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Satellite infrastructures, earth-space sustainability, and the Global South

Florian Rabitz *, Inga Popovaitė, Vidas Vilčinskas

Kaunas University of Technology, Lithuania

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ABSTRACT

Satellite infrastructures are indispensable elements of Earth-Space sustainability, including in a North-South context. Using social network analysis, we assess the positionality of the Global South in organizational partnerships in the satellite sector. Using data on satellite launches registered between 1998 and 2023, we find that the Global South, with the notable exception of China, is virtually excluded from satellite manufacturing and exerts only marginal operational control. Current patterns of production and control grant a small number of industrialized countries, plus China, considerable structural power for appropriating satellite-related sustainability benefits and for shaping political outcomes in the issue area. We highlight the need to align satellite infrastructures with Earth-Space sustainability and broader norms of global justice, including by strengthening technology access and transfer, and by improved satellite data-sharing.

1. Introduction

Satellite infrastructures are critical assets in Earth-Space sustainability (Burket et al. 2021). They provide information that is indispensable for the governance of a wide array of activities in outer space and back on Earth. They are key for global navigation, communications, and logistics; allow for environmental monitoring including in contexts such as climate change or natural disaster preparedness; enable the management of increasingly dense space traffic; and deliver capacities for space observation, including for the detection of space-based hazards such as collision risks from asteroids (Koenig and Chyba, 2007; Wulder and Coops, 2014; Borowitz, 2017). Satellite infrastructures hold particular importance for developing countries, where they could in principle offer numerous benefits for disaster preparedness, natural resource management, telecommunications in remote regions, and other issues (Wood and Weigel, 2011: 1111-1113). The extent to which satellite infrastructures allow for the participation of the Global South is thus crucial from a perspective of sustainability and global justice: Satellite infrastructures produce tangible sustainability benefits, and those benefits are distributed unevenly.

Satellite infrastructures are socio-technical systems that blend technology, knowledge, institutions, and other elements (Geels, 2004; Thacker et al., 2019). In addition to satellites themselves, these systems comprise research and development activities, manufacturing capacities, launch sites, but also regulatory instruments such as the 1974 Convention on Registration of Objects Launched into Outer Space, or contemporary initiatives to reduce space debris from defunct satellites and other objects. Within this wider socio-technical system, this paper assesses patterns of production and control. We explore the position of the Global South in the satellite sector against the background of a rapidly developing outer space economy and an intensifying debate on how to ensure fair, equitable, and sustainable space futures (Yap et al., 2023). We use social network analysis for assessing collaboration in the global satellite sector, drawing on public data for recorded satellite launches since the late 1980s. Our collaboration network represents organizations, both public and private, that have jointly constructed, operated or owned satellites, or contracted their construction from each other, between 1988 and 2023. This network consists of 580 organizations from 72 countries connected by 3907 instances of collaboration. Analyzing patterns of North-South and South-South collaboration, we highlight the virtual exclusion of the Global South from satellite construction, as well as its limited ownership and operational control. Weak domestic manufacturing capacities in developing countries contribute to high rates of internationalization, that is, a strong dependence of domestic organizations on partnerships with organizations from abroad. We note that the Chinese satellite industry is the only exception from this overall pattern, yet with Western export controls hampering internationalization of the Chinese space sector (see Zhang and Seely, 2019; Morin and Tepper, 2023: 7-8).

Global patterns of production and control thus grant a small number of countries considerable structural power for shaping outcomes in the global satellite sector, including regarding the distribution of derived

* Corresponding author.
E-mail address: florian.rabitz@ktu.lt (F. Rabitz).

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sustainability benefits (see Strange, 1987; Morin and Tepper, 2023). We conclude that there is a need to align contemporary satellite infrastructures with international sustainability objectives as well as global justice more broadly (McGee and Wenta, 2014; Corsi et al., 2020, 2021; Schneider et al., 2024). Specific angles for reform could include robust new international mechanisms for space technology transfer, or novel arrangements for satellite data-sharing (Borowitz, 2017; Cirac-Claveras, 2019). Doing so could leverage satellite infrastructures for Earth-space sustainability, including through the improvement of relevant governance capacities (Yap and Truffer, 2022; Yap and Kim, 2023).

Section 2 situates our argument within the wider problem field of technological infrastructures and global justice, while also bringing in considerations of structural power. Section 3 discusses the linkages between satellites, the space economy, and Earth-space sustainability. Section 4 presents our data and methods, whereas section 5 contains our empirical analysis. Section 6 concludes.

2. Technological infrastructures, structural power, and global justice

Infrastructures are “complex socio-technical systems” that “consist of accumulations of physical technology that are embedded within human systems and are operated on behalf of society” (Thacker et al., 2019: 324). Whether as factories, highways, airports, submarine cable systems, or hydroelectric dams, infrastructures have broad relevance for socio-economic development as such (Munim and Schramm, 2018). They are at the core of numerous high-priority issues in contemporary global politics, including via direct and indirect impacts on all Sustainable Development Goals and most of their targets (Thacker et al., 2019). Achieving international temperature targets in line with the 2015 Paris Climate Agreement requires the substitution of fossil energy infrastructures with renewable ones over the course of two or three decades (Di Silvestre et al., 2018), as well as comprehensive changes in transportation infrastructure (e.g. Kharlamova et al., 2022). The sustainability of global water resources requires a transition towards integrated “green-gray” infrastructures that blend natural resource systems with engineered approaches (Vörösmarty et al., 2021). Protecting the high seas from pollution requires transformational change in the shipping industry (Wan et al., 2016). These linkages between infrastructure, sustainability, and economic development are increasingly recognized, as scholarship is moving beyond a narrow focus on security, particularly of “critical” infrastructure (Aradau, 2010; see Bueger et al., 2023).

The conventional understanding of global infrastructure is as material substrates of international regimes. Port infrastructure underpins the international trade regime, just as digital infrastructure does for the international financial system or, for that matter, satellites for telecommunications (Cowhey, 1990; Zacher and Sutton, 1996). In this line of thinking, global infrastructure is part of wider patterns of interdependence, which creates demands for collective management to achieve mutually beneficial outcomes between states (Keohane and Nye, 1987). But already in the 1980s, a wider intellectual current emerged from regime theory emphasizing structural power relations in the global political economy that supervene on infrastructures in sectors such as banking and communications (Strange, 1982). Conceptually, this analytical focus on structural power ties into earlier debates in dependency theory on the dominance of a core of technologically advanced nation states over a periphery in the global economy (e.g. Cardoso and Faletto, 2024). In such a reading, global infrastructures reflect persistent and systemic patterns of inequity (see Hills, 1994). These patterns continue to be a matter of critical debate until the present day, even in issue areas that may intuitively appear surprising. Climate modeling, for instance, relies on a technological infrastructure that concentrates in some countries of the Global North, with concomitant effects on the participation of researchers from the Global South in international scientific assessment processes (see Corbera et al., 2016). Over the past two decades, however, critical reflections on global infrastructure have moved beyond a narrow North-South framing towards an increasing focus on South-South collaboration in global infrastructure development. The most pertinent empirical example is China's Belt and Road Initiative, which accounts for a considerable share of contemporary infrastructure development in the Global South (see Huang, 2016). At the same time and echoing earlier concerns about power structures and exploitation in North-South affairs, the new South-South collaboration, particularly in extractive industries, has sometimes drawn strong criticism, up to and including charges of neo-colonialism (e.g. Agbebi and Virtanen, 2017).

We contextualize the problem of technological infrastructures within the broader problem of global justice, which we approach in terms of access to the benefits associated with technological innovation. We follow Papaioannou (2011: 327) in that “claims for just distribution of resources and/or capabilities co-evolve with technical change and innovation”, meaning that the “moral and political struggle for social justice and equality cannot be divorced from innovation and the system of social relations in which innovative activity takes place” (Papaioannou, 2011: 327). Our specific point of reference are the diverse benefits that satellites can provide in the context of Earth-space sustainability. As we elaborate below, our focus is on the production and control of satellite technology. We analyze global patterns of production and control to assess global inequalities in the access to technological benefits. There is an important qualifier to this approach, related to data-sharing arrangements, that we also discuss further below. For the purposes of this section, we simply note that global distributions of technology and technological benefits have important normative implications, including in a North-South context. This is of course not specific to satellites and Earth-space sustainability, but is a defining political issue across many issue areas of global governance, from vaccine manufacturing capacities (Tatar et al., 2021) to digital technologies (Kwet, 2019).

Our approach is structural insofar that we are not assessing global distributions of technological capacities but, as we pointed out, patterns of production and control. To stress this relational element, we specifically refer to technological infrastructures that connect “dispersed nodes of consumption and demand, [as well as] production and supply”, thus shaping “the subsequent social, ecological, and technical interactions of any system” (Gilbert et al.: i). Technological infrastructures thus constitute a major element of structural power (Strange, 1987). The positionality of countries and industries in technological infrastructures shapes the relative benefits that they can derive as well as their interests (Barnett and Duvall, 2005: 53). Organizations can thus leverage their positionality to align outcomes with their respective interests (Winecoff, 2020: 213). Many analyses of structural power accordingly opt for network-analytical approaches, including recent work on the politics of outer space (Morin and Tepper, 2023).

Structural power thus shapes the distribution of benefits and accordingly directly impacts matters of global justice. As noted above, these benefits derive from technological infrastructures but are not identical with them. In the case of satellite infrastructures, benefits exclusively take the form of data. In principle, they can thus be provided as a public good, avoiding distributional conflict on the demand side while facing well-known challenges of undersupply (see Barrett, 2007). The problem of satellite data as a public good is thus fundamentally different from the problem of satellite infrastructures as (asymmetric) global patterns of production and control. The provision of technological benefits as a public good can bypass problems of structural inequality, yet there are important caveats and practical limitations to which we return in the conclusions of this text (see Wulder and Coops, 2014). However, it is important to note that satellite infrastructures are only one part of the larger puzzle, with the question of data (and data governance) constituting a separate issue, and one that is largely beyond the scope of this paper.

As noted, we understand the benefits that derive from technological infrastructures primarily in relation to sustainable development. In this context, it is important to note that infrastructure forms a major part of contemporary conversations on sustainability. Target 9.1 of SDG 9 calls for the development of "quality, reliable, sustainable and resilient infrastructure", whereas target 9.a aims at the facilitation of "sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support". Sustainable development is where infrastructure development connects to the problem of international technology transfer (Corsi et al., 2020). In areas such as climate, energy, health, agriculture, or transportation, technology transfer is crucial for developing infrastructures in the Global South that are aligned with sustainable development (e.g. McGee and Wenta, 2014; Pandey et al., 2022; Corsi et al., 2020, 2021). Ratcheting up North-South and South-South technology transfer is crucial for the implementation of the Sustainable Development Goals and related goals, targets, and objectives (Corsi et al., 2021; Schneider et al., 2024). In diverse international forums, dedicated bodies exist today that address technology transfer in sustainability contexts, from the UN Technology Facilitation Mechanism that supports the implementation of the Sustainable Development Goals, over the Technology Mechanism of the UN Framework Convention on Climate Change, up to the Committee on Capacity-Building an Transfer of Marine Technology under the 2023 agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (Harden-Davies et al., 2024).

The positionality and participation of the Global South in the global satellite infrastructure thus raises numerous theoretical and conceptual issues on power, equity, and sustainability. These issues, in turn, fold into the larger problem of sustainability and resource distribution in outer space futures (Yap et al., 2023).

3. Satellite infrastructures and the space economy

Until roughly the turn of the millennium, outer space had been the exclusive domain of the national and regional space agencies of a select few industrialized countries. Since then, a series of interlocking economic and technological changes have given rise to a complex organizational ecosystem in which diverse public and private institutions collaborate and compete in the provision of a wide range of space-related activities (Mazzucato and Robinson, 2018; Morin and Beaumier, 2024). The space economy is conventionally defined as "the full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilizing space" (OECD, 2022: 28). This includes diverse products and services, at different levels of technological readiness, ranging from space transportation and tourism over satellite telecommunications, global navigation systems, and Earth observation, up to the potential exploitation of space resources, from Rare Earth elements situated in asteroids up to lunar ice deposits that could provide hydrogen fuel for the further exploration of the solar system (see Goswami and Garretson, 2020; Tutton, 2021; Markard et al., 2023). Between 2023 and 2035, the market value of the space economy is projected to increase threefold to approximately 1.8 trillion US$ (WEF, 2024).

Satellites are at the core of this new space economy. Over the past 20 years, their number has increased sevenfold to approximately 7000, with hundreds of new launches taking place every year. One technological driver of this massive increase is miniaturization. Legacy satellites launched in the second part of the 20th century could easily weigh several tons, with concomitant implications for launch costs. Conversely, next-generation mini-, micro-, and nanosatellites respectively weigh several hundred kilograms and less, making them easier to deploy, including through large satellite constellations such as *Starlink* or *OneWeb*. The satellite industry has also greatly benefited from across-the-board reductions in launch costs, which are primarily due to contemporary spacecraft being designed for maximal reusability, and that have greatly facilitated access to outer space during the past two decades.

The increasing centrality of satellite infrastructures for a wide range of economic and social activities makes them crucial for equitable and sustainable socio-economic development, including in the countries of the Global South. Four issue areas stand out. The development of *communications infrastructure* is a major challenge in various developing countries, notably in remote and rural areas. The positive impact of communications infrastructure on economic development is, today, widely understood (David, 2019). Increasing access to the internet and to information and communication technologies more broadly is central to goal 9 of the Sustainable Development Goals, yet access remains insufficient in some parts of the Global South. *Geographic information systems* are critical for addressing sustainability challenges in areas such as urban planning, precision agriculture, early-warning systems for natural disasters, or climate monitoring (Borowitz, 2017). These information systems typically require satellite-based remote sensing. Satellites can also facilitate the *monitoring of policy indicators*. Especially when combined with machine learning techniques for extracting information from imagery, satellite technology can enable the more effective measurement of sustainability policy performance than is possible via other methods, notably conventional household surveys (Burke et al., 2021). Finally, satellites facilitate various types of *scientific research*. This includes research related to sustainability and the Earth system with direct relevance and tangible benefits for developing countries.

Satellite infrastructures are thus indispensable elements of Earth-space sustainability. They are also key for building up relevant governance capacities. From a sustainability and equity perspective, there is thus a compelling rationale for ensuring adequate participation in satellite infrastructures for the countries of the Global South. There is a broad and ongoing debate on technology transfer for satellites and other types of space technology, notably in their linkage to sustainability and the Sustainable Development Goals (Wood et al., 2024). In 2021, the UN General Assembly adopted the Space2030 Agenda which, among other things, calls for all countries to "benefit socioeconomically from space science and technology applications and space-based data, information and products, thereby supporting the achievement of the Sustainable Development Goals" (UNGA, 2021). The 2015 Sendai Framework for Disaster Risk Reduction, recently in partnership with the UN Platform for Space-based Information for Disaster Management and Emergency Response, aims among other things at the international transfer of satellite and related technologies for improving disaster preparation and response in developing countries. At the regional level, in 2018, the UN Economic and Social Commission for Asia and the Pacific adopted an action plan promoting the vision that all member states of the region "can access, use and develop space science, technology and its applications to the fullest extent at the national and regional levels to achieve the goals set out in the 2030 Agenda for Sustainable Development" (ESCAP, 2018: 3). There is thus broad recognition of the crucial role that access to space technology, satellite technology in particular, can play for the politics of global sustainability. However, existing political commitments to that end remain a promise yet unfulfilled.

Technology access and transfer, whether in a North-South or a South-South context, thus presupposes international collaboration between satellite manufacturers, owners, and operators. Industrialized countries with strong manufacturing capacities can directly produce satellites for their own uses. Most developing countries, conversely, are dependent on satellite technology manufactured abroad. Accordingly, as we show further below, their degrees of internationalization (i.e. cross-border organizational collaborations as a share of total organizational collaborations) tend to be considerably higher than is the case for most industrialized countries. This also adds to the political problem of satellite infrastructures: Developing countries tend to have a greater dependence on international collaboration than industrialized countries, which shifts political bargaining power towards the latter (Keohane and Nye, 1987).

4. Data and methods

We construct our dataset based on publicly available information on all satellite launches recorded in 1988-2023 and provided by the US-based Union of Concerned Scientists.[1] Based on this, we generate an edgelist of organizations connected by partnerships. Organizations are either public or private, and range in size from small-scale laboratories and startups to large-scale industrial players and national space agencies. The organizations in our dataset are headquartered in 71 different countries but also include multinational partnerships such as the European Space Agency (ESA) or the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). Organizations can be linked by up to three different types of partnerships: joint contracting (i.e. two organizations jointly constructing a satellite on behalf of a third party), joint ownership or operations (i.e. two organizations sharing ownership or operational control over a given satellite), and the contracting of satellite construction from a specific organization by a prospective operator or owner. In our network, 3907 partnerships connect 580 different organizations.

Our approach requires us to specify the precise geographical origins of the organizations engaged in these types of partnerships. For the most part, we assign organizations to the countries in which they are physically sited. For multinational organizations with dependencies in multiple countries, we use the jurisdiction in which these organizations are legally headquartered as the country of origin. While this allows us a more granular analysis of organizational partnerships across international borders, it can present a slight oversimplification in cases where legal headquarters and organizational activities are split across jurisdictions. Airbus, for instance, is headquartered in the Netherlands yet conducts most of its operational activities in France and elsewhere. Corporate mergers and acquisitions present another challenge. In general, we assume organizational continuity: as our analysis does not disaggregate partnerships by time, the partnerships that are incident to an organization at an earlier point in time remain attached to that organization even if, at a later point, the organization merges with another entity. Notably, there are some instances where this leads to changes in countries of origin. Organizational continuity also applies to changes in organization names.

The primary reason for the importance of organizational countries of origin is that it allows us to trace patterns of international technology transfer both in a North-South and South-South context. These terms, just as related terms like “Global North” and “Global South”, are analytically diffuse. However, we adopt them due to their practical significance as political categories: large parts of international politics, including in the sustainability domain, are structured around somewhat ambiguous notions of “North” and “South” without explicitly defining the precise membership of these categories. Precise empirical operationalizations of “North” and “South” are impossible and different ways of approaching the issue suffer from different conceptual challenges. For pragmatic reasons, we consider the “Global South” as identical with the G77/China. Analogously, we consider non-G77/China members as the “Global North”. This is a pragmatic methodological choice that entails conceptual issues which are beyond the scope of this paper.[2]

Conceptually, our analysis presumes that the structure of inter-organizational partnerships in the satellites sector reflects patterns of power and inequity, as well as the sectoral alignment with global sustainability policy. More specifically, organizational partnerships represent operational control over satellite technology as well as capacities to engage in satellite construction on behalf of third parties. This approach generates a comprehensive global picture of who is capable of using, operating, or constructing satellite technology, in which geographical locations, and in collaboration with which partner organizations.

Methodologically, we apply several network-analytic techniques, notably centrality measures and community detection, to the organizational partnerships in the satellite sector. Network analysis figures prominently in the emerging social scientific literature on outer space (e.g. Morin and Tepper, 2023; Morin and Beaumier, 2024; see also Mazzucato and Robinson, 2018). It is a natural choice for analytical approaches, such as ours, that focus on larger patterns of organizational relationships, rather than intrinsic organizational attributes. In other words, we are less interested in how the industrial capacities of different countries compare to each other, and rather in the global patterns that emerge from intra-industry collaboration.

We remove self-loops that occur for satellites that are produced and owned by the same organization. We similarly remove organizations that do not engage in partnerships with other organizations. This can be the case for corporations with strong in-house capacities such as SpaceX. Excluding SpaceX from our analysis has some important implications to which we return in the conclusions. Our dataset also consists of numerous parallel edges, where the same pairs of organizations are connected by multiple partnerships simultaneously. Some parts of our analysis require merging these parallel edges. Finally, parts of our analysis systematically distinguish between domestic and international partnerships. We determine whether a partnership is domestic or international based on the geographic location of the respective organizations or, in the case of organizations with a multinational scope of activities, based on their legal headquarters. For organizations that are multinational by definition, such as ESA or EUMETSAT, we code *all* partnerships with other organizations as international.

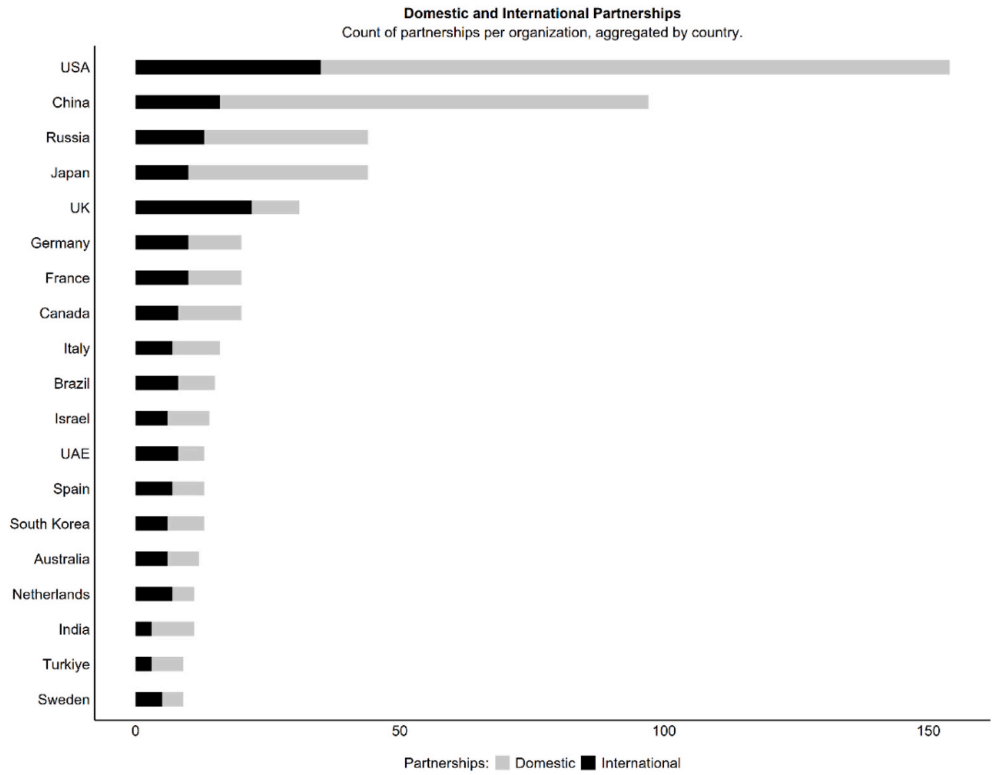
5. Analysis

We first assess the relative importance of both countries and organizations in the collaboration network. The upper half of Fig. 1 shows partnerships by country. The distribution is heavily slanted towards industrialized countries with strong national space programs as well as competitive industrial players from the aerospace and defense sector. Organizations sited or headquartered in the USA jointly account for 158 inter-organizational partnerships. For China, the number is 98. Together, the top-5 countries account for more than half of all partnerships globally. From the outset, this shows the sectoral dominance of a handful of countries of the Global North, with only China being a serious contender from the Global South. The figure also illustrates important differences in domestic versus international partnerships. Countries with strong domestic satellite sectors unsurprisingly tend to have greater shares of domestic partnerships. This is particularly the case for China: Whereas China is ranked number two globally in terms of organizational partnerships, and as the most important player from the Global South, Chinese organizations engage in an extremely limited number of international partnerships. Conversely, countries with limited numbers of partnerships have high internationalization rates and, in many instances, no domestic partnerships at all. This indicates a lack in domestic capacities and thus highlights the critical importance of international technology transfer. We also note that there are 121 *other* countries in the UN system for which our data does not indicate any organizational partnerships in the satellite sector at all. In other words: whereas the distribution of partnerships is already skewed among the 72 countries under consideration here, this skewness further increases once we broaden the focus to all 193 UN system countries.

The bottom panel of Fig. 1 shows the considerable variation between countries in the degree to which their national organizations are internationalized. For approximately half of the countries in the dataset, most

[1] See https://www.ucsusa.org/resources/satellite-database.

[2] Notably, some developing countries, such as Palau, are not members of the G77/China, but should still be considered part of the “Global South”. The identification of the G77/China with the “Global South” and of others with the “Global North” thus does raise complicated conceptual issues. Practically, however, our dataset does not contain organizations sited in non-G77/China developing countries.



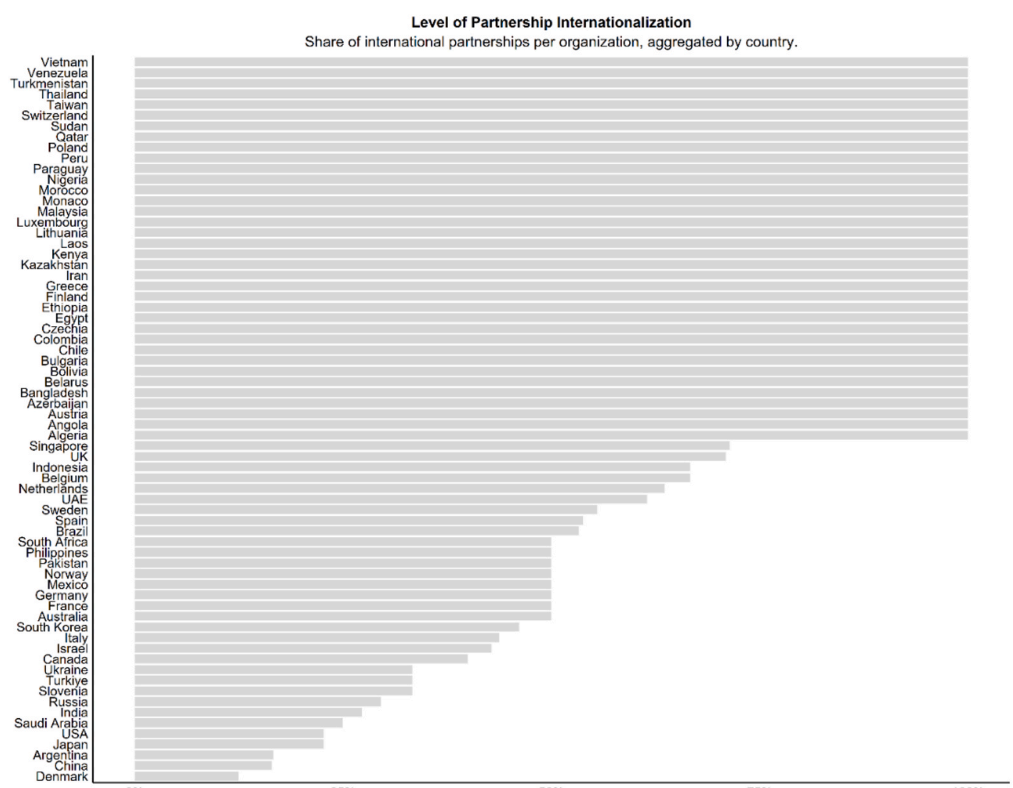


Fig. 1. Organizational partnerships by country (top) and degree of internationalization.

of which classify as belonging to the Global South, partnerships are exclusively international. The absence of domestic partnerships in these cases indicates a lack of capacities: Only by partnering with organizations from abroad are these countries capable of manufacturing, operating, or owning satellites. The bottom panel also shows the tendency for countries of the Global North to have greater shares of domestic partnerships in the satellite sector. China and the USA are particularly notable for having internationalization rates of below 25%. Other than China, India and Saudi Arabia are notable outliers among the countries of the Global South due to their relatively low degrees of internationalization.

Fig. 2 ranks organizations by degree centrality, that is, the total number of partnerships that they are respectively engaged in. Degree centrality is a conventional way of measuring the importance of a given node. The figure shows a clear dominance of organizations from the Global North. Airbus and Eutelsat have particularly high degree centralities owing to their partnerships on the more than 600 satellites of the OneWeb mega-constellation. Overall, European and North American legacy aerospace manufacturers dominate the partnership network, with a strong showing by the national ministries of defense of the USA, China, Russia, and France. Chinese organizations, such as the China Association for Science and Technology (CAST), or the China Aerospace Science and Technology Corporation (CASC), are the only notable players from the Global South that have significant centrality in the global satellite sector.

Fig. 3 breaks down types of inter-organizational partnerships by geography. As noted previously, partnerships are linkages between satellite contractors, between satellite operators, or between contractors and operators. One striking result is that North-South partnerships are overwhelmingly between operators; in the case of South-South partnerships, they are virtually exclusively so. This means that organizations from the Global South are partnering up for jointly *operating* satellites, while satellite construction takes place in the Global North (as exemplified by the existence of North-South operator-contractor partnerships). This finding qualifies the high degrees of internationalization that, as pointed out previously, tend to characterize most countries of the Global South: For the most part, internationalization implies that organizations from different countries of the Global South enter partnerships for operating satellites manufactured in the Global North. High degrees of internationalization, in other words, are indicators of the considerable asymmetry that characterizes the global satellite industry.

We also find that organizations from the Global North tend to have slightly denser local collaboration networks than those from the South. Fig. 4 shows a density plot for the local clustering coefficients of Northern and Southern organizations. These coefficients represent the degree to which the vertices that are connected to a focal vertex are also connected between themselves. The coefficient thus assumes a maximum value of 1 where all vertices in the immediate neighborhood of a focal vertex are connected as well. It is 0 if none are connected, as in star-shaped arrangements. For our purposes, greater local clustering indicates greater integration in collaboration ecosystems, implying higher degrees of specialization and diversification.

Fig. 5 visualizes the network and applies community detection via the Louvain method. In network analysis, communities are typically understood as those parts of a network where nodes are more strongly connected to each other than they are connected with the rest of the network. The Louvain method, one of the more common approaches to community detection, initially assigns each node to its own community, iteratively emerging based on gains in modularity (i.e. the density of intra-community edges compared to inter-community edges; see Blondel et al., 2008). The community structure in the partnership network highlights, once more, the structural power of the Global North in the satellite sector: Most of the communities in the network consist primarily or even exclusively of organizations from the Global North. In these communities, organizations from the Global South play limited roles at best. The only notable exception to this general pattern are two communities that consist almost exclusively of Chinese organizations, with limited foreign partnerships to Turkish or Brazilian organizations. This community structure highlights the strong position that China occupies in the global satellite industry. It is, however, also likely a result of the international isolation of the Chinese space industry due to US export controls (see Zhang and Seely, 2019). Notably, with very few exceptions organizations from outside the US and China only collaborate with organizations from either country, but not both at the same time:

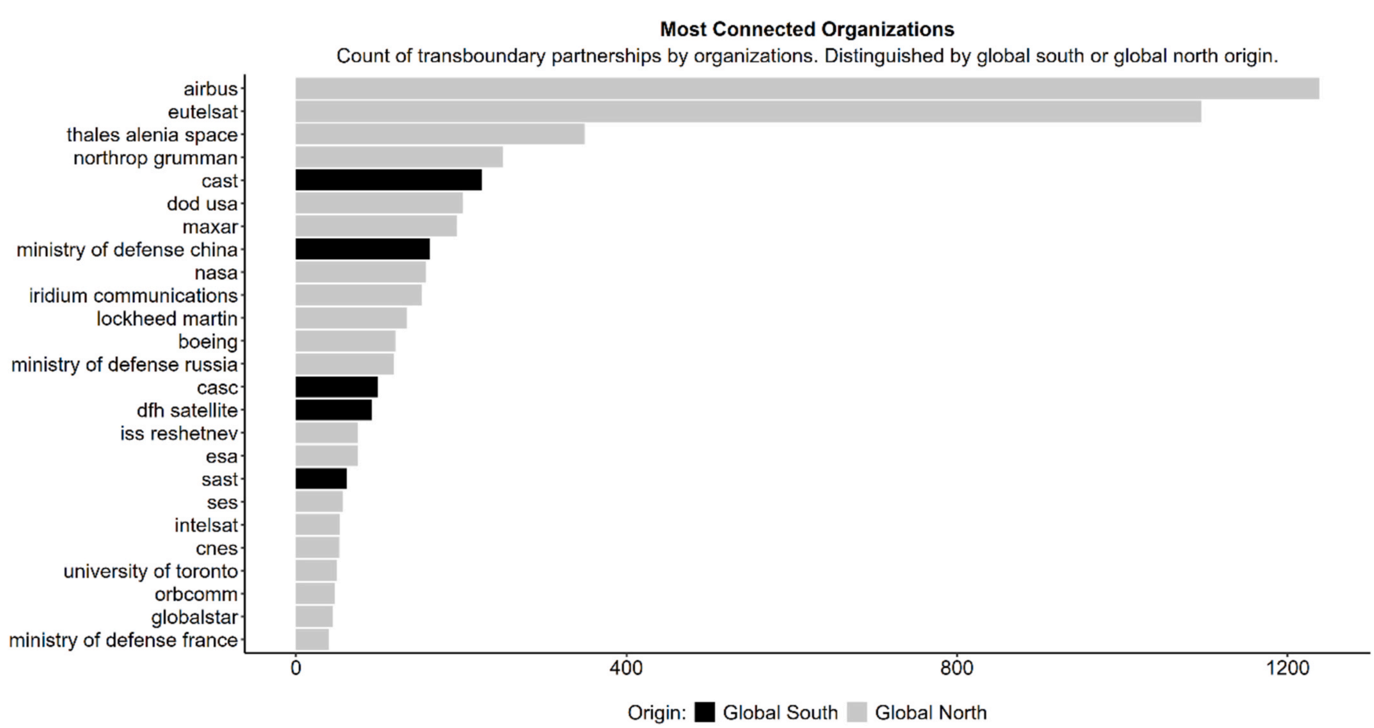


Fig. 2. Organizational partnerships by degree centrality, top 25 most-connected organizations.

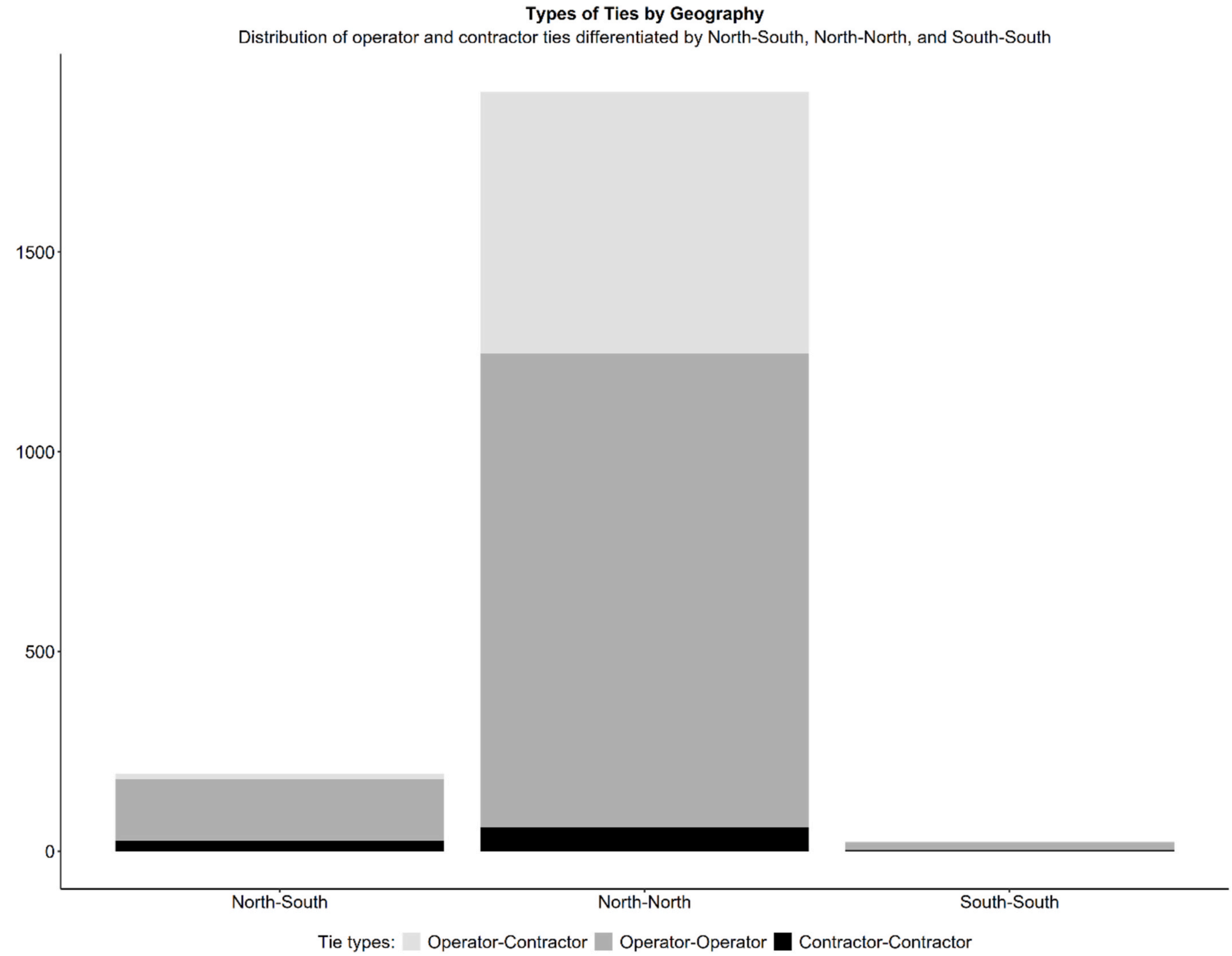


Fig. 3. Types of partnerships by geography.

The large number of foreign partners for US-based organizations mostly refrains from cooperating with Chinese organizations; and the smaller number of foreign partners for Chinese organizations mostly does not engage with US-based organizations. This means that the US-centric part of the network is mostly disconnected from the Sinocentric part. As Chinese space organizations have comparatively limited internationalization (see above, lower panel of Fig. 1), the possibilities for Chinese leadership in South-South collaboration, and for enhancing technology access and transfer for developing countries, are limited as well.

Overall, the empirical analysis thus indicates a structural dominance of the Global North in the satellite sector. Except for China, organizations from the Global South are structurally dependent on collaboration with their Northern counterparts. This also applies to developing countries, such as India, that have built up a strong space program in recent years. Particularly when it comes to manufacturing capacities, the Global South plays hardly *any* role in the satellite sector (China, again, being the exception). Local collaboration networks also tend to be more tightly integrated in the Global North, suggesting diversification and specialization in organizational partnerships. The broader picture that emerges is thus one of profound global asymmetries which, in turn, translate into a structurally disadvantaged position for most countries of the Global South when it comes to the production, control, and use of technology critical for key aspects of global sustainable development.

The structural asymmetries in the satellite sector show very limited variation over time. In terms of the number of partnerships, the USA consolidated its leading position in the early 1990s and maintained it until the present day, with China and Russia competing for second place until 2016, when Chinese predominance solidified. Some changes in ranking notwithstanding, the countries that dominate in terms of the partnerships of their respective domestic organizations have remained remarkably stable since the turn of the millennium, although some countries (such as Brazil, the UK, or Spain) have gradually decreased their degrees of internationalization over the past decades as they have successfully build up domestic satellite industries. In terms of the geographical distribution of partnerships, Fig. 6 shows the continuing prevalence of North-North collaborations, the continuing irrelevance of South-South collaborations, and marginal increases in the North-South dimension. Structural asymmetry, in other words, appears to be a historically stable feature of the satellite sector and is thus likely to remain so in the absence of disruptive policy intervention or technological and economic change.

6. Conclusions

Leveraging a previously unused dataset, this paper has analyzed the global satellite sector as a critical technological infrastructure underpinning earth-space sustainability. Our social network analysis of organizational partnerships in the satellite sector highlights

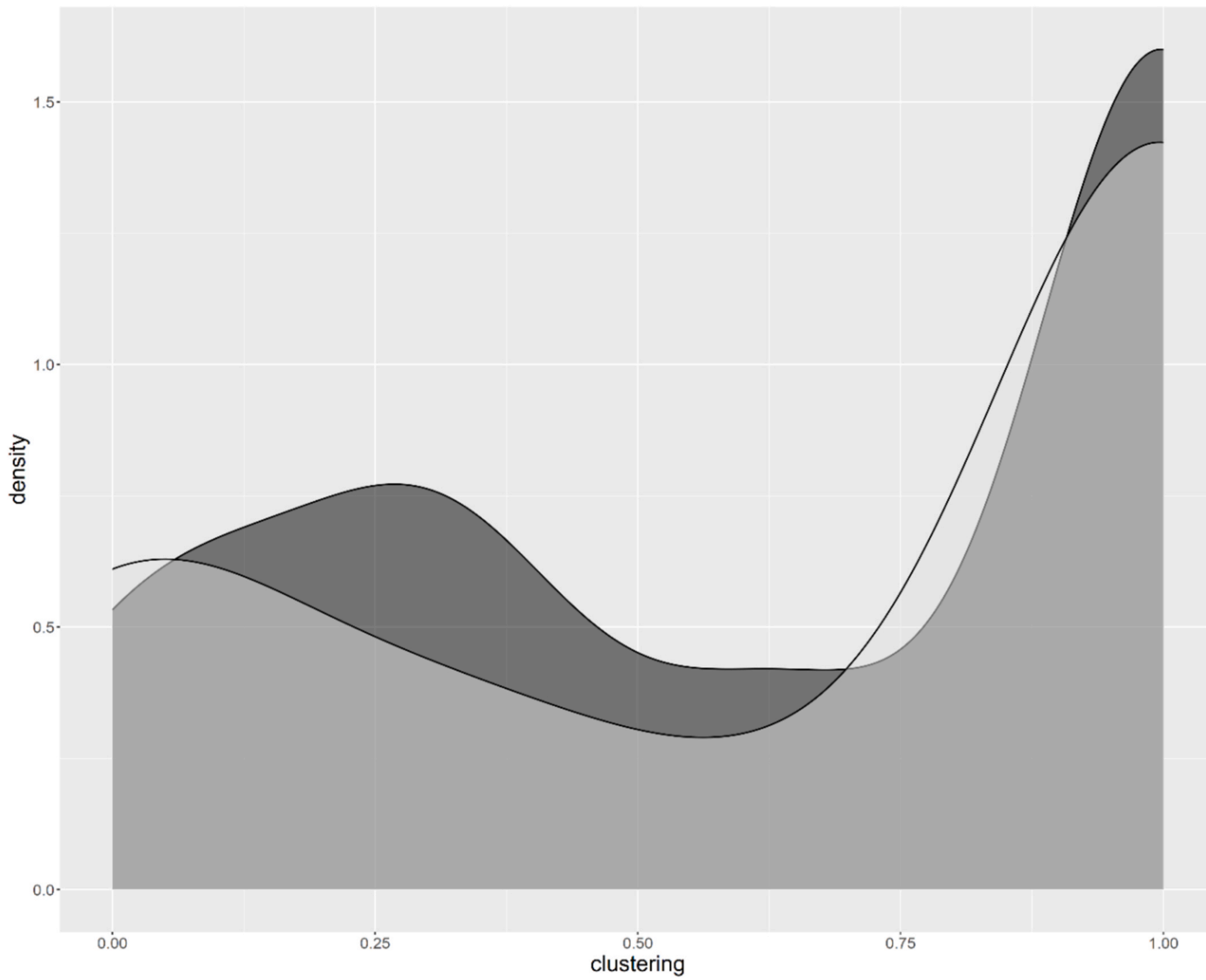


Fig. 4. Density plot of local clustering coefficients for organizations from the Global North (black) and Global South (gray). Organizations with degrees≤1 removed when calculating clustering coefficients.

considerable asymmetries in a North-South context. Among other findings, we have shown that the countries of the Global South are largely marginalized in the global collaborative structure of the satellite sector, particularly when it comes to manufacturing capacities. The notable exception is China, which has built up a significant technological infrastructure over the past few decades, yet with limited international partnerships, primarily as a result of Western technology export controls. With satellites forming a material backbone of Earth-space sustainability (Yap and Truffer, 2022), such structural asymmetries are not aligned with international targets and objectives, including the Sustainable Development Goals. The implication is that many sustainability-related benefits will be distributed unevenly, accruing primarily to a small number of industrialized countries. The satellite sector thus mirrors many other areas of global governance characterized by profound inequities between North and South (e.g. Hills, 1994; Kwet, 2019; Tatar et al., 2021). With the space economy still in its early developmental stages, our findings indicate a need for robust policy interventions to ensure that, over the medium term, outer space activities align with broader notions of global justice.

An implicit assumption behind our argument is thus that the benefits associated with satellite infrastructures would be distributed more equitably if the infrastructures were distributed less asymmetrically. This assumption is based on the notion that countries, or regions, would have greater abilities to tailor satellite usage to their respective needs and priorities, rather than relying on services provided by others. This is a general pattern that can be observed in many other areas of technological infrastructures with highly asymmetrical global distributions. During the COVID-19 pandemic, for instance, the benefits associated with vaccine technology were primarily absorbed by the (few) countries with corresponding manufacturing capacities (Tatar et al., 2021). While geographic concentration may help to avoid redundancies and to reduce transaction costs, there is considerable anecdotal evidence to support the idea that those who control technology appropriate most of its benefits. Beyond that, however, it is important to bear in mind the overuse of orbital space, primarily driven by dramatic increases in satellite launches, which directly feeds into the problem of space debris (see Morin and Couette, 2025). In this respect, improved technology access and transfer for the countries of the Global South might backfire by further exacerbating orbital congestion and thus aggravating the space debris challenge.

What options are there for better leveraging satellites for Earth-space sustainability? One way that we have already alluded to is technology transfer. Various initiatives and proposals for improving space technology transfer are presently under discussion across a range of

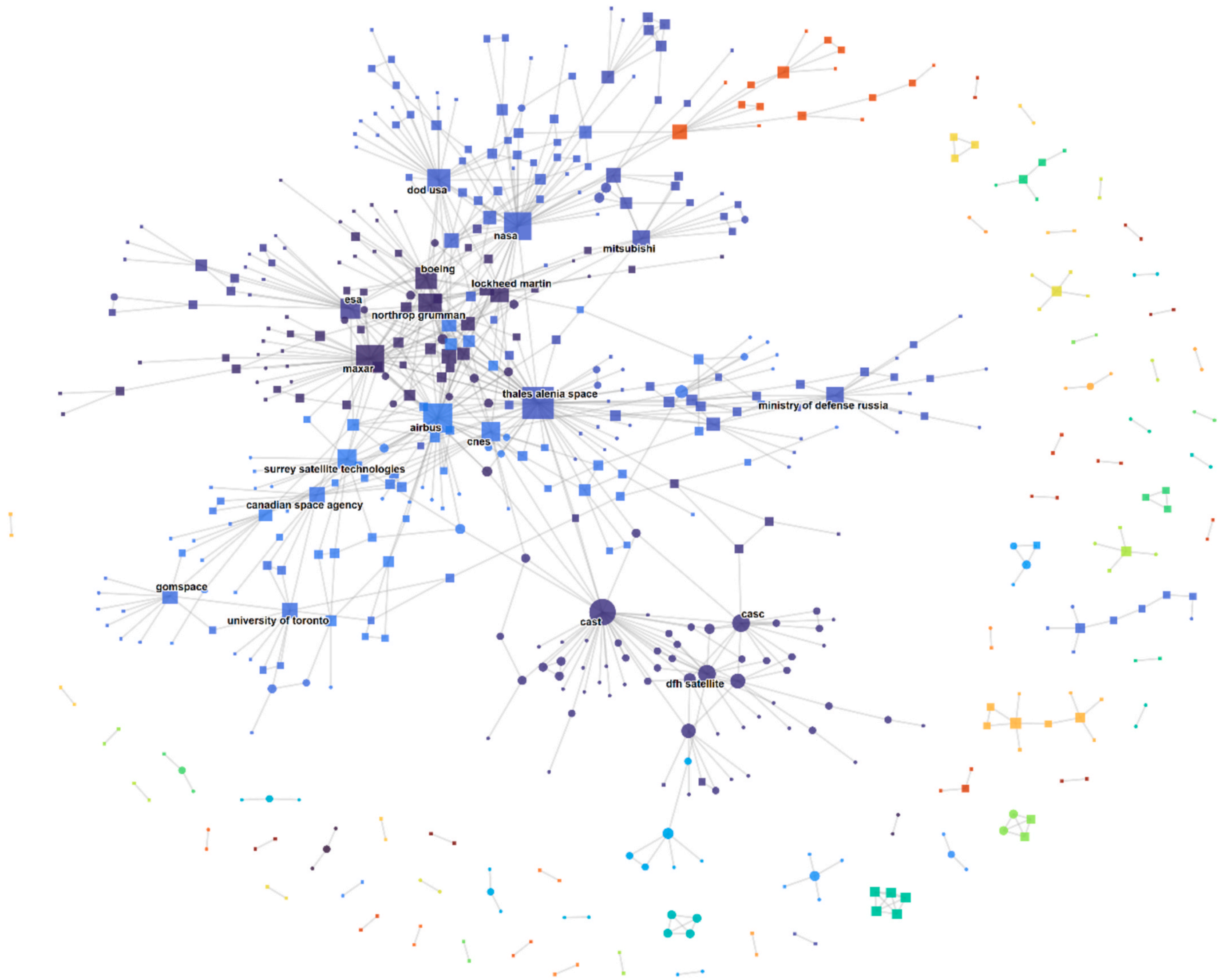


Fig. 5. Visualization of the partnership network. Nodes are organizations (circle: Global South, rectangle: Global North). Node size scales with degree centrality, colors indicate community membership.

international forums. Technology transfer typically faces considerable political challenges which, in the present case, are likely to be exacerbated by the dual-use aspects of satellite technology outlined above. At least in the short term, adequate solutions for satellite technology transfer would thus appear to be elusive. Improved satellite data-sharing may be more feasible. As data can be shared as a public good, the problem structure of data-sharing is different from that of global satellite infrastructure. As is often the case (Barrett, 2007), the main challenge is to ensure adequate supply of data as a public good, by satellite owners and operators that incur costs for doing so, and that may have incentives to restrict data access for commercial or other reasons. Some types of satellite data are increasingly subject to international arrangements, such as the UN Remote Sensing Principles, the UN Platform for Space-based Information for Disaster Management and Emergency Response, or the Sendai Framework for Disaster Risk Reduction, that facilitate access and sharing. Other types of data are increasingly subject to restrictions (Borowitz, 2017; Cirac-Claveras, 2019). The Artemis Accords, a new international space governance instrument promoted primarily by the USA, exempts the private sector from open data-sharing comments, contributing to a broader trend towards the enclosure of the data commons.

The consequences of access restrictions can be considerable. Open-access satellite data for forest imaging tends to have limited resolution and accuracy, forcing researchers and civil society organizations that monitor deforestation to turn to commercial providers. The same problem applies to commodity producers that are legally required under the European Union's Deforestation Regulation to present satellite data as evidence that their value chains do not contribute to deforestation (Alkema et al., 2024). The European Space Agency has occasionally limited public access to satellite images of sensitive regions, including the Red Sea. While such restrictions are motivated by security concerns, they also hamper the ability of scientists and the wider public to acquire data for environmental monitoring and other sustainability-related purposes. The US has implemented similar access restrictions over the years. The 1997 Kyl-Bingaman Amendment prohibited high-resolution satellite imaging of Israel, hampering geographical and archaeological research. The US International Traffic in Arms Regulations place export controls on satellite technology, including for purposes of environmental observation. The US government has also been known to acquire exclusive rights of high-resolution satellite images to prevent public access, notably for Afghanistan after 9/11 (Scoles, 2018).

Space law offers entry points for improved data-sharing. The Outer Space Treaty, the center piece of international space law, stresses the collective rights of humanity, as well as collective interests of states, in

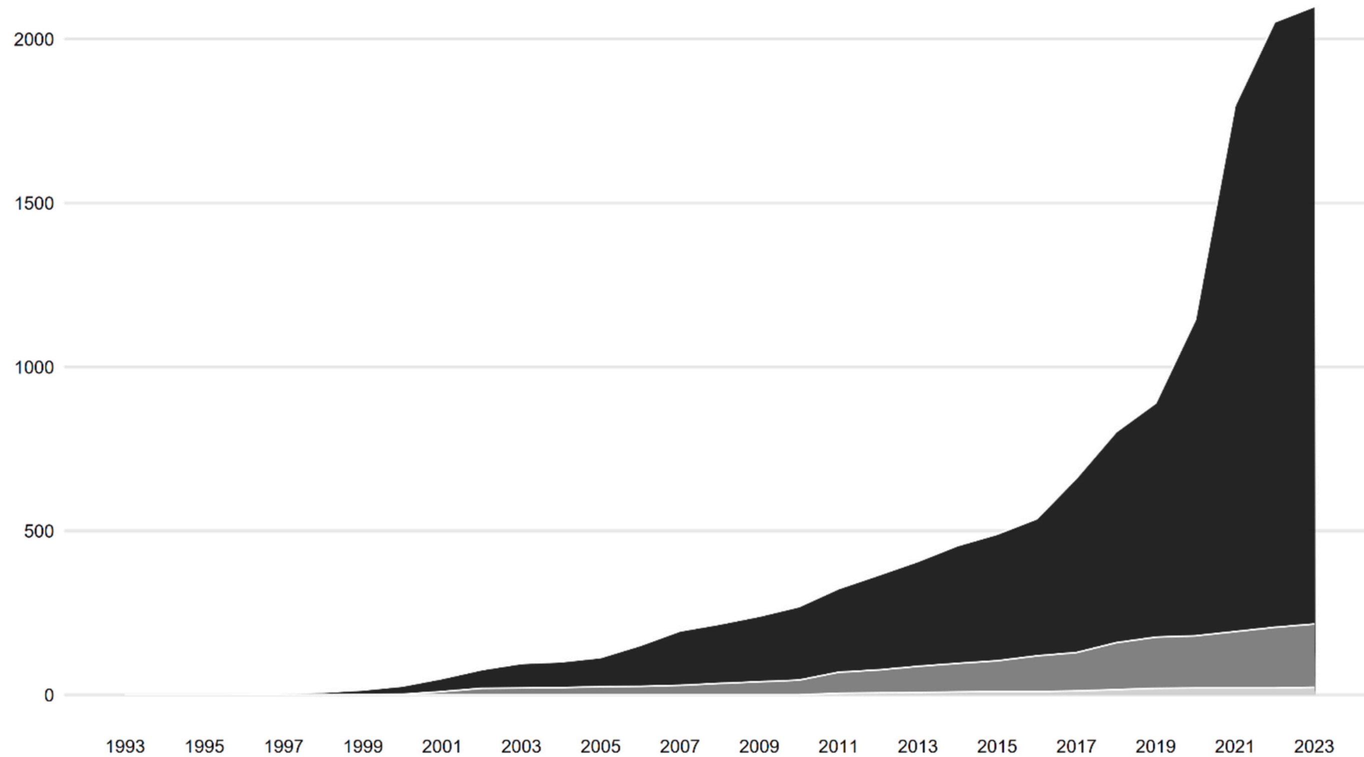


Fig. 6. Cumulative changes in North-North (black), North-South (dark gray) and South-South (light gray) partnerships over time.

the exploration and use of outer space. It also obliges its state parties to "inform […] the public and the international scientific community […] of the nature, conduct, locations and results" of space-based activities (Outer Space Treaty, Articles 1 and 11). Moving towards alternative data governance models, such as data cooperatives or public data trusts (Micheli et al., 2020), could improve data access by the Global South and thus contribute to a more equitable distribution of technological benefits even in the absence of robust technology transfer mechanisms. However, there is no reason to believe that the problem of data-sharing is inherently easier to solve than the problem of technology transfer.

The dual-use aspect of satellite technology generally complicates governance solutions for sustainability (see Hurova, 2023). The technology is entangled in broader geopolitical rivalries and frequently subject to restrictions on export and use. The resulting trade-offs between security and sustainability may be hard to circumvent. At the same time, the stark asymmetries in global satellite infrastructures, and the frictions and barriers with existing data-sharing arrangements, both indicate a need for policy action to ensure greater global equity in the use of satellite technology for sustainability. Such policy action, however, also needs to take into account limits to orbital carrying capacity, which means that the solution cannot simply be for the countries of the Global South to launch more and additional satellites of their own. While satellite technology provides important sustainability *benefits*, it also causes sustainability *challenges*, whether these relate to orbital debris, to the unsustainable extraction of raw materials for satellite manufacturing, or to the atmospheric and terrestrial impacts of satellite launches. There is thus a need to develop an integrated framework for satellite governance that leverages the technology for sustainability while mitigating harmful impacts on the planetary and space environments.

CRediT authorship contribution statement

Florian Rabitz: Writing – review & editing, Writing – original draft, Validation, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Inga Popovaitė:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Vidas Vilčinskas:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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