. One key point was that highly rational motivations – such as a desire for data with a specific spectral frequency and spatial resolution – may be mixed with more political motivations such as national pride. Historical examples show that developing countries that have already started satellite programs faced three common strategic decisions. The decisions include priorities for the program capabilities and the relationship of the satellite program with domestic and international entities. Examples from eight countries show a diversity of strategies. Most countries, however, used international partnerships as part of their process of technological capability building. Based on this history, this scenario is at the center of this analysis.

The second major goal of the paper is to consider what lessons from the literature on technological learning provide useful guidance for developing countries that execute international collaboration with the goal of capability building. The paper explores the key concepts and frameworks within technological learning. This starts by defining national development as a process of enhancing technological capability. Developing countries are latecomers in the satellite field, so they may move through a reverse technology trajectory – from manufacturing to process innovation to product innovation. Meanwhile, issues such as the level of absorptive capacity of an organization affect their learning, as does the tacit nature of a technology.

The analysis closes by citing three key lessons that can be applied to collaborative satellite projects. There may be other useful applications, however. Future work will continue this analysis. The authors propose to undertake in-depth examination of specific satellite projects undertaken by developing countries. The chosen satellite projects will fit into the model described in Figure 8**.** The goal is to understand the dynamics of these projects and to learn how they relate to literature about technological learning and other relevant areas.

The results of the proposed research will shed light on an important dynamic. International collaboration on space projects is common, but it is often undertaken without a full appreciation for the complexities and challenges that can be involved. When a developing country seeks to build local technological capability via a partnership with a foreign firm or government, they need to recognize the importance of learner initiative and the role of tacit knowledge in impacting their learning opportunities.

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