5G Kick-off in India and Brazil: InterState Competition, National Systems of Innovation, and Catch-up Implications for the Global South

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This essay presents some main features of the kick-off of 5G in India and Brazil extracting implication for Global South catch-up. Based on some main neo-Schumpeterian contributions on long-waves, long-cycles, and catch-up, attention has been paid to the interstate competition between the US and China, the global pressures and linkages of the Indian and Brazilian National Systems of Innovation, and the development of key infrastructures and productive capabilities by the domestic and multinational firms involved in the kick-off of 5G. Two main Global South cases capturing the interrelated geopolitical and technological tensions of the 21st century transitioning capitalism are discussed.

Keywords: 5G Kick-off, India, Brazil, Interstate Competition, National Systems of Innovation, Catch-up, Global South

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I. Introduction

Wireless technologies have advanced dramatically since the first Morse code transmission in the late 20th century. 5G is the next generation of wireless network technologies that enables a drastic reduction in data transmission time over today's most widespread network, 4G LTE. 5G enables a substantial improvement in capacity for vehicle auto-guidance, remote operations, robotics, artificial intelligence, and other dual-use applications (CISA, 2023; Duffy, 2020). In military terms, 5G improves communications and situational awareness among deployed forces in the field, and expands the use of drones and remotely controlled objects (Congressional Research Service, 2022). In commercial terms, 5G enables the deployment of new domestic and industrial devices and applications in the Internet of Things, an estimated $13 billion market by 2035 (Qualcomm, 2023, 2017).

The secular dispute between the US and China today has a main area of competition around 5G (Kennedy and Lim, 2018; Balbo, 2022). The US, from the initial development of its telecommunications infrastructure with the beginning of the internet with its hub in the Silicon Valley, dominates a large part of the global optical fiber cables; it has developed companies, such as Intel, Qualcomm, Broadcom, and Texas Instruments, that, jointly with some East Asian firms, such as Taiwan Semiconductor Manufacturing Company (TSMC) m and Samsung, have a main market share of a key segment for 5G development: semiconductors (CISA, 2023; Moraes, 2004; Qualcomm, 2023). However, China has made accelerated progress through Huawei in the manufacture of equipment and towers for 5G, leading this segment and making Chinese-scale efforts to dominate the semiconductor segment and develop optical fiber (Majerowicz, 2019; Majerowicz and Medeiros, 2018).

The shaping and property of network infrastructure, production capabilities, private sector joint ventures and partnerships, STI linkages, patents, standards, and market regulations that are being shaped in the Global North around 5G will directly affect Global South. 5G has come to play a prominent role in the foreign policy and STI agenda of most countries in the world, offering a new opportunity to consolidate or reduce technological and productive asymmetries. In view of the discussion introduced by Gonzalo and Harfuch (2020) and Gonzalo and Haro Sly (2022), this essay presents some main features

of the 5G kick-off in India and Brazil, extracting implication for Global South catch-up. Based on some main neo-Schumpeterian contributions on long waves, long cycles, and catch-up, main attention has been paid to the interstate competition between the US and China, the global pressures and linkages with the Indian and Brazilian National Systems of Innovation (NSIs), and the development of key infrastructures and productive capabilities by the domestic and multinational firms involved in the 5G kick-off.

Given the size of their domestic markets (the largest of South Asia and South America), the geopolitical relevance they have for the US and China, the capabilities accumulated around their NSIs, and the domestic and multinational firms operating in both countries, Indian and Brazilian cases have main relevance to the 5G and the catch-up literature. Nevertheless, the literature introducing data, analysis, and implications for the Global South has been scarce. Accordingly, this essay introduces two main cases capturing the interrelated geopolitical and technological tensions and dilemmas of the 21st century transitioning capitalism.

This essay follows a method of appreciative theorizing which aims to provide casual explanations based on historical appreciations and empirical data (Nelson and Winter, 1982; Freeman and Louçã, 2001; Gonzalo, 2022b; Porto *et al.*, 2021). Complementary sources have been used: news and articles from specialized journals on telecommunications and business, academic papers and official documents. In addition, in 2019, four interviews were conducted to key-informants from the Indian and Brazilian IT industry and academia.

After this introduction, the essay has three main sections. Section 2 introduces a brief framework to discuss 5G and catch-up in the Global South. Section 3 presents the cases of India and Brazil, with an introduction of the global dispute between the US and China around 5G. Finally, Section 4 presents the implications oriented to the catch-up discussion in the Global South.

II. Interstate competition, NSI pressures and linkages, and 5G kick-off

Advances in wireless technology infrastructure, from 2G standard in the early 1990s (with a speed of 0.064 Mbps) through 4G (up to 200 Mbps), have been accumulative but more than incremental (CISA,

2023; Qualcomm, 2023). Each new generation provided dramatic improvements not only in transmission speed but also on service quality, congestion management, cell hand-over, and signal quality. The full deployment of 5G will imply improvements in bandwidth, speed, and latency enabling the emergence of new Internet of Things business models involving massive quantities of data (CISA, 2023; Duffy, 2020). As a result, products that were once separate are now more easily integrated, abolishing borders among telephones, music players, the Web, TVs, cameras, etc.

Numerous authors have studied how technological revolutions have historically been associated with long cycles or long waves of infrastructure, knowledge, and production capabilities accumulation (Kondratieff and Stolper, 1935; Mandel, 1981; Kuznets, 1940; Freeman and Louca, 2001; Gonzalo, 2022b). For the neo-Schumpeterian literature, technological revolutions give place to "techno-economic paradigms," understood as constellations of technological systems inaugurated by radical innovations that are later expanded to a set of incremental innovations in all industries (Freeman and Perez, 1988; Perez and Soete, 1988; Perez, 2001). With each new techno-economic paradigm, new possibilities emerge, which may be used by incumbent or latecomer countries and firms, depending on their responses and catch-up strategies (Lee, 2019). Particularly, sectorial policy, firm-level strategies, and institutional building have been deeply explored for different industries (Lee and Malerba, 2017; Porto *et al.*, 2021; Lee, 2019; Lee *et al.*, 2014).

However, contemporary neo-Schumpeterian analysis has not paid considerable attention to the relationship between technological and economic conditions, and geopolitical processes and global linkages and networks of key importance to understand the initial configuration of 5G. Indeed, List's (1841) seminal contribution on the National System of Political Economy explicitly acknowledged the geopolitical influence over the development of domestic capabilities. From Kondratieff's perspective, long waves are not a strictly techno-economic phenomenon, but partially a manifestation of the behavior, sometimes harmonious and sometimes not, of the socioeconomic and institutional system at the national and international levels (Kondratieff and Stolper, 1935; Freeman and Louca, 2001; Gonzalo, 2021). Mandel (1981) criticized Kondratieff mechanistic cyclical analysis using the concept of long waves. The author argued that even if the causes of the end of the

expansion are endogenous to the behavior of capital accumulation, the passage to a new expansionary phase can only result from external or exogenous factors. Perez (2001) and Freeman and Louca (2001) acknowledged that a new techno-economic paradigm implies changes in National State's hierarchies at the international level.

In the same vein, authors related to the Latin American structuralism have stressed on the centrality of interstate competition as a main driver for capitalism development, with direct implications in terms of technological development, government infrastructure and research and development (R&D) expenditures, and standards determination (Medeiros, 2013, 2003; Fiori, 2020; Gonzalo, 2022a, 2022b; 2018; Cassiolato and Gonzalo, 2015; Cassiolato *et al.*, 2018; Scerri and Lastres, 2013). The influence of geopolitical processes and factors, the role of diasporas and other global networks, and the importance of the type of association and partnerships between multinational and national firms to facilitate (or limit) NSI capability building and catch-up processes have been explored (Gonzalo, 2023a, 2018; Gonzalo and Cassiolato, 2017; Gonzalo and Kantis, 2021). Moreover, the relevance of the kick-off "momentum" for the subsequent development of an NSI or entrepreneurial ecosystem has also been studied (Gonzalo, 2023a, 2018; Gonzalo and Cassiolato, 2017; Gonzalo and Kantis, 2021; Gonzalo *et al.*, 2022). In this line, the initial 5G global and regional institutional and productive setting is a key moment, given that it will configure several aspects of the subsequent development.

The scenario of technological fluidity and international tensions of 5G kick-off presents a window of opportunity, and it is a source for deepening the international asymmetries between Global North and Global South countries. Although 5G has been considered a new phase of the wireless telecommunication technology and infrastructure evolution (not a new techno-economic paradigm), several relevant factors are associated to the timing and the type of 5G adoption to be studied in the Global South. In this essay, the possibilities and limitations for India and Brazil's "catch-up" through 5G will be observed highlighting: a) the global interstate competition between the US and China and the subsequent global pressures and linkages with the Indian and Brazilian NSIs, and b) the initial development of key infrastructures and productive capabilities by the domestic and multinational firms involved in the 5G kick-off in each country.

III. The US, China and the 5G kick-off in India and Brazil

The upsurge in competition with the rise of new Asian players for the control of key inputs and infrastructure related to 5G is a visible historical process. The open rivalry between the US and China is reflected in blocking acquisitions of firms with capabilities in the development and manufacture of last-generation microprocessors and international pressures from the US on 5G adoption. For instance, in March 2021, the US Federal Communications Commission designated five Chinese tech firms as posing an "unacceptable risk" to national security (*i.e.*, Huawei, Zhongxing Telecommunication Equipment (ZTE), Hytera Communications, Hangzhou Hikvision Digital Technology, and Dahua Technology; DW, 2021). One of the last episodes occurred in October 2022, with the US imposing restrictions over chip exports to China, affecting firms such as TSMC, South Korea's Samsung, and Netherlands-based ASML.

Most of the world's data traffic passes through the US, giving it the management of the international surveillance system (Moraes, 2004). The optical fiber segment is dominated by the US (Subcom), Europe (Alcatel Submarine Network), and Japan (NEC) firms; conversely, Intel, Qualcomm, Broadcom, Micron Technology, and Texas Instruments, with some key Asian companies, such as TSCM and Samsung, control most of the semiconductors' market share have also advanced into 5G developments (CISA, 2023; Moraes, 2004; Qualcomm, 2023). Broadly, the US has mainly based its strategy on the "platform economy," with a sectoral profile oriented to services as main user branches. It complements its leadership in digital platforms by developing an industrial network focusing on the design of the most advanced generations of semiconductors and on the leadership in the domain of cloud computing, artificial intelligence, and big data.

In the case of China, 5G development should be understood as a State-led strategy of technological leapfrogging (Lee, 2021; Majerowicz and Medeiros, 2018; Majerowicz, 2019; Cassiolato *et al.*, 2015). A process of accelerated learning from the deliberate adoption of imported technologies, including the acquisition of companies in Europe and the US, has been implemented. Telecommunications were established as a priority for China in the early 1980s, supporting telecommunication equipment companies, such as GDT, DTT, ZTE, and Huawei (Sharma, 2019). Thirty years after their founding, Huawei Technologies and

ZTE have transformed the global telecommunication equipment market. Some factors have been fundamental: the role of the Chinese government in terms of public procurement, protection of the domestic market, and opening of markets abroad; the strategic alliances made (forcing multinational companies to establish joint ventures with Chinese companies); the financial backing to sell products of equal quality at lower prices than their competitor; and Huawei's aggressive R&D policy (Balbo, 2022; McIvor *et al.*, 2020; Becard and Macedo, 2014; Majerowicz, 2019; Majerowicz and Medeiros, 2018; Cassiolato *et al.*, 2015).

At the foreign policy level, the US has launched a campaign that includes a wave of trade restrictions, tariff barriers and non-price restrictions to prevent Huawei from building 5G networks outside of China. Overall, the UK and Australia banned Huawei, whereas Japan, Canada, and New Zealand are increasing their restrictions. Western Europe is positioned at an intermediate level. France stated that it does not plan to ban Huawei's participation, but will step up controls. Germany has not banned Huawei but maintains pressure on the Chinese company to meet strict security criteria. The Nordic countries did not explicitly ban Huawei, although they maintain control of their 5G networks through national providers that mostly use Ericsson and Nokia equipment. By contrast, countries such as Russia, Thailand, Pakistan, South Africa and Kenia, between others, have moved forward with trials for 5G deployment from Chinese equipment. In this context, the Indian and Brazilian 5G market emergence is of main importance.

A. India

Global linkages and tensions around 5G at the Indian NSI. Since its independence, India has given a main place to science development (Joseph e*t al.*, 2008; Gonzalo, 2022a). A dense network of universities, institutes, and STI organizations was constructed during the Nehruvian period, still being a key asset for the Indian NSI (Joseph *et al.*, 2008; Gonzalo, 20221, 2018; Gonzalo and Cassiolato, 2017). India produces around half a million software engineers per year. R&D investments have historically been concentrated around energy (mainly but not only nuclear), space, and defense (Gonzalo, 2023, 2018; Gonzalo and Cassiolato, 2017; Joseph *et al.*, 2008). However, with a social and productive structure being extremely heterogeneous, Nelson's

(1977) discussion on "The Moon and the Ghetto" directly applies for India, a country that has developed one of the most important nuclear and space programs in the world but still have around one-third of its population without private toilets (Gonzalo, 2022a). A main contemporary challenge for the Indian NSI is the need to transform science and technological development into productive and social development and welfare. Consequently, STI policy has been reoriented in the last decades to "spread" the Indian science and technology capabilities, and public support has been increasingly oriented to the Indian business groups, startups, and multinational firms.

The development of information and communication technologies in India, particularly software and computers services, has closed links with the US since its origin (Gonzalo, 2023a, 2018; Gonzalo and Kantis, 2021). After attempting to develop an indigenous computer during the 1970s, India went for a model based on IT service exports, with the US firms as main clients (Parthasarathy, 2000; Porto *et al.*, 2021). The Indian diaspora played a leading role in the development of Silicon Valley and now occupies top positions in major US technology companies, many of them now related to the 5G business. After the dotcom crisis in the US, many Indian-Americans returned to India to set up venture capital funds or become entrepreneurs, reinforcing the networks with the Silicon Valley (Gonzalo and Kantis, 2021; Saxenian, 2005). After decades of support, the Indian IT sector has grown, Indian firms have become more sophisticated, and today, major US technology companies, including Google, Cisco, and IBM, have R&D centers in India (Porto *et al.*, 2020; Lee *et al.*, 2014; Gonzalo et al., 2022; Gonzalo and Kantis, 2021).

For the US, the Indo-Pacific region has gained increasing relevance to counterbalance China (White House, 2022). Since the downfall of the USSR and in the face of China's global reemergence, the relationship between India and the US gained volume based on economic complementarity and shared geopolitical interests (Gonzalo, 2022a, 2018). Different US-led initiatives have been launched in the last years, with India as a main partner, (*e.g.*, Quadrilateral Security Dialog and the Indo-Pacific Economic Framework for Prosperity). This complementation increasingly includes cooperation, technical transference, and data sharing oriented to digital technologies and ecosystems, with increasing capital flows from the US (Gonzalo, 2023, 2018).

In parallel, China has grown as a main issue for the Indian foreign policy in this century. India suffered its greatest military defeat in 1962 against Mao's troops and territorial disputes with China are still a source of tension (Gonzalo, 2022a). China's expansion directly affects India, competing for resources, investments and territories. China is advancing in economic and diplomatic terms in the Indian Ocean and South and Central Asia through the financing of ports in Sri Lanka. This policy of seduction toward the Maldives strengthens China's ties with Pakistan and Nepal by financing infrastructure, including people of the northern Himalayas through the new Silk Road. India's marked trade deficit with China, particularly in machinery and equipment, reflects the industrial and technological asymmetry between the two giants. Particularly, telecommunication equipment (*i.e.*, cellular phones and 3G and 4G networks) are being imported from China, representing around one-third of the Indian imports from China in 2021 (Comtrade, 2022).

Although the Indian NSI institutional policy efforts are oriented to reduce import dependence from China (*e.g.* through the "Make in India" program), Huawei has been operating in India for the last two decades. In 2016, Huawei launched a Global Service Center in Bangalore to provide services from India to Africa, the Middle East, and Asia (Kewalramani and Kanisetti, 2019). Most of the players involved in India telecommunications have been using Huawei equipment.

The Indian government has remained ambiguous about the participation of Chinese companies in the 5G business. In 2019, a committee was set up to examine the security of Huawei equipment (Satija, 2019). During the COVID-19 pandemic, India banned TikTok and around 60 Chinese applications, arguing that they were making inappropriate use of data generated by Indian users. In October 2020, the CEO of India's leading government think tank, the Niti Aayog, noted that 5G will be open to all vendors, although special attention will be given to equipment security (The Wire, 2020). There exist several and diverse policy recommendations from public agencies and think tanks, such as to diversify suppliers to avoid overdependence on one supplier, to strengthen controls on imported equipment through the installation of an exclusive equipment review center ("no-back-door"), to restrict or ban Huawei, to publish a list of safe suppliers, to use the scale of the Indian market as a bargaining tool in price and local content, and to shore up domestic R&D capabilities around the digital ecosystem

(Kewalramani and Kanisetti, 2019; Sharma, 2019).

5G governance incentives and institutions are still being developed under the general concept of Digital India. The report of the 5G High-level Forum presented in August 2028 highlighted three priorities: 1) rolling out early, efficient, and pervasive 5G networks; 2) building India's industrial and R&D capacity in the design and IP dimensions of 5G; and 3) expanding the manufacturing base in 5G for semiconductor fabrication and assembly and test plants (Government of India, 2018). In the short term, the report suggested that India has productive possibilities to participate through assembly and test plants. A three-year program, "Building an End-to-End 5G Test Bed," was initiated in 2018 with the objective of prototyping technologies compatible with 5G standards, involving a number of science and technical institutes. Progress has also been made in defining standards and funding research projects (Baxi, 2019). In October 2022, 5G was officially launched in India, with different public support schemes to stimulate domestic groups and startups.

Main player of the Indian 5G kick-off. India is the world's largest consumer of data, and the Indian smartphone market has reached 500 million users, still with huge growth potential (Kewalramani and Kanisetti, 2019; Sharma, 2019). However, 4G service still has some challenges in India, including low quality, low download speed, and lack of connectivity in some rural areas (Sharma, 2018). A main challenge for 5G takeoff is the lack of optical fiber infrastructure; India has around 0.1-km per capita optical fiber route, whereas Japan and the US have 1.35 km and China has 0.87 km (Sharma, 2019). Moreover, without local production of telecom equipment (*e.g.*, towers, semiconductors, and optical fiber), 5G network development involves importing equipment representing a substantial outflow of foreign reserves and a deepening of the dependence on Chinese imports.

The main conglomerates disputing the Indian telecommunications are Jio Platforms, Bharti Airtel, and Vodafone Idea. Jio Platforms has had a strong growth in recent years, taking more than 500 million users and converting into the largest telecom service provider. Bharti Airtel is the second largest provider, followed by Vodafone Idea. Being in a war price over the Indian telecommunication market in the last years, some doubts were formed about the financial capacity of Indian firms to advance with 5G. In this context, North American technology companies and hedge funds have visualized an opportunity to increase

their participation in the Indian market by providing financing and technology.

Jio Platforms is the telecommunications subsidiary of the largest Indian conglomerate, Reliance Industries Limited (RIL) which mainly belongs to the Ambani family. The RIL was founded in the 1960s oriented to the textile business and consolidating in polyester production. Following the pattern of the catch-all Indian national groups, in the 2000s, RIL diversified into oil and gas, oil infrastructure, food industry, insurance, and film industry. In 2010, the RIL acquires Infotel Broadband Services Limited, the only 4G provider in India up to that time and, along with other assets of the conglomerate, formed Jio Platforms. In 2017, it established the paid plan for 4G network at an extremely low price, allowing it to expand its customer base (Samsung was Jio´s 4G equipment provider). In 2020, after integrating with another RIL group company, Rancore Technologies, and acquiring Indian company Radisys, to strengthen its in-house capabilities, Jio claimed to be self-sufficient around 5G.

During the COVID-19 pandemic, Jio Platforms has initiated a meteoric leverage process through the sale of 25% of its shareholding seeking to accelerate RIL's transition into the digital business. In April 2020, Facebook took 10% of its shares. Subsequently, several US private equity funds took another 10% (e.*g.*, KKR, Vista, General Atlantic, TPG, L Catterton, and Silver Lake), followed by funds from the United Arab Emirates. In July 2020, Intel contributed with $250 million and took 0.39% of Jio Platforms' shares (Techcrunch, 2020). In October 2020, Jio closed a deal with Qualcomm Technologies to develop 5G-oriented software and systems. Jio also closed a deal with Google to develop and manufacture smartphones (3G, 4G, and 5G) in India. The JioPhone, an ultra-affordable 4G smartphone, was launched in n 2021 (Techcrunch, 2021). Jio is also working with Samsung on 5G (Business Today, 2020). In an event between India's main business groups and US President Donald Trump in 2020, Trump asked RIL's Chairman Mukesh Ambani, "Are you going to do 5G too?"; to which Ambani replied, "We're going to do 5G. We are the only network in the world that doesn't have a single Chinese component" (Business Today, 2020).

Bharti Airtel signed in 2019 a $1 billion deal with Nokia to develop a single radio access network, which will enable 5G implementation. Airtel also have a partnership with Korean telco SK Telecom around 5G and with Qualcomm, to use radio access network-based 5G

Table 1
Telecommunication equipment used by Indian companies

Company	Dependence on Chinese hardware equipment
Jio Platforms	Does not use Huawei or ZTE equipment
Vodafone Idea	Adopts a "multivendor" strategy, which includes any equipment vendor
Bharti Airtel	Uses equipment from different vendors, including Chinese companies
BSNL	Over 40% of its equipment is from ZTE, and 9% from Huawei.

Source: Quartz (2020)

networks in India. All in all, Airtel has Chinese equipment in its 3G and 4G networks (Quartz, 2020). Vodafone Idea has been operating in India since 2018 from the merger between Vodafone (the UK) and Idea Cellular (India). Nokia and Vodafone Idea announced in June 2020 the successful implementation of the first phase of the world's largest deployment of dynamic spectrum refarming in India (Nokia Press, 2020). Finally, BSNL, the state-owned company, with losses in recent balance sheets, seems oriented to the extension of 4G in rural India and looks unlikely to be able to guide the development and implementation of 5G.

Up to the end of 2020, India's major telecommunication group, Jio Platforms, has not been using Huawei and ZTE equipment. However, Vodafone Idea and Bharti Airtel have "multivendor" type strategy that includes Chinese vendors, whereas paradoxically, state-owned BSNL has 40% ZTE and 9% Huawei equipment (Quartz, 2020).

With commercial 5G launched in India in October 2022, only two of the three major telecom operators have been providing 5G services: Airtel 5G and Jio 5G (The Indian Express, 2023). Although Airtel's "5G Plus" service works on the existing 4G network's infrastructure, Jio's "True 5G" network is a standalone (SA) network. At the beginning of 2023, Airtel 5G and Jio 5G will be mainly available in Delhi, Mumbai, Chennai, Bengaluru, Hyderabad, and other main Indian cities. At present, Aitel and Jio opted to tie up with 5G makers, such as Ericsson, Nokia and Samsung Electronics (Bloomberg, 2022). Mobile phone brands such as Xiaomi, RealMe and Nothing have launched updates that support Airtel and Jio 5G services. Google, Oppo, Apple, and

Samsung will be launching their services during 2023. Since 2022, Apple has been assembling iPhone 14 in India.

B. Brazil

Global linkages and tensions around 5G at the Brazilian NSI. After a colonial period in which minor relevance was given to science and technology indigenous development, Brazil gradually evolved into transforming in the main Latin American economy with several industrial and STI achievements. Similar to India, most of Brazilian institutional STI density was created during the 1950s, with the industrial growth accelerating in the 1960s and 1970s based on import substitution promoted by the state with strong participation of foreign capital and technology (Cassiolato and Lastres, 2021). Some main institutions have a key role during these years, and they are still a reference for the Brazilian NSI (*e.g.*, Petrobras, a state-owned Brazilian corporation anchored in the petroleum industry, and National Development Bank of Brazil (BNDES).

During the 1970s and 1980s, Brazil also developed industrial and technological capabilities in telecommunications (Szapiro and Cassiolato, 2013). Up to the mid-1990s, participation of products developed with national technology in the Brazilian telecommunications market reached 13.9%; in addition, more than a hundred small and medium enterprises were developed around telecommunications with domestic production, including radio and digital multiplexers, data packet switching and telex, low-cost earth stations for satellite communication, digital switching systems, optical fiber, and induction-loop phone card (Szapiro and Cassiolato, 2013). However, the privatization of the telecommunication industry in 1995 resulted in a raise of imports, the entry of large multinational manufacturers (with a reduction in participation of national enterprises in the market share) and the reduction of investments in R&D (Szapiro and Cassiolato, 2013). In the 2000s, the Chinese telecommunication firms take advantage of the Brazilian telecommunication denationalization, and Chinese 3G and 4G equipment were massively imported due to their better prices and financing proposal.

Brazil established diplomatic relations with the People's Republic of China in 1974. The began to collaborate in science and technology in the 1980s, generating the launch of the space cooperation program in

1988. Later milestones in China's approach to Brazil are the Strategic Association signed in 1993 and the Global Strategic Partnership in 2015 (De Sousa, 2021; Malena, 2015). Since the late 2000s, China has become Brazil's first trading partner, with more than two-thirds of its exports to the Asian country being raw materials (*e.g.*, soybeans, oil, and iron). However, Brazil achieves sustained trade surpluses of around 40 billion dollars per year (MDIC, 2020). China also leads in terms of the origin of foreign direct investment in Brazil (American Enterprise Institute, 2020). Cooperation in science and technology between Brazil and China maintains a preponderant role, reaching a share of 30% of all international acts signed by both countries (Sly, 2019).

Since 2017, the BNDES has studied the potentialities of 5G and the Internet of Things in Brazil, defining rural areas, health, smart cities, and industry as priorities (BNDES, 2020). The BNDES estimates that in 2025 the Internet of Things could represent a market of between 50 and 200 billion dollars in Brazil. BNDES documents emphasize the Brazilian limitations for hardware production, highlighting the relevance of propping up capabilities for developing prototypes to diminish the dependency on Chinese equipment (BNDES, 2019).

In the call for bids for 5G in early 2020 the Brazilian government enabled Huawei equipment. However, some technical and security specifications can be considered a restriction. Mainly, an SA network will be created, implying that new equipment will be required (De Sousa *et al.*, 2021). This condition cannot benefit Huawei, which already have 3G and 4G equipment spread around the whole Brazil.[1]

The Brazilian decision of not restricting Huawei in the 5G bid was not warmly received in the US (De Sousa *et al.*, 2021). Ambassador Todd Chapman alerted the Brazilian government about the possible consequences if Huawei participates in the 5G network in Brazil. This event affirms that the issue with Huawei is not a commercial question for the US but rather a matter of national security. Brazilian Vice President Hamilton Mourão told the press that he is not afraid of the US, and explained that more than a third of current 4G networks already use Huawei equipment. Vice President Mourão has been a

[1] Currently, the 3G and 4G networks achieve coverage of mostly of the Brazilian territory. However, only two-thirds of the population is connected. A major challenge for Brazil is to connect the areas furthest from the large urban centers.

main nexus in maintaining the relationship between Brazil and China. The senior Brazilian military and the Vice President visited China in May 2020, showing a pragmatic attitude. Two main domestic business groups has been supporting Huawei equipment acceptance as part of strategy of good relation with China: mobile phone operators that already have Huawei equipment and the agribusiness groups that export to China.

Main player of the Brazilian 5G kick-off. Huawei and ZTE were installed in Brazil in 1999 and 2002, respectively. The arrival of the Chinese companies took place in two structural and parallel processes, that is, the privatization of the Brazilian telecommunications sector (Szapiro and Cassiolato, 2013) and the "Going Global Strategy," which encouraged Chinese companies to internationalize (Cui and Liu, 2019). In Brazil, Huawei targeted the infrastructure equipment segment and offered network and information technology solutions. The other Chinese giant, ZTE, focused on the mobile phone market. Today, Huawei is responsible for implementing sections of the 3G and 4G networks of almost all Brazilian operators, providing communication services for banks, oil platforms, and mining companies. Thus, a third of Brazilian communication data traffic passes through Huawei equipment (Da Silveira, 2019)

Consequently, the development of the telecommunications sector in Brazil during this century mainly occurred through the importation of Huawei and ZTE equipment with a significant and growing Brazilian trade deficit in the electronic equipment and telecommunications sector with China ((Szapiro and Cassiolato, 2013; Becard and Macedo, 2014). The experiences with Vivo and Tim, two of the largest local operators (more than 30% of the telecommunication equipment market), are emblematic of the strategy of "collaborative competition" between the two Chinese providers. Huawei won contracts to install 3G networks, whereas ZTE obtained them to supply terminals (telephones and modems; Becard and Macedo, 2014).

Huawei created its largest R&D and distribution center for Latin America in 2012 to meet the demands of the 4G installation in Brazil (Macedo, 2014). In 2018, it installed an Internet of Things Laboratory, where 2,000 people work (Huawei, 2019). In 2019, Huawei completed one of the largest connectivity projects in the world, installing a nearly 6,000-km transatlantic optical fiber cable linking Brazil with Cameroon. It was Huawei's first large-scale project in the submarine cable sector,

Table 2
Providers of 3G/4G network in Brazil

Operator	Core	Accessory equipment
Vivo	Ericsson	Ericsson and Huawei
Tim	Ericsson	Ericsson, Nokia Siemens, and Huawei
Claro	Ericsson and Nokia Siemens	Ericsson, Nokia Siemens, and Huawei
Oi	Nokia Siemens	Nokia Siemens and Huawei
CTB	Huawei	Huawei
Sercomtel	Huawei	Huawei

TELECO (2020). Initial offers of 5G commercial services were launched in Brazil in 2022 mainly by Vivo, Tim, and Claro. Brasilia, Belo Horizonte, Porto Alegre, San Pablo, Salvador, Rio de Janeiro, and other main cities already have some type of 5G service. Huawei, Nokia, and Ericsson 5G equipment are being used.

showing that the company has acquired advanced capabilities (even though it still lags far behind established players with 10% of the world total submarine cable). Symbolically, it is the first time that Africa and South America will be connected through their respective stations in Kribi, Cameroon, and Fortaleza, Brazil, without mediating through the US or Europe (Bastarrica, 2018).

For their part, Nordic companies Ericsson and Nokia have a long history in Brazil. Ericsson sold its first telephone station to Brazil in 1900 and opened a branch office in the 1920s. In the mid-1940s, Ericsson began receiving orders from Companhia Telefónica Brasileira (CTB), and in the 1950s, it installed an industrial plant in Sao Paulo. In 1960, Ericsson supplied all telecommunication equipment for Brazil's new capital, Brasilia. Toward the end of the 1990s, the Brazilian government auctioned 10 mobile phone licenses (the largest auction in the world up to that time). Ericsson's contracts included the supply of equipment for the cellular operator in San Pablo, leading Ericsson to start a manufacturing base station and mobile phone plant. Today, Ericsson has approximately one-third share of the Brazilian market for fixed telephones, mobile systems, and terminals. Nokia also participates in a significant portion of telecommunication equipment in Brazil. In 2001, Nokia founded the Institute of Development and Technology to research and develop mobile software and information technology.

Table 2 shows the Brazilian operators with their respective suppliers

of core and accessory equipment. Most of the operators use Huawei, Ericsson, and Nokia. In 2012, four of the five operators that acquired licenses to implement 4G networks in Brazil selected Huawei (*i.e.*, Vivo, Claro, Tim, and Sunrise). Huawei has been responsible for implementing 40% of the Vivo network, 38% of the Claro network, and 25% of the Tim network (TELECO, 2020).

IV. Catch-up implications for the Global South

This essay stands for the relevance of adopting a broad and historical-based understanding of techno-economic paradigms, NSIs, and catch-up (Freeman, 1982; Freeman and Louçã, 2001; Cassiolato and Gonzalo, 2015; Gonzalo, 2018, 2022a, 2022b; Gonzalo et al., 2019). Although disruptive and powerful, 5G kick-off and diffusion is a scalable and path-dependent process. Consequently, the fact that Huawei 3G and 4G equipment are already spread in most of the telecommunication networks of the word is a main asset for Huawei, given that 5G network can (at least initially) be "endorse" to 4G equipment. 5G can and will enable the development of the IT industry and digital ecosystems by itself. However, understood as a "technological system," in line with Freeman, the integration among infrastructure, equipment, and productive/digital capabilities around 5G is a crucial aspect with concrete policy and catch-up implications. A country can catch up by importing the whole equipment and only developing its software industry, but the global competition and rules will be played and stated by the ones who dominate most of the technological system.

The US and China, in association with some East Asian firms (and countries), such as Samsung, TSMC, and Nordic firms Ericksson and Nokia, seem to be the real global players in the full deployment of 5G. Despite their geopolitical and economic centrality and the capabilities accumulated around their NSIs, neither India not Brazil have domestic manufacturers of telecommunication equipment of 4G and 5G, not solvent semiconductor firms. This fact put Brazil and India, two of the most important Global South countries, some back seats in the 5G global discussion. Furthermore, as aforementioned, one of the main limitations of the pressure from the US to limit the use of Huawei equipment is that they are already part of the 4G network of Brazil and India, and a ban on Huawei will imply an additional cost for telephone operators, related to the replacement of equipment. Certain physical

and productive irreversibility, when added to the lower prices and financial proposal of the new 5G equipment, favors Huawei.

Given its historical tension with China and its growing geopolitical and economic complementarity with the US, including close links with the Silicon Valley, India presents a greater penetration of the US companies that was reinforced during the COVID-19 pandemic. In parallel to the ban on TikTok and other Chinese applications, Jio Platforms, the main player in Indian telecommunications, has advanced on its integration with Intel, Google, Facebook, and Apple. Thus, Jio Platforms can take the lead in the 5G path of development, leveraging on technology transference and funding provided by the US "big tech" and hedge funds. The potential size of the Indian market (around 5G smartphones and in terms of digital platforms) and the centrality that the Indo-Pacific has acquired for the US are key drivers. Huawei has not been banned as an equipment supplier in India, but Jio and Airtel seem to prefer East Asian or Nordic firms as providers. Given India's geopolitical interest and the fact that it still has no 5G equipment nor semiconductor producers, the quick adoption of 5G infrastructure and the developing of the domestic digital ecosystem can be a quick catch-up path for India, in line with the historical development of the IT sector in the country. However, the huge trade deficit in telecommunication equipment, particularly with China, will still be an economic and geopolitical issue for this catch-up path.

In Brazil, Huawei has shown a growing presence since the 2000s, with China consolidating its position as Brazil's largest trading partner. In turn, Bolsonaro's administration has shown an almost total alignment with the US. Thus, there seems to be a dichotomy between Brazil's administration, with a strong geopolitical–ideological affiliation with the US, and the economic interests linked to China, mainly related to the Brazilian agribusiness sector and the mobile phones operators. In this context, not much efforts have been exerted to consolidate the domestic capabilities in Brazil during the last years, suggesting that 5G kick-off is considerably more related to the global interests and multinational strategies than to any catch-up strategy.

Despite the delay caused by the geopolitical tensions (in India, 5G started three years later than in South Korea), 5G kick-off has given the opportunity to some incumbent mobile operators to deepen their insertion into the Indian and Brazilian market by importing and adapting 5G equipment, which is the case of Jio Platforms and Airtel

in India, and Vivo, Tim, and Claro in Brazil. As aforementioned, the mobile operators that already have Huawei equipment are one of the domestic actors that make pressure to allow Huawei 5G equipment. A clear partnership between national and transnational business groups (and in some cases between two transnational business groups) is seen at the 5G kick-off, mainly driven by the market opportunity. Not much geopolitical intentions or alignments seems to be in the incumbents mobile operators, and the main motivation of these first movers seems to be the new base of consumers and data they will reach in two huge markets, such as of Indian and Brazilian.

In a second level of global relevance and productive and technological complexity, there exist several initiatives and catch-up trajectories that can be adopted by Global South countries. By now, India seems to be considerably more focused than Brazil. As stated in the Report of the 5G High-level Forum (Government of India, 2018), India can aspire in the short term to engage in the 5G assembly and test plant segments and in a middle term in the production or development of semiconductors, in a partnership with the US, and in Nordic or East Asian firms. The size of Indian and Brazilian markets should be used to negotiate domestic technological efforts and suppliers' integration to the 5G value chain. The complementation between global and regional oligopolies, such as in the case of Jio Platforms and Facebook/Intel/Apple, a typical mode of the modern peripheral insertion into global capitalism, should be surrounded by public policy to encourage domestic technological and productive efforts. In a similar sense, a whole agenda related to the 5G digital ecosystem development and governance should be discussed in such countries with a huge consumer base, data, and digital transactions. A significant space exists for domestic business groups and startups in this matter.

Despite the already mentioned limitations, the tension between the US and China can hold Global South countries to negotiate better terms for technology transfer and financing, location of some nodes of the telecommunications value chains, promotion of joint ventures in critical technologies, training of human resources, financing of local R&D efforts, and creation of software and app developments. Several domestic institutions and productive actors in India and Brazil can play a role. The configuration and coordination of the Global South NSIs will have main relevance in the determination of standards, public procurement linked to technology transfer, and industrial policies to

consolidate domestic players.

In addition, despite their significant territorial and demographic size, India, Brazil, and other Global South countries still show extreme levels of productive, regional, and social heterogeneities (Gonzalo, 2022a, 2019; Cassiolato and Lastres, 2021; Joseph et al., 2008). Such heterogeneities also exist in the telecommunications landscape. Although 4G network covers a good part of the Indian and Brazilian territory, in rural areas, the quality of the service is intermittent, with low speed and with segments of the population that still do not have access to smartphones. A dilemma that remains for the Global South public policy is whether the State should heavily invest in the development of the 5G network or should concentrate in upgrading the 3G and 4G networks, leaving 5G development to the private sector. This alternative is not a black or white; there can be mixed efforts, which, however, will imply a complementation of efforts and targets between the public and private sectors.

This essay has presented some main features of the 5G kick-off in India and Brazil, extracting implications for Global South catch-up. Historically, Global South countries have been exposed to the expansion of the Global North. During the 21st century, the reemergence of the Indo-Pacific has been witnessed as the gravitational center of global capitalism, with China and India as main players and the US still maintaining its financial, military, and technological leadership in key areas. How the Global South countries positioned themselves in this secular transition will determine if it will imply a window of opportunity for catch-up or a renewed source of technological, productive, and social asymmetries.

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