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Space Technology and Africa's Development: The Strategic Role of Small Satellites

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Introduction[1]

In 2014 the African Union adopted a 10-year Science, Technology and Innovation Strategy for Africa (STISA-2024). The strategy provides a flexible framework for adopting flagship programs that involve a number of countries based on their needs, capabilities and long-term development objectives. Some areas of technological endeavor, however, represent foundations upon which economic activities are constructed. One of those areas is building geospatial data infrastructure. This can be achieved through a variety of data-collecting measures ranging from large satellites to unmanned aerial vehicles.

The opportunity to use remote sensing technology for development has never been greater. There are over 100 remote sensing satellites currently in orbit, with over half designed to gather imagery that could be used for development.[2] The industry is also growing: the OECD estimates that over 250 satellites will be launched during this decade alone, compared to half that amount during the last decade.[3] Recent innovations around satellite technologies have also driven down costs and made it viable for low-income countries to develop cost-effective satellite programs.

This paper examines small satellite programs as windows of opportunity for countries to achieve their development goals. First, it locates the potential socioeconomic benefits of satellites in low-income countries. Next, it explores the recent history of, and lessons learned by, South Africa, Brazil, and South Korea. While tens of other countries have developed satellite programs, these case studies offer insights into how and why countries have created successful programs. Next, this chapter examines the latest technologies and focuses on emerging opportunities for current and future space programs. Lastly, it develops concrete options and a clear strategy for policymakers in emerging markets to consider when designing future programs.

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[1] I am grateful to Charles Warren for his research assistance in the preparation of this paper.
[2] OECD, *The Space Economy at a Glance* (OECD, 2011), 64, http://dx.doi.org/10.1787/9789264111790-en.
[3] Ibid., 65.

1. Small Satellites and Geospatial Data

Space-based remote sensing capability accords a means for countries to address development challenges and provides a powerful catalyst for catch up. Geospatial data refers to this remotely acquired data when it is associated with a particular geographic location. This section will examine small satellite technology and further use the "value of information" concept as a means to understand why geospatial data can improve the prospects for development. The section will also analyze the common developmental issues that geospatial data can effectively address. It concludes with a discussion of the broader social goods gained as result of the process of collecting and analyzing geospatial data: that is, the capability building and learning via technology that are fundamental ways to catch up.

Why Small Satellites?

Traditional satellites are characteristically monolithic platforms designed to be large in size and mass in an effort to address multiple complex tasks in orbit and create economies of scale.[4] Undesirably, this configuration renders such satellites vulnerable to relatively lowered mission reliability and robustness while concomitantly increasing mission complexity, costs, and lead times. To mitigate these drawbacks, the industry began to produce smaller satellites at lower costs by the late 1990s, providing an appealing window of opportunity for new entrants into the market, including developing countries.[5] As outlined in Table 1, small satellites (also referred to as mini-satellites) constitute a group of spacecraft hierarchically ordered with a fueled mass of less than 500kg.

[4] R.S. Jakhu and J.N. Pelton, *Small Satellites and Their Regulation* (New York, NY: Springer, 2014), 1.
[5] Hubert George, "Remote Sensing of Earth Resources: Emerging Opportunities for Developing Countries," *Space Policy* 14 (1998): 31. Danielle Wood and Annalisa Weigel, "Building Technological Capability within Satellite Programs in Developing Countries," *Acta Astronautica* 69, no. 11 (2011): 1113.

Small Satellite Class	Mass Range (Kg)
Femtosatellites	<0.1
Picosatellites	0.1 - 1
Nanosatellites	1 - 10
Microsatellites	10 - 100
Minisatellites	100 - 500

Table 1. Small satellite nomenclature

Whereas traditional satellite programs focus on complex large-scale efforts and risk-averse engineering design teams, small satellites tend to have relatively fewer functionalities yet more innovative designs.[6] One particular area of rapid growth has been in imagery: small satellites, once relegated to university-based teams, have become an economical means for developing countries to collect detailed imagery specifically for development purposes[7]e.g. natural resource management, infrastructure development, food security etc.

Small satellites have traditionally been launched into orbit as space-filler 'hitchhikers' on a launch vehicle dedicated to a specific large satellite(s) or as nonpaying payloads during test launches of launch vehicles still under development. The continuing surge in the utility of small satellites, however, has led to a rise in the development of launch vehicles aimed at small satellites. Examples in the US include LauncherOne by Virgin Galactic,[8] Pegasus by Orbital ATK Inc.,[9] and Golauncher family of launch systems by Generation Orbit Launch Services,[10] among others.

The emanating propitious trends in small satellite cost, innovations, and applications have rendered the implementation of space technology for national development an attainable venture for many African nations. Historically, such projects were widely assumed to be capital-intensive and wasteful, especially for less-developed countries. On the contrary, assimilating space technology has the potential to accelerate the attainment of national development goals and further indicates a visionary and technology-savvy society.

[6] Danielle Wood, *Building Technological Capability within Satellite Programs in Developing Countries*, Dissertation (Cambridge, MA: Massachusetts Institute of Technology, 2012), 20.
[7] Jakhu and Pelton, *Small Satellites and Their Regulation*.
[8] Virgin Galactic, *LauncherOne Service Guide Version 0.2*, (Virgin Galactic, LLC, March 2016), 2.
[9] Orbital ATK, *Pegasus User Guide. Release 8.0*, (Orbital ATK, Inc, October 2015), 1.
[10] Generation Orbit Launch Services, Inc, *GoLauncher Family of Launch Systems*, accessed July 18, 2016, http://generationorbit.com/gofuture/

Small Satellites versus Emerging Flying Technologies

The foremost emerging technologies that challenge space technology are Aerial Unmanned Systems (UAS) commonly referred to as drones and High-Altitude Platforms (HAPs). UAS constitute rotary and fixed-wing unmanned airplanes. HAPs are fully or partially autonomous airplanes or airships (manned or unmanned) designed to operate at a typical altitude of 17 to 22 km.[11] This altitude is preferred because it is above the jet stream and characterized with a layer of relatively mild wind and turbulence across most regions.

The impact of emerging competing flying technologies on small satellites will be commensurate with the impact on space technology as a whole. Due to the unique nature of space technology, small satellites are unlikely to be singled out and influenced in isolation by these emerging technologies. This is because small satellites are simply a scaled-down version of the exacting space technology. Consequently, small satellites are matchless in addressing applications that lend themselves to the three main advantages of space technology:

i. Ability to simultaneously and instantly observe, measure, and monitor multiple phenomena across large expanses on earth. Examples of such phenomena include earth's atmosphere, landmass, and water bodies.
ii. Capability to operate independent of the remoteness of a location on earth and of any incapacitating natural disasters.
iii. Exclusive capability to execute a required application—for example the Global Navigational Satellite System (GNSS). Implementing such a system terrestrially by using emerging flying technologies comparable in technical success and universal acceptance is a daunting, near-impossible task.

As long as the intended application is suited to any of the above stated conditions, then small satellites will always have an edge over any emerging flying technology. However, this does not imply that small satellites are completely immune to the threat offered by competing

[11] T.C. Tozer and D. Grace, "High-altitude platforms for wireless communications," *Electronics & Communication Engineering Journal* 13, no.3 (2001): 127-37.

technologies. Applications that require quick mobilization and deployment, on-demand flexibility, fleeting or specific narrow application, and lower cost are best suited for emerging flying technologies and not small satellites. Such applications are relevant for surveillance, disaster monitoring, security, and defense.

Emerging flying technologies will largely form synergies with small satellites to address the varying needs of African countries. Any perceived competition between the two may be misleading because emerging flying technologies will primarily serve to highlight and dislodge satellites from those applications for which the latter is less suited. Satellites will similarly draw attention to those applications that are unsuited for emerging flying technologies. Rather than choose one or the other, African countries should implement both vital technologies in a manner that supplements each other.

The Value of Geospatial Data for Development

Because launching satellites or simply buying remote sensing data can be costly, it is most useful to examine the process in terms of the value of the resulting information.[12] Macauley defines the "value of information" model as the different outcomes obtained using satellite imagery compared to not using it.[13] In other words, the increased level of information from launching a satellite will not necessarily be valuable in any direct sense; instead, by comparing outcomes with and without the information, the actual value for development purposes can be ascertained.[14]

Consequently, a prerequisite framework and mechanism that clearly link the development issue in question with the intended geospatial resource is essential prior to acquiring small satellite technology. Otherwise, African countries immensely risk rendering the costly acquired geospatial data 'valueless' owing to acute underutilization or complete neglect.

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[12] George, "Remote Sensing of Earth Resources: Emerging Opportunities for Developing Countries," 28.

[13] Molly K. Macauley, "The Value of Information: Measuring the Contribution of Space-Derived Earth Science Data to Resource Management," *Space Policy* 22, no. 4 (2006): 281.

[14] Ibid.; NASA, *Measuring Socioeconomic Impacts of Earth Observations: A Primer* (Applied Sciences Program in the Earth Science Division, n.d.), 12, www.nasa.gov/sites/default/.../SocioeconomicImpactsPrimer.pdf.

For instance, evidence suggests that geospatial data can meaningfully impact public health.[15] To illustrate, using multiple methodologies, NASA researchers found that geospatial data from the Malaria Early Warning System (MEWS) translated to approximately 500,000 fewer new malaria cases across 28 countries.[16]

Despite the recent advances in small satellite design for gathering geospatial data, it could be more cost-effective for developing countries to purchase geospatial data rather than collect their own. To be sure, developing countries have two sources of off-the-shelf data: international partners and the private sector.[17] For instance, the International Charter: Space and Major Disasters allows countries to acquire data during times of emergency.[18] Partnerships, however, have proven costly and ineffective insofar as they cannot provide the right data in the right timeframe for many countries.[19] For example, data from the U.S. government's LANDSAT program and the joint Brazilian-Chinese project CBERS became publicly available in 2007 and 2008, respectively.[20] This was 35 years after the LANDSAT program inauguration and 9 years after CBERS's inauguration.

Although private companies also provide a means to access data, the data are likely to be costly—i.e., the higher the resolution, the higher the cost.[21] While some countries may be able to meet their needs through purchasing geospatial data, others will want to strive for a broader goal—e.g., launching small satellites to collect and then analyze data domestically. Although the latter approach is more resource-intensive, it possesses added benefits. It bestows control and ownership of collected data; nurtures a domestic space technology capability; contributes to the national innovation sphere; and has the potential to generate revenue from sale of data, among other benefits.

[15] NASA, *Measuring Socioeconomic Impacts of Earth Observations: A Primer*, 27–31.
[16] Ibid.
[17] Wood, *Building Technological Capability within Satellite Programs in Developing Countries*, 47.
[18] Wood and Weigel, "Building Technological Capability within Satellite Programs in Developing Countries," 1113.
[19] Wood, *Building Technological Capability within Satellite Programs in Developing Countries*, 47. Wood and Weigel, "Building Technological Capability within Satellite Programs in Developing Countries," 1113.
[20] Adigun Ade Abiodun, "We Must Harness Space for Sustainable Development," *Space Policy* 29, no. 1 (2013): 8.
[21] Wood, *Building Technological Capability within Satellite Programs in Developing Countries*, 47.w

Despite the value of information gathered from geospatial data, challenges remain among many African countries. First, a lack of local policymaking infrastructure and human capital may impede any tangible results. In that sense, MEWS's success must be viewed in context: the program enlists multiple countries and donor agencies in the effort. Next, human capital constraints pose problems to interpreting data, regardless of whether it was purchased externally or produced by a domestic satellite.[22] Moreover, for the data to be actionable, it needs to be paired with other development indicators using GIS data that may not even exist.[23] Fourth, data analysts need to provide geospatial information at the correct time/place and with a high enough degree of generalizability for policymakers to use.[24] The value of the information is also predicated upon the quality of the bureaucracies that may use the data for secondary purposes.[25] Lastly, policy interventions that respond to the new information—valuable though it may be—can entail high costs.[26]

Despite the challenges to using geospatial information, it shows great promise in improving resource assessment and management, public health, early-warning systems, disaster management, and agribusiness decisionmaking. In terms of the environment and sustainability, geospatial data allows countries to monitor pollution, weather, and crop yields.[27] Freshwater and marine applications, including fishery management, are also common.[28] The public health benefits of valuable geospatial information are many, particularly in modeling and understanding disease vectors and the interaction between the landscape and communicable diseases.[29] Early warning systems for various disease and famines have been developed in coordination between national and multilateral agencies as well as universities.[30] Natural disasters, then, provide a means for remote sensing as a tool to mitigate the effects of the disaster after it occurs. Since

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[22] Committee on the Geographic Foundation for Agenda 21, Committee on Geography, Mapping Science Committee, National Research Council, *Down to Earth: Geographical Information for Sustainable Development in Africa* (Washington, DC: The National Academies Press, 2002), 14, http://www.nap.edu/catalog/10455.html.
[23] Ibid.
[24] George, "Remote Sensing of Earth Resources: Emerging Opportunities for Developing Countries," 29.
[25] Macauley, "The Value of Information: Measuring the Contribution of Space-Derived Earth Science Data to Resource Management," 279.
[26] Ibid., 281.
[27] Wood and Weigel, "Building Technological Capability within Satellite Programs in Developing Countries," 1111.
[28] Abiodun, "We Must Harness Space for Sustainable Development," 6.
[29] Ibid., 7.
[30] Abiodun 2013: 7; NASA, *Measuring Socioeconomic Impacts of Earth Observations: A Primer*, 27–30.

developing countries are especially prone to disasters, new data sources can allow them to respond more effectively during times of crisis, such as typhoons, severe weather, and flooding.[31]

In regard to agribusiness decision-making, small satellites may be beneficial if a sufficiently wide search swath (resolution) and high revisit time (cycles per day) are generated by a system of small satellites. High resolution and high revisit time are measures of merit for effective and efficient satellite usage in agricultural applications. A system of small satellites must be able to observe and measure soil moisture and provide useful data on crop growth and development. Satellite sensor resolution is primarily influenced by instrument aperture (real and or synthetic) and sensor frequency operating band. To drive and maintain small satellite operations, available power is a key commodity.

Commercially available small satellite systems capable of providing 30–50 km resolution and 1–2 visits per day do not exist. However, research and development of miniaturized RF remote sensing instruments, designed to be used on Earth-orbiting small satellite constellations, is quite advanced. This research and development focuses on obtaining RGB imagery through mid-wave infrared sensors that yield day and night imagery.[32] These small satellite constellations are 6U or 12U form-factor. Other research and development includes miniaturization of radio frequency remote sensing instruments based on Monolithic Microwave Integrated Circuit, advanced materials, multi-band dual-polarization feed with an optimized corrugated horn, and micro-machined filters.[33] This effort is designed to reduce cost, complexity, integration facilities, and launch vehicle size.

Small satellite constellations useful in agribusiness applications may be tested and manufactured within 18 months.

[31] Wood and Weigel, "Building Technological Capability within Satellite Programs in Developing Countries," 1111.
[32] Lauren Wye, "SRI CubeSat Imaging Radar for Earth Science," presentation at Earth Science Technology Forum, June 24, 2015, https://esto.nasa.gov/forum/estf2015/presentations/Wye_S6P8_ESTF2015.pdf.
[33] Hannah R. Goldberg, Matthew Beasley, and Chris Voorhees, "Asteroids to Agriculture: Carving a Niche in Earth Observation Using Asteroid Prospecting Instruments on an Earth-Orbiting CubeSat Constellation," presentation at Small Satellite Conference, Technical Session XI: Science/Mission Payloads I, 2016, http://digitalcommons.usu.edu/smallsat/2016/TS11SciPayload1/2/.

In addition to specific policy uses of geospatial data for development, countries pursuing small satellite programs will also develop important capabilities and will gain valuable technological learning for catch up. By designating funding and resources toward a small satellite and data analysis program, a country can transfer skills and knowledge from a foreign partner to build domestic capabilities in the management and dissemination of data.[34] In developing such a program, countries can target the skills and needs in a way that is analogous to the modular nature of the satellites, launching and analyzing data on a particular topic.

2. Past Experiences: Lessons Learned

Case studies provide important insights into the process of building satellite programs for development purposes. While numerous countries have experimented with these programs, the different experiences of Brazil, South Africa, and South Korea in particular elucidate the challenges and opportunities of creating satellite programs for development.

Brazil: The Research and Partnership Model

Brazil's satellite program dates back to 1961, when President Jânio Quadros formed the Organization Group of the National Space Activities Commission.[35] While the early program emphasized rocketry, toward the end of the 1960s the core components of Brazil's satellite program emerged: a meteorology program, a graduate school dedicated to space science, and early work related to remote sensing.[36] INPE was founded in 1971, and it has operated under Brazil's Ministry of Science and Technology since 1985. The program emphasized research: analyzing weather patterns and preparing a new generation of researchers who could not only understand remote sensing data but leverage it for broader goals. Because Brazil covers a vast terrain with many resources, remote sensing at INPE allowed the country to better understand its

[34] Ibid., 1118.
[35] Antonio Fernando Bertachini de Almeida Prado, "A Short History of the Academic Activities at the Brazillian National Institute for Space Research," *Journal of Aerospace Technological Management, Sao Jose Dos Campos* 3, no. 1 (April 2011): 5.
[36] Ibid.

resources and mitigate risks that threatened them (e.g., unsustainable logging).[37] For instance, satellites have been able to detect deforestation in the Amazon and help researchers to better understand the threats posed by climate change.[38] INPE has also been able to develop coursework and master's programs to train researchers.

Just as Brazil emphasized developing local research capabilities related to space research, it also sought a long-term partner to develop its technological platform: China. The China Brazil Earth Resources Satellite (CBERS) program began in July 1988 following an agreement between INPE and the Chinese Academy of Space Technology.[39] The initial $300 million investment was meant to pair Brazil's research capabilities with China's technological skills (and capital) in order to launch two remote sending satellites, CBERS-1 and CBERS-2.[40] The first satellite entered orbit in 1999 and the second in 2003.[41] Each carried advanced imaging sensors, cameras, and scanners.[42] Brazil subsequently developed a domestic launch facility in Alcântara, proving that it could increase its domestic capabilities beyond research.[43] At least one of the goals of the program was to mirror the success of the Brazilian airplane manufacturer Embraer.[44]

Recent troubles, however, have cast a shadow over Brazil's catch up in the satellite sector. An explosion at the Alcântara facility in 2003 killed more than twenty people and destroyed the surrounding buildings.[45] More recently in 2013, Brazil launched CBERS-3 to replace the now decommissioned CBERS-2. The $127 million project, however, failed to reach orbit. The recent

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[37] Ibid.
[38] Johanna Mendelson Forman et al., *Toward the Heavens: Latin America's Emerging Space Programs* (Washington, DC: Center for Strategic and International Studies, August 2009), 11. T.A. Stone and P. Lefebvre, "Using Multi-Temporal Satellite Data to Evaluate Selective Logging in Para, Brazil," *International Journal of Remote Sensing* 19, no. 13 (1998): 2525.
[39] INPE, "CBERS - China-Brazil Earth Resources Satellite," 2011, 6, http://www.cbers.inpe.br/ingles/satellites/aplications.php.
[40] "CBERS - China-Brazil Earth Resources Satellite," accessed June 4, 2014, http://www.cbers.inpe.br/ingles/satellites/history.php.
[41] Forman et al., *Toward the Heavens: Latin America's Emerging Space Programs*, 9.
[42] K Bensebaa, G.J.F. Banon, and L.M.G. Fonseca, "Spatial Resolution Estimation of CBERS-1 and CBERS-2 CCD Cameras," *International Journal of Remote Sensing* 33, no. 2 (2012): 604.
[43] Forman et al., *Toward the Heavens: Latin America's Emerging Space Programs*, 9.
[44] "China-Brazil Satellite Launch Fails, Likely Fell Back to Earth," *Reuters*, December 10, 2013, http://www.reuters.com/assets/print?aid=USBRE9B90XK20131210.
[45] Committee on the Geographic Foundation for Agenda 21, Committee on Geography, Mapping Science Committee, National Research Council, *Down to Earth: Geographical Information for Sustainable Development in Africa*, 3.

impediments to Brazil's satellite program demonstrate that partnership models can yield important technology transfers and develop capabilities, but success in space is never guaranteed.

South Africa: Start, Stop, Start (Small) Again

South Africa has one of the oldest space programs in Africa and serves as a symbol of the birth—and rebirth—of satellite programs on the continent. As early as 1958, the South African government arranged a partnership with NASA to track satellites.[46] The Astronomical Society of Southern Africa, an amateur group, also helped track satellites for Project Moonwatch, a NASA program that ran from the late 1950s to the mid-1960s.[47] The focus of the Apartheid government, however, was heavily oriented toward rocketry, spy satellites, and regional as well as domestic defense concerns.[48]

South Africa did begin to create domestic satellite capabilities for non-military use. Greensat, a dual-use satellite, emphasized the positive externalities of space research, including making "vehicle tracking and regional planning" possible.[49] The strong South African university system provided a backdrop for much of the civilian and commercial research related to space and satellites in particular. Writes Chris Alden, "[T]he University of Stellenbosch became the nerve centre for the space programme, having at its disposal the intellectual and financial resources of the South African state."[50] Before the end of Apartheid, South Africa boasted "up to 1500 personnel from 70 different public and private companies [who] were working on projects either on site or scattered around the country."[51] With the end of Apartheid, the Greensat program was disbanded in 1994.

While the cancellation of South Africa's space program during the transition period could have been the end of the country's satellite capabilities, academic research institutions and eventually public leadership led to both the revival of the program and an emphasis on small satellites in

[46] Chris Alden, "South Africa's Space Program: Past and Present," *Strategic Review for Southern Africa* 29, no. 1 (2007): 39.
[47] Keith Gottschalk, "South Africa's Space Programme - Past, Present, Future," *Astropolitics* 8, no. 1 (2010): 2.
[48] Alden, "South Africa's Space Program: Past and Present," 41.
[49] Ibid.
[50] Ibid.
[51] Ibid., 42.

particular. The University of Stellenbosch began developing the low-earth orbit satellites in the late 1990s—the first to do so on the continent.[52] The results were tangible, as South Africa gained new technical skills and built much-needed human capital. Sunsat-1, a microsatellite, was launched successfully in February 1999. A second satellite, Sumbandila, entered space in 2009. Perhaps more importantly, both satellite projects provided hands-on experience for South Africa's next generation of engineers. The former project helped to train 100 engineers between 1992 and 2001.[53] The latter project involved over 30 master's students and at least two PhD students.[54] It also involved the launch of CUBE-SAT1, a project affiliated with the Cape Peninsula University of Technology in Cape Town.[55]

The African National Congress (ANC) also played an active role in setting space policy even before it came to power. For instance, the ANC had a technology policy in place before Mandela became president and created the Department of Science and Technology in 1994.[56] In 2009, then president Kgalema Motlanthe signed into law the National Space Policy Act that created the South African National Space Agency (SANSA) designed to "foster research in space science, advance scientific engineering through human capital, support the creation of an environment conducive to industrial development in space technologies within the framework of national government policy."[57] SANSA already boasts many benefits from remote sensing specifically. South Africa's satellite data can help to respond to natural disaster (e.g., the 2013 floods in South Africa and Mozambique), track space weather, and monitor informal settlement growth across the country.[58] SANSA intends to launch its next microsatellite by 2019, investing over 230 million Rand in the project that builds on lessons learned from South Africa's previous

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52 Gottschalk, "South Africa's Space Programme - Past, Present, Future," 8.
53 Arno Barnard, *Education and Nano-Satellites: A South African Perspective* (Stellenbosch University, n.d.), http://www.nanosat.jp/4th/pdf/Day2_6_PanelDiscussion2_Internationl%20Space%20Education%20using%20Nano-Satellite/2_Mr.ArnoBarnard/Panel2_Mr.Arno_Barnard.pdf.a
54 Ibid.
55 Linda Nordling, "Africa Analysis: Issues Space Policy Must Address," *Sci Dev Net*, January 17, 2014, http://www.scidev.net/sub-saharan-africa/policy/analysis-blog/africa-analysis-issues-space-policy-must-address.html.
56 Gottschalk, "South Africa's Space Programme - Past, Present, Future," 6.
57 Republic of South Africa, *South African National Space Agency Act, 2008*, n.d., 2. South African Space Agency (SANSA), *Annual Report 2012/3* (Pretoria, South Africa: Department of Science and Technology: Republic of South Africa, n.d.).
58 South African Space Agency (SANSA), *Annual Report 2012/3*.

satellites.[59]

South Korea: Latecomer, Quick Learner

South Korea's satellite program reflects a two-pronged strategy that involves accepting foreign technology transfers and at the same time developing domestic capabilities. The country was a relative latecomer to satellite programs: it was not until 1989 that the Ministry of Science and Technology created the Korea Aerospace Research Institute (KARI).[60] The program has developed rapidly ever since. KARI boasts almost a thousand employees and a budget close to half a billion dollars.[61] South Korea has four satellites in orbit and plans to launch an addition four before 2018.[62]

Importantly, South Korea approached remote sensing development from the perspective of learning and catch up. For instance, its three KITSAT satellites, launched between 1992 and 1999, promoted domestic capability building through acquiring technology and then creating local parts over time:

	KITSAT-1	**KITSAT-2**	**KITSAT-3**
Launch Date	1992	1993	1999
Mass	50 kg	50 kg	110 kg
Lifetime	5 years	5 years	3 years
Partner	University of Surrey, UK	SaTREC	SaTREC
Goal	Learning	Use Korean parts	First earth observation satellite
Lee et al, "Korea's First Satellite"[63]			

Table 2. South Korea's KITSAT satellites.

[59] Keith Campbell, "Space Agency Developing New Satellite As It Seeks to Stimulate the Sector," *Engineering News*, June 14, 2013, http://www.engineeringnews.co.za/print-version/space-agency-developing-new-satellite-as-it-seeks-to-stimulate-the-sector-2013-06-14.
[60] Chin Young Hwang, "Space Activities in Korea—History, Current Programs and Future Plans," *Space Policy* 22 (2006): 195.
[61] Ibid.
[62] Committee on Earth Observation Satellites (CEOS), *The CEOS Database 2014*, 2014, http://database.eohandbook.com/.
[63] Jun Ho Lee et al., *Korea's First Satellite for Satellite Laser Ranging* (SaTREC Satellite Technology Research Center, 2005), cddis.gsfc.nasa.gov/lw14/docs/presnts/ops3_jlp.pdf.

In addition to building upon previous models, South Korea also leveraged its university system. Following the success of KITSAT, South Korea focused on capability building to foster the growth of small satellite programs domestically, particularly through local universities.[64] The Satellite Technology Research Center (SaTReC), created in 1989, developed not only the KITSAT program but also a separate program designed specifically for learning: the Science and Technology Satellite (STSAT) series.[65] For instance, the STSAT3 satellite, launched in 2013 by SaTREC, contains remote sensing capabilities and was designed and built domestically.[66]

While South Korea has made a concerted effort to develop a system of learning, it has also reached other milestones in its domestic satellite and remote sensing programs. First, the government has been successful in commercializing the data: in 2008, the government sold $22 million worth of remote sensing data to different clients.[67] Next, SaTReC has also produced its first spin off company: SaTReC-I.[68] The firm helped Malaysia launch its first small satellite for remote sensing in 2005. Third, South Korea has made the transition from acquiring satellite technologies to being able to launch them domestically. In 2013, South Korea successfully launched its STSAT-2C.[69]

3. Policy Options and Implications

From 2000 to 2009, fifteen countries created new space programs.[70] The increasing popularity of and advances in small satellite technology does not mean, however, that policy has a diminished role. Instead, it is imperative that countries seeking to develop small satellite programs for development purposes craft the right policies. To that end, there is no one-size-fits-all approach

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64 Jun Ho Lee, Kyung In Kang, and Jong Ho Park, "A Very Compact Imaging Spectrometer for the Micro-Satellite STSAT3," *International Journal of Remote Sensing* 32, no. 14 (2011): 3935.
65 Hwang, "Space Activities in Korea—History, Current Programs and Future Plans," 195.
66 Jun Ho Lee et al., "Optomechanical Design of a Compact Imaging Spectrometer for a Microsatellite STSAT3," *Journal of the Optical Society of Korea* 12, no. 2 (June 2009): 196.
67 Won-hwa Park, "Recent Developments in South Korea," *Space Policy* 26 (2010): 118.
68 Hwang, "Space Activities in Korea—History, Current Programs and Future Plans," 195.
69 Miriam Kramer, "South Korea Launches Rocket in 1st Space Success," accessed June 5, 2014, http://www.space.com/19553-south-korea-launches-naro-rocket-satellite.html.
70 Giorgio Petroni et al., "Strategies and Determinants for Successful Space Technology Transfer," *Space Policy* 29 (2013): 252.

but rather a range of options for policymakers to pursue. Selecting the correct domestic development priorities is an essential first step to designing an effective small satellite program.[71] The major policy options include pursuing individual or joint programs, determining when and how to create new government agencies, financing the projects, and deciding between trade-offs at the program level.

Individual or Joint Programs

Because space technology can be seamlessly applied across national borders, policymakers have a choice to spearhead small satellite programs as individual nations or as joint ventures with other nation(s). The external collaborative outlook can target bilateral engagements with another nation or a multinational agency; or, be multilateral in nature encompassing several countries and/or multinational agencies. Examples of such agencies include the European Space Agency and the International Telecommunications Union. The African Union and regional economic blocks such as the East African Community, Southern African Development Community, and Economic Community of West African States are most likely to be the collective vehicles of multilateral small satellite implementation.

Although an individual country's effort to acquire and utilize small satellite technology may be relatively less prone to implementation delays and project protracting bureaucracy, this option is vulnerable to constricted funding. This is because of the plethora of deserving needs competing for a piece of the inadequate national budget. Shared campaigns on the other hand may be better funded due to multiple contributors and enjoy a wider talent pool, but they are susceptible to competing national interests, misaligned priorities, and redundant bureaucracy. Consequently, it is sensible for policymakers to pursue joint programs with partners that have identifiable common needs and are at a comparable stage of addressing them using small satellite technology. Otherwise, a solely domestic-led small satellite program is likely to be the prudent option.

Government Agencies

[71] Charles Warren, Interview with Danielle Wood, telephone, January 24, 2014.

Any successful small satellite program will require the combination of political will, high-level government leadership, and specific policies designed to meet the country's needs. First and foremost, political will and government leadership at the highest levels are essential to a successful project. Unlike other forms of infrastructure for development (e.g., roads, bridges, and electricity projects), small satellite programs can take even longer to develop and will not produce immediate benefits to citizens. In developing countries, the potential for political uproar and popular dismay with the satellite program are nontrivial concerns. Strong leadership over the program, however, can obviate these problems: if the small satellite becomes a source of national pride, then policymakers can placate some of the concerns about opportunity costs of the project and avoid the program becoming politicized.[72] Also, if policymakers can make the case that the small satellite program will address natural disasters, then public buy-in will be more likely.[73] In essence, the direct link between space technology and the issue it seeks to address should be explicit and easily understandable by the public.

In addition to high-level leadership, policymakers may need to create new government agencies to build an effective small satellite program. A basic three-level structure can serve as a starting point for any new program. First, the government should select a commission of notable academics and policymakers to create a high-level strategy for the country's small satellite program.[74] The commission would be responsible for assessing the current level of knowledge within the country and the diaspora, creating a feasible strategy for the program, selecting the correct technology platforms to meet the country's needs, and envisioning the scope of personnel development required. Next, it must create a new government agency wholly dedicated to space that can oversee the technical aspects of the program.[75] This body will be well positioned to coordinate other sub-agencies, including a body dedicated specifically to remote sensing.

Without an agency that can interpret the data from a small satellite program, the infrastructure project will not add value to the country's development agenda nor meet its targets. While all

[72] Ibid.
[73] Ibid.
[74] Peter M.B. Waswa and Calestous Juma, "Establishing a Space Sector for Sustainable Development in Kenya," *International Journal of Technology and Globalization* 6, no. 1/2 (2012): 165.
[75] Ibid.

countries will require agencies and programs tailored to their specific needs, this three-tiered structure will provide a template for developing the necessary bureaucratic infrastructure to accompany the new technologies.

Financing

Depending on the scope of the program, a small satellite project could cost between tens and hundreds of millions of dollars.[76] The first obvious source of financing is from bilateral and multilateral development organizations. The drawbacks, however, are well known: donor funding does not build local capabilities in remote sensing, because most of the projects are often short term. This is not to say that development agencies cannot play a role at the margins; only that creating a national small satellite program must be funded by the host government. The second source is the private sector. Buying imagery and then technology directly from private companies will allow countries to gather information for development purposes faster and more efficiently at the outset. The drawbacks of relying entirely on the private sector, however, are two-fold. First, while the satellite data already exist, purchasing them on a one-off basis can prove extremely expensive over the long term.[77] Second, creating a small satellite program entails a high degree of risk, and the private sector may not be ready to invest in such a program at scale.

Because donors and the private sector should not be relied upon solely to finance small satellites, governments should finance the projects as a new form of public good. That is, not unlike a road, the satellite program should benefit all citizens in the country.[78] Funding for the program can thus be drawn from various relevant government agencies, including existing budgets for development, agriculture, and science and technology. The space commission can design a strategy for encouraging company spin-offs in the long term, which will add value to the domestic economy over time. Also, assuming a successful launch of the program, the marginal cost of additional imagery will be comparably low. As a result, the government's space

[76] Warren, Interview with Danielle Wood.
[77] U.M. Leloglu and E. Kocaoglan, "Establishing Space Industry in Developing Countries: Opportunities and Difficulties," *Advances in Space Research* 42 (2008): 1882.
[78] Warren, Interview with Danielle Wood.

commission could develop a means to sell the data regionally or internationally to generate revenue. If this business model is not feasible, the government can also quantify the number of lives saved and/or the aggregate savings due to the new information.[79]

Program Trade Offs

Regardless of the country, small satellite programs will face two important tradeoffs. First, policymakers will have to decide whether they plan to design a domestic launch program or rely upon another country to launch the technology into space. Although the latter option is cheaper than the former, it also means that the country's launch timeline will be tied to that of other countries.[80] Meanwhile, planning on a domestic launch will require high levels of domestic expertise and capital investments over long time scales in order to send a satellite into space.

Second, policymakers will have to determine the scope of their intended project: do they want to use the satellite for learning, or to produce the highest quality data? The training versus performance trade-off is not immutable: over time, a country may be able to produce its own technologies and launching capability for a small satellite. Although the technology for a small satellite is relatively well known and the training straightforward, a learning curve still exists. In the short term, then, the country must weigh its need for training against a more immediate goal of collecting high-resolution data.

Role of Universities and Research Institutes

Satellite programs are inherently knowledge-intensive and can have three important linkages with universities and research institutes. First, much of the knowledge needed to advance such programs is constantly changing and requires regular updating. University-based research activities could play an important role in ensuring that the programs reflect the best available scientific and technical knowledge. Second, the development of satellite programs can also feed back into research and teaching activities at universities.

[79] Ibid.
[80] Danielle Wood, "Proposing a Satellite Mission for Kenya," *Unpublished*, n.d.

For example, the Stellenbosch University Satellite (SUNSAT) program in South Africa was specifically designed to enrich teaching at the university. The focus was not just on teaching but also on preparing students to function in practical settings such as industry. The program became an important venue for training students on the job and imbuing in them the discipline needed for executing engineering projects.

Conclusion: The Wider Systems of Innovation

It is common for many emerging technologies to be defined as part of existing sectors. This is usually done to accommodate the needs of existing institutional arrangements. Although this approach may help to reduce bureaucratic tensions between different arms of government, it often undermines the ability of countries to harness the system-wide benefits of emerging technologies. The emergence of small satellites underscores the importance of placing the technology in the context of wider systems of innovation that go beyond national boundaries. This is an area of innovation governance that could benefit from stronger engagement of African regional economic communities and other transnational technology arrangements. Even more important is the need to adopt approaches that are informed by the benefits of open global innovation systems in a sustainable manner.

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