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Historical Reflections & an Economic Approach to LEOs as Infrastructure

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Introduction

This paper explains the context of the satellite industry from three related but distinct standpoints. These are presented in part 1, which is divided into sections addressing economics, then history and then business practices. Following that we will consider the relationship between digital infrastructure generally and satellite internet specifically. We start by addressing the basic economic question: who pays whom for what and under which circumstances? In a normal capitalist marketplace, the relationships among buyers and sellers, the state and public beneficiaries are all relatively clear. For digital infrastructures it is not very clear but for satellites it is even less clear for reasons that we will see.

The current convoluted set of relationships can best be understood from an historical perspective and so in the second part we will turn to the legacy we inherit and consider what the assumptions, expectations and behaviours of people, starting in around 1957–1958 with the International Geophysical Year, laid out the precedents that have become our legacy.[2]

In the third part we turn to the businesses themselves and their predecessors in government programmes that experimented with alternative business models. These conflicting revenue generating models offer us a baseline from which to

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2 F.L. Korsmo, The genesis of the International Geophysical Year, *Physics Today*, 2007, 60(7), pp. 38–43. Available at: https://pubs.aip.org/physicstoday/article/60/7/38/686853/The-Genesis-of-the-International-Geophysical-Year (accessed: 20/12/2024).

compare variations in practice. We will see how satellites fit into the bigger picture of data infrastructure and how the economics of infrastructure allows us to discern specific trade-offs.[3]

The problem: *Cui bono* & who bears the cost?

Let's start with that fundamental question that bridges law and economics: *cui bono*? Before we can say anything about what the cost: benefit ratio might be, we need to have some idea of what the value of the network is, who ascribes value to it, and what relationship the value proposition holds to those who finance it. In the early history of infrastructure, systems were mostly private and faced competition, other than roads which have been mostly public for the past few hundred years. During the twentieth century most infrastructure elements became either sanctioned monopolies or public entities, sometimes through state owned enterprises, sometimes as public utilities, sometimes using other governance models. Only towards the late 20th century did liberalisation ideals begin to move more infrastructure towards private, competitive models. A landmark was the US AT&T telecommunications monopoly which was broken into competing elements starting in with an antitrust case filed by the US Justice Department in 1974 and culminating in the breakup of the system in 1984, followed by the privatization of British Telecom in the same year. Large swathes of other telecommunication, energy, water, transportation and other utilities in Britain and elsewhere were liberalized. The World Trade Organization and the European Union accelerated that trend in the early 2000s with the wholesale liberalization of telecommunications networks and services.

With early infrastructures, only small numbers of wealthy people could make use of what was on offer. The change occurred when it became clear to industrialized economies that the spillover effects of good quality, universal access was a major contributor to national economic growth. Infrastructure, in that sense, has been compared with, or even equated to, childhood education and, for the United States after 9-11, with the banking system which, when damaged, was re-labelled as "critical infrastructure" because its tight interconnectedness and massive spillover effects were newly recognized.

While we might wish to address the value question by measuring the benefits to individuals, to capture the logic of an infrastructure that offers cheap access and where extensive or universal service is required, we must consider what the spillover effects might be. This is not an easy measure to come to partly because infrastructure has become a foundation to the majority of

3 C. Giannopapa, A. Staveris-Poykalas, S. Metallinos, Space as an Enabler for Sustainable Digital Transformation: The New Space Race and Benefits for Newcomers, *Acta Astronautica*, 2022, 198, pp. 728–732. Available at: https://ui.adsabs.harvard.edu/abs/2022AcAau.198..728G/abstract (accessed: 20/12/2024).

economic activity, but economists try to measure, for example, how expensive a transport strike (or snow day shutdowns) are, or how much a big electricity outage costs to an economy. The resulting figures are very difficult to interpret and can hardly be directly used to address a question such as: how much would it be worth to re-build a system such as a smart energy grid.[4] Nevertheless, we need some kind of guide to help make decisions about things such as "how much can be spent to upgrade the broadband system", or "what is the cost of delaying the roll-out of 5-G for two years", or "what will the breakeven point be for a particular LEO constellation"?

The answer for LEOs cannot be limited to how many people use the system, or even how high a price the market can bear. The answer will have to come back to the spillover effects and some guess as to what the widespread economic benefits of the system might be over a relatively long period of time. We have an idea of what those spillover effects are, but it is much more difficult to measure them in aggregate, as opposed to recounting anecdotes, or "cases" which describe their effects. We have known since the 1980s that satellite telephony could provide polar explorers, isolated services providers and, of course, the military, with a valuable alternative. In those years the issue was less about the comparative costs of different infrastructures but rather the difference between access and no access, where building broadband (or ISDN) access would cost a few thousand dollars, compared with a few hundred dollars in fees for occasional hookup time.

For any investment the critical determinant of value is the timeframe in which the price can be amortized, the type of pay-off expected, and the date upon which the payoff is required.[5] Flaws in dealing with these simple dimensions of finance is sufficient to explain the failures of every preceding LEO project. For the current ones, the determinants might have more to do with the critical relationships between government engagement and private sector business models, in particular how procurement of services is going to be handled in the medium term, what the value of spin-offs might be for government users (military, surveillance, launch services, etc.), and what rules get applied for things such as taxation, subsidies, and crucially interconnection pricing.

4 We do try to think this through when we are asked whether a union's pay claim is reasonable or when we consider whether it is worth buying a whole lot of expensive snow removing equipment.

5 McKinzie estimated that initial cost for a LEO system is between $5–10 billion, that maintenance would run to $1–2 billion per year and that the components' lifespan is around five years. C. Daehnick et al., *Large LEO satellite constellations: Will it be different this time?*, McKinsey & Company, New York 2020. Available at: https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/large-leo-satellite-constellations-will-it-be-different-this-time (accessed: 20/12/2024).

How did we get here?

To place the current situation in the context of longer trends, let's look back to a perspective from the 1990s. We could go back even further, to the founding of Inmarsat in the mid 1970s, or even earlier to Sputnik, or even the 1920s imagining of satellites in what was largely the realm of science fiction. What characterized the image, the plans, and even the early commercial investments of the 1990s was a gamble on there being a market beyond both military and civil government buyers. There was also the reasonable hope that continued liberalization in countries such as the US and Britain would bring real markets into military services (such as lesser-secure communications and maybe a large part of GPS) and perhaps statutory functions such as property registries or land management for national parks and other government-owned estates.

Governments could certainly become real, lucrative markets, but the big money from the 1990s perspective was going to come from businesses such as mining companies, big agriculture, and transport/logistics (beyond what Inmarsat was doing). One example of this led to a study of the LEO industry in the late 1990s because the UK Civil Aviation Authority and their National Air Traffic Control Service needed to know whether and when LEOs would be reliable as well as financially feasible to integrate into their existing communications systems, or perhaps even supersede the legacy technologies.[6]

There were never a large number of companies involved, but enough to give a sense that most of the major problems were being addressed by firms not directly associated with governments. It was remarkable in retrospect in that there were no gazillionaires pouring their money and egos into the sector and it looked for a good long while that we were not heading towards any sort of monopoly, even if NASA was going to continue playing the anchor role.

Launch technologies were one broad area of exploration with quite successful trials of high-altitude airplane launches, plausible plans and trials of equator-based shipboard launchpads,[7] and a wide range of ideas about cheap designs and rocket fuels. There were investments in what we might call very-low stations, or very high-altitude communication equipment comparable to satellite technologies installed in drones and dirigibles, or even tethered balloons. Later both Google and Facebook, as well as various broadband companies, spent considerable sums on piloting such schemes.[8]

6 J. Liebenau, *The Economics and Business Models of LEOs with Regard to the Provision of Communication Services for Civil Aviation*, unpublished report, UK Civil Aviation Authority, London 1999.

7 Sea Launch, *Wikipedia*. Available at: https://en.wikipedia.org/wiki/Sea_Launch (accessed: 20/12/2024).

8 T. Simonite, Alphabet and Facebook's Stratospheric Internet Plans Get Tangled in High-Altitude Red Tape, *MIT Technology Review*, 26 March 2016. Available at: https://www.technologyreview.

Small, very inexpensive satellites were being built at a commercial spinoff of Surrey University and sold to governmental and private land management, mineral exploration and other such organizations.[9] They had three simple ideas behind their business model: include only minimally necessary technologies, keep the whole package very small, and use as many off-the-shelf components as possible. This third idea was most intriguing because it required advanced engineering applied to product testing so that they could identify, for example, the very highest quality couple of batteries out of a large batch of apparently identical products. Prices were already low by the late 1990s around ten years after the founding of Surrey Satellite Technology Ltd. [SSTL], who knew that together with others developing low-price launch services they were headed to a scalable market. By the early 2000s they had launched and commercialized remote sensing services and the successful Disaster Monitoring Constellation.

Illusions about the company came to an end in 2004 for some when Elon Musk acquired a 10% stake[10] (and was awarded an honorary doctorate from the university) but four years later Airbus Industries, through EADS Astrium, took over. From that time on the SSTL served mainly their customers, including the Galileo system and more recently products such as S-Band Synthetic Aperture Radar to monitor suspicious shipping activity. It also produced an Active Debris Removal technology to de-orbit space stuff.

Surrey Satellite Technology Ltd during its first twenty years is but one example of potential business models for the satellite industry and as they were also leading researchers into constellation engineering, a model of how a relatively integrated LEOs business might have constituted a coherent supply chain as well as competed for private sector and governmental business. It was also apparent what the market niches were likely to be in sectors such as resources exploitation. As for telecommunications services the targets were all marginal: exploration and adventure, emergency services, special redundant lines of communication, and suchlike.

Perceived obstacles

So, what were the perceived obstacles? Three categories will both help explain the problem as of the early 2000s help to frame it for the second quarter of the 21st century. The first of these will always be scientific, not always in the sense

com/2016/03/26/71292/alphabet-and-facebooks-stratospheric-internet-plans-get-tangled-in-high-altitude-red-tape/ (accessed: 20/12/2024); M. Reynolds, Facebook and Google's race to connect the world is heating up, *Wired*, 26 July 2018. Available at: https://www.wired.com/story/google-project-loon-balloon-facebook-aquila-internet-africa/ (accessed: 20/12/2024).

9 Surrey Satellite Technology Ltd. Available at: https://www.sstl.co.uk/ (accessed: 20/12/2024).

10 SpaceNews, SpaceX Takes 10 Percent Stake in Surrey Satellite Technology, SpaceNews 2023. Available at: https://spacenews.com/space-x-takes-10-percent-stake-surrey-satellite-technology/ (accessed: 20/12/2024).

that there are insoluble problems but in the sense that our expectations are always on the rise. A few longstanding, large scale research themes have emerged that are either specific to LEOs, such as the mathematics and physics of constellation structures, or at the intersection of either telecommunications, such as spectrum management, or closely related technologies, such as theories associated with earth sensing problems.

The second area of obstacles is in the technical realm and continues to include now the hundred year old problems of rocket fuel and launching as well as the newer problems of controlling satellites and the perennial effort to extend miniaturisation. Reuse of rockets, from early space shuttle designs to recent reusable launch systems, fall into that category.

It is the third realm, that of policy, that will persist as the most troubling of the clusters of obstacles. Much of this will become a matter of law and public preference after various communities have expressed their opinions, shaped their norms, institutionalized them and moved toward legislation. However, before the bread and butter of satellite law can become routine for concerns such as business affairs, international dispute resolution and regulatory compliance, many problems need to be carefully considered so that jurisdiction can be clarified, social norms articulated and institutions appropriately shaped. Some of these were already on the minds of participants in International Geophysical Year discussions in 1957!

Early stakeholders

Before we turn to the current business models and their economic context, it is important to understand the earlier efforts to commercialize satellites both because there is much to learn from the ways in which choices were made in the period from the 1970s to the 2000s and because many of the practices and institutions of that era have become precedents for current organizations and activities.

I like to think of Inmarsat as a key predecessor in part because it had a recognizable relationship with both governmental and commercial interests and because its various iterations exemplify critical features that have been variously built into subsequent business models. Following the Convention on the International Maritime Satellite Organization (of the International Maritime Organization—IMO) in 1976, INMARSAT immediately launched three (now 15) geostationary satellites and became operational before the end of that decade.[11] What is remarkable is that from the outset its remit spanned governmental, inter-governmental and commercial governance. By the end of the 1990s it was privatized and after a spell on

11 *Convention on the International Maritime Satellite Organization*. Available at: https://www.imo.org/en/About/Conventions/Pages/Convention-on-the-International-Maritime-Satellite-Organization.aspx (accessed: 20/12/2024).

the stock market it was largely acquired by Harbinger Capital and then an investment consortium until more recently (2021) acquired by Viasat.[12]

The subsequent history of satellite companies should not be regarded as a simple linear progression as, in addition to the many dead ends and reverses, the broad foundation to the current set of business models is comprised of companies such as ORBCOMM, founded in the late 1980s, Globalstar in the early 1990s, and Iridium, in the late 1990s. European ventures, such as O3b, and others, such as the UAE Yahsat, were founded in the following decade. This early generation of satellite companies all suffered financial turbulence, going in and out of bankruptcy: ORBCOMM in 2000, Iridium in 2001, Globalstar and Teledesic both in 2002, etc. Clearly there were problems in the business models although the dot.com bust of 1999 and the larger telecoms financial crash of 2001–2004 directly contributed to the crisis of investor confidence.

What were those business and why were they all so flawed? The basic components of the business models were largely common although their structures were distinct as each sought a unique or at least competitive niche. They had in common an idea of strategic planning for digital access although their core customer base varied from governments to rural communities to maritime users to emergency and NGO organizations.

LEO business models

The locus of revenue generation, however differed and the choices made about where premium profits might accrue in relation to where cross subsidies might be used distinguished the companies and shaped their finances and sometimes their technologies. This is evident, for example, in the choices of LEO constellation configuration or indeed whether the satellites might be placed in a medium- or geostationary orbit. It is evident in what connections were made to maritime or aviation interests, civil governmental or military establishments.[13] The technical trade-offs may be somewhat clear, between high versus low latency configurations, between expensive, heavy, powerful payloads versus mini-satellites, between broad global coverage versus orbital geometries that allow services only for densely populated latitudes.

Starlink's initial intention, if Elon Musk's comments on opening in 2015 are to be believed, was that it would provide backhaul traffic and 'about 10% of local business and consumer [internet] traffic',[14] in high-density cities. It was soon estimat-

12 Viasat, *Viasat history*. Available at: https://www.viasat.com/about/who-we-are/viasat-history/ (accessed: 20/12/2024).

13 Bipartisan Policy Centre, *Overview of the Low Earth Orbit Satellite Industry*. Available at: https://bipartisanpolicy.org/leo-satellite-industry/ (accessed: 20/12/2024).

14 O. Cliff, SpaceX Seattle, *YouTube*, 2015. Available at: https://www.youtube.com/watch?v=AHeZHyOnsm4 (accessed: 31/12/2024); *Starlink*, Wikipedia. Available at: https://en.wikipedia.org/wiki/Starlink (accessed: 20/12/2024).

ed to cost around $10 billion[15] and the US Federal Communication Commission offered and later revoked $885.5 million worth of federal subsidies to support rural broadband customers.[16] Nevertheless, revenues seem to have moved from eight years of losses to a small profit currently, based in large part on a little over 4 million subscribers.[17] These subscribers pay for broadband at various levels of service but there is also a business line for the US Space Development Agency for military and dual-use satellites but this may not continue as a major revenue stream given the preference shown for competitors York, Lockheed Martin and Northrop Grumman. Nevertheless, military applications for related businesses, especially Starshield,[18] are likely to continue to be closest to the core of the business model.

OneWeb has a very different business model and one primarily dependent on national satellite organizations, in particular that of the UK government, the regional, formerly intergovernmental organization now liberalized company, Eutelsat, and big investors including Bharti Global (of India) and Japan's SoftBank.[19] It has had satellites in orbit for little over 5 years and currently targets governments (including military users), large corporations and (isolated) communities rather than individual customers, as is core to the Starlink business model.

At the same time that OneWeb began to build its LEO constellation, Amazon established Kuiper in effect to compete more directly with Starlink. It began launching only late in 2023 and offers low-latency broadband connections at prices affordable to many individual consumers.[20]

The long-established SES (formerly Société Européenne des Satellites) is a publicly quoted company largely owned by the government of Luxemburg that is based on a different business model to provide telecommunications network

15 G. Shotwell, SpaceX's Plan to Fly You Across the Globe in 30 Minutes, *YouTube*, 14 May 2018. Available at: https://www.youtube.com/watch?v=Dar8P3r7GYA&t=591s (accessed: 20/12/2024).

16 U.S. House Committee on Oversight and Accountability, *Comer Probes FCC Decision to Revoke Starlink Funds*, 7 October 2024. Available at: https://oversight.house.gov/wp-content/uploads/2024/10/10.7.2024-Letter-to-the-FCC58.pdf; https://oversight.house.gov/release/comer-probes-fcc-decision-to-revoke-starlink-funds/#:~:text="In%202020%2C%20the%20FCC%20awarded,%2C%20video%20calls'%20and%20more (accessed: 20/12/2024).

17 Starlink, *X*, Available at: https://x.com/Starlink/status/1839424733198344617 (accessed: 20/12/2024).

18 Starshield, *SpaceX*. Available at: https://www.spacex.com/starshield/ (accessed: 31/12/2024); M. Sheetz, SpaceX Unveils 'Starshield,' a Military Variation of Starlink Satellites, *CNBC*, 5 December 2022. Available at: https://www.cnbc.com/2022/12/05/spacex-unveils-starshield-a-military-variation-of-starlink-satellites.html (accessed: 31/12/2024).

19 OneWeb, *Our story*. Available at: https://oneweb.net/about-us/our-story (accessed: 31/12/2024).

20 Amazon Staff, Amazon shares an update on Project Kuiper test satellites space launch: October 2023 update, *About Amazon*, 16 October 2023. Available at: https://www.aboutamazon.com/news/innovation-at-amazon/amazon-project-kuiper-test-satellites-space-launch-october-2023-update (accessed: 31/12/2024); T. Kohnstamm, Everything You Need to Know About Project Kuiper, Amazon's Satellite Broadband Network, *About Amazon*, 11 November 2024. Available at: https://www.aboutamazon.com/news/innovation-at-amazon/what-is-amazon-project-kuiper (accessed: 31/12/2024).

backhaul services for both leading economies and emerging economies, services for the hyperscalers [Amazon's] AWS and [Microsoft's] Azure, and a variety of other products such as platforms for digital broadcasting. Its broad customer base and network of medium-orbit as well as geostationary satellites puts it in a different competitive position. Unlike the leading LEO firms, SES grew substantially by acquisition and it backs, for example, O3b, along with Google and investors HSBC and some leading asset management companies.[21]

Data infrastructure and where LEOs fit

With an understanding of the basic economics and associated business models, we can focus on the character of the satellite business from the perspective of data infrastructure. The term and its synonyms such as e-infrastructure, digital infrastructure and information infrastructure has come to mean that underlying set of facilities, utilities and services that constitute the internet, very broadly defined, and the means to access it. We include in this of course the data centres, internet exchanges, hosting services, broadband networks and all the businesses that support or depend on them. Included are the vast network of undersea cables and of course the satellite constellations that provide connectivity.[22]

These are clearly associated with economic activity, but the relationship is not simple. That is because in some places sophisticated data infrastructure is a consequence of prosperity, in some cases it is a prerequisite for economic growth. In many places national economic policies are predicated on the assumption that it needs to be extended through investments; from local businesses, from government, from development agencies such as the World Bank, or from foreign direct investments by multinational companies.

However, just as we have seen the differences among the business models for LEO firms, there are many different ways in which the architecture of data infrastructures shape the markets and in particular determine the source of premium profits. For example, the condition as to whether the telephone/broadband network operator has access to high rents from household customers as opposed to those providing "over the top" services such as Netflix or Amazon Prime. Consider all the different players and their claims to premium profits: in some places

21 *SES Annual Report 2023*, SES Satellite, Luxemburg 2024. Available at: https://www.ses.com/sites/default/files/SES-Annual-Report-2023.pdf (accessed: 31/12/2024). See also: SES (Company), *Wikipedia*. Available at: https://en.wikipedia.org/wiki/SES_(company) (accessed: 31/12/2024) with links to industry reports about numerous acquisitions, documenting its growth strategy.

22 J. Liebenau, P. Karrberg, Modelling the Economic Impact of Cloud for Development: An Analysis of Banking, E-Commerce and Telecoms in Egypt, Indonesia, Kenya, Mexico, and Turkey, *Proceedings of the TPRC2024 – The Research Conference on Communications, Information and Internet Policy*, 2024. Available at: https://ssrn.com/abstract=4910699 (accessed: 31/12/2024).

payment systems are regarded as utility services, in some places they are a profit centre. In some places Google effectively charges local network operators for the opportunity to offer access to GMaps and Gmail to their customers, in other places it is the network operator who charges Google for the service they provide in carrying their internet traffic.

It is for this reason that numerous alternative business models have emerged for the satellite industry and that there are no set conditions for competition as yet. Just as with other aspects of data infrastructure, the key determinants are going to be who the target markets are—governments, corporations, individuals or other bodies—and their scale and willingness to pay. Crucially, it also depends on the patience of investors. This differentiates the deep pockets and long range strategic planning that the American technology giants can apply from smaller competitors who take considerable risks when seeking to finance their activities through debt. It also differentiates them from governments that may or may not be willing to tolerate spending that could take more than a decade to bear fruit.

Trade-offs and choices

At the end we come to the core economic problem which we can frame around the simplest definition of economics: the distribution of scarce resources. Its starting point is the determination of the costs in relation to the benefits of the system. We have seen the basic entry cost is on the order of $10 billion and the most common beneficiaries are either investors who expect to make profits through revenues or through sale of the business (entrepreneurial exit). The other kind of beneficiary would be those who can utilize satellites for a related purpose such as national governments who expect returns through economic growth, or the major commercial users of internet such as Amazon (with Kuiper) who benefit both by the infrastructure components for their AWS business and through extending internet access to more customers for their e-commerce businesses.

Over the past 30 years the cost has come down dramatically, first through the development of small, cheap satellites such as those from Surrey, then through dropping cost to launch and then to simple scale economies associated with significant growth. The targets for revenue have not changed in type very much but they have changed in scale since internet access has dramatically widened and even more significantly traffic has boomed. This has incentivised business models based on individual and small group access, on business and supply chain customers, and on governments.

At this point it is appropriate to remind ourselves that there is a balance that needs to be struck between commercial and national interests. This is both because the national interest will eventually determine the rules of the game but also because governments constitute a critical, and in some cases the dominant, source of revenue for the companies. This is rarely an easy circle to square if for no other reason than that the time frames in which business and policy are made are usually radically different. National policies often prioritize very long term goals and are framed in terms of national growth, security and the preferences either of some authoritarian leadership or some interpretation of the popular will. Security in particular often prevails and a military goal of controlling information (or access to information) is sometimes sought at (almost) any cost.

In a close-to-ideal situation, that is, one with large amounts of available finance, a spread of options and alternative elements of infrastructure would be planned. There would also be judicious choices among short, medium and long-term development projects. We have come to the point that LEOs in particular are able to offer rapid infrastructure installation so long as the huge entry costs are met. This doesn't obviate the need, however, to resolve the conflicting interest and alternative incentives between state and private interests. So, we should return to the questions about who benefits from which elements or functionalities of satellite systems and what the costs are to whom for choices made.

The main determinant of who benefits most and which sacrifices are required at the national level is a function of the extent to which an economy is reliant on data. For this we can use an approximation of data intensity by sector. For example, clearly some sectors are entirely reliant on data and associated services, such as banking and finance, online services and entertainments, e-commerce, etc. Other sectors are reliant to some degree but not to as great an extent, such as education, mainstream retail, export and import reliant businesses, etc. Others are far less dependent on digitalization for their basic functioning, even if digital accounts and communication are commonplace. These include many of the primary sectors such as agriculture, mining and fisheries.[23] So, a country such as Britain which is heavily reliant on banking and finance, has a great deal to gain from advanced, widespread digitalization while a country largely reliant on small-scale farming and oil & gas. For Egypt, a country with a large, occasionally restive population and an authoritarian government, the priorities of the army prevail. So, where there are trade-offs necessary between, say, privacy and surveillance or between unincumbered international data exchange and internal control, the loss of economic advantages that occur from advanced data infrastructure is a small proportion of current GDP. For a country such as Poland, which has done so much to become integrated into the European Union over the past 20 years, lack of access to advanced data infrastructure would be a major disadvantage. That is both because part of its economic transition has been to shift towards more data intensive sectors and because the very mechanisms of EU integration are predicated on uses of data services for trade, administration and citizen engagement. Some countries sacrifice little by prioritizing uneconomic practices, others are effectively

23 F. Calvino et al., A Taxonomy of Digital Intensive Sectors, *OECD Science, Technology and Industry Working Papers*, 2018, 14. Available at: https://www.oecd-ilibrary.org/docserver/f404736a-en.pdf?expires=1732893402&id=id&accname=guest&checksum=6A35209425167ACD-86501006F7FE6514 (accessed: 31/12/2024).

forestalling economic ambitions, while for others it is effectively unthinkable to lose any opportunities afforded by effective data infrastructure components.

This approach allows for a somewhat different way to calculate value and to assess *cui bono*. While it may not provide an overall deadweight cost to maintaining an authoritarian/military state, it can show what the drag is going to be when data infrastructure is not used, in terms of slower growth of e-commerce or lesser engagement in trade or even brain drain that results from lack of access to digital economy jobs. Policy processes that determine these choices differ and are not yet synchronized either internationally or even internally. It is a rare occurrence that domestic industrial policy is well connected with space policy, although the European Space Agency and functions such as GOVSATCOM do make some effort.[24] Such policies notwithstanding, the initial conflict at the core of our analysis of the economics of LEOs as infrastructure lies is the relationship between the public and the private realms.

Conclusions

Satellite law will have to deal with all those familiar categories of rights and responsibilities that any commercial litigation encounters. It will have to devise the means to resolve grievances that arise from damages in space, including space debris and the Kessler syndrome and those that arise from context specific technicalities such as spectrum interference. It will also have to resolve all those ambiguities anticipated in discussions during the International Geophysical Year about jurisdiction, property rights and requirements for international coordination. In addition, there are specific economic features that will lead to disputes about who has access to data infrastructure. Where an undersea cable offers potential connection to a landing site the decision to build an internet exchange and associated data centres might be regarded as a cost-benefit calculation. The initial investment is likely to be a billion dollars or more and that price can be assessed in terms of the overall short- or medium- term trend for a usage area.

The problem looks different for satellite usage. For a constellation owner the entry cost may be an order of magnitude greater than connecting to a cable. However, for a customer the initial cost of interconnection is far smaller. This may mean that people's attitude towards connectivity will be very different and they may turn to the law to press for their perceived rights to connectivity. It may also mean that advocates of specific civic interests such as privacy or empowerment, or of social concerns for environmental protection will turn to the courts to pursue their goals.

That is where the big picture of satellite law and economics will be revealed.

24 *Resolution on the European Space Policy*, European Space Agency (ESA), June 2007. Available at: https://esamultimedia.esa.int/multimedia/publications/BR-269/offline/download.pdf (accessed: 31/12/2024).

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