Becoming an intellectual monopoly by relying on the national innovation system: the State Grid Corporation of China's experience.

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Abstract

This paper examines the origins of global leaders under intellectual monopoly capitalism. State Grid Corporation of China (SGCC), the leading firm in artificial intelligence applications for the energy sector, became an intellectual monopoly relying heavily on China's national innovation system –particularly public research organizations and public funding, and innovation and energy policies. SGCC is unique because it did not rely on technology transfer from global leaders, unlike other national champions from developing or emerging countries. We provide evidence that contributes to thinking that SGCC first became a national intellectual monopoly and only afterwards expanded that monopoly globally. We empirically study SGCC's innovation networks. We proxy them using big data techniques to analyze the content, co-authors and co-owners of its publications and patents. Results also suggest that SGCC is capturing intellectual rents from its increasingly transnational and technologically diverse innovation networks by leveraging its national innovation system.

Keywords: Catching-up; Intellectual Monopoly; Innovation Systems; Outsourcing Innovation; China; State Grid Corporation of China.

JEL Codes: O30; O34; L12; L94.

1. Introduction

Traditionally, catching-up and leapfrogging have been seen as theoretically feasible -although historically difficult- growth strategies for peripheral countries' firms, requiring a certain level of technical competence and institutional development (Abramovitz, 1986; Lee and Lim, 2001; Lee and Malerba, 2017; Pérez and Soete, 1988). Catching-up also came to be associated with Global Value Chain (GVC) upgrading (Gereffi, 2014; Giuliani et al., 2005; Humphrey and Schmitz, 2002; Lee and Gereffi, 2015).

Firms trying to employ such strategies are facing new challenges related to the growing importance of intangible over tangible assets (Haskel and Westlake, 2018) which is affecting GVC dynamics (Gereffi, 2014) and leading to the emergence of intellectual monopolies (Pagano, 2014). The growing concentration of intangible assets in certain corporations leaves other companies in a subordinate position due to their lack of technical autonomy. Their best alternative becomes to integrate production networks led by intellectual monopolies that capture most of the value produced in these networks and garner intellectual rents from their innovation networks (Rikap, 2021).

In this context, firms from the People's Republic of China (hereafter China) seems to be leapfrogging and/or catching up in various industries (Fan, 2006; Gu et al., 2016; Lee et al., 2016; Li et al., 2019). Under intellectual monopoly capitalism, this should mean the emergence of Chinese intellectual monopolies.

We study State Grid Corporation of China (SGCC), China's power grid constructor and operator, with a twofold hypothesis. (1) SGCC has become an intellectual monopoly; and (2) SGCC's intellectual monopoly initially was confined to China (what we will call a national intellectual monopoly), and relied mostly on China's national innovation system, but -in the last decade- it has developed into advancing towards becoming a global intellectual monopoly.

SGCC became a world leader with a legal monopoly in Ultra High Voltage (UHV) technologies and then employed artificial intelligence (AI) applications to reconfigure the energy industry towards clean energy and smart grids (Mah et al., 2017; World Intellectual Property Organization, 2019). This paper shows that SGCC is a unique case because, unlike previous studies on the emergence of national champions, SGCC could not follow other corporations in its attempt to become a global leader. No other firm had adopted these technologies. Hence, SGCC could not rely on technology transfer or reverse engineering. Moreover, this article provides evidence that SGCC developed UHV and AI technologies by initially organizing innovation networks mainly Chinese public research organizations, including universities, and other Chinese companies, and by relying on China's public research and development (R&D) funds and (innovation and energy) policies. In a second stage, SGCC expanded its intellectual monopoly (and its operations) globally.

Our overall results highlight the role played by national (and sectoral) innovation systems (Freeman, 1987; Lundvall, 1992) in the emergence of a (national) intellectual monopoly. To our knowledge, there are no in-depth analyses of the inception of global intellectual monopolies in emerging countries. Our analysis of these factors is our main empirical contribution. In conceptual terms, this paper also contributes to integrating (national) innovation systems and catching-up with the emergence of (global) intellectual monopolies.

We employ a schematic model that distinguishes stages in the development of an intellectual monopoly, coupled with a novel empirical methodology based on big data analysis techniques. We conduct network and cluster analyses to investigate SGCC's most relevant research fields and innovation networks. We identify SGCC's most institutionalized collaborations within those networks by focusing on the network of those organizations with a higher frequency of co-publication. We show that SGCC's patents tend not to include other applicants while SGCC organizes innovation networks with several organizations. This result, and the fact that State-Owned Enterprises like SGCC have a relatively higher capacity to profit from innovations than other types of firms in China, lead us to argue that SGCC garners most of the intellectual rents of its innovation networks. On top of the concentration of intellectual property rights, these are the key features of an intellectual monopoly (hypothesis 1). Furthermore, network maps outline that, initially, those innovation networks were mostly national and depended heavily on public R&D funding; subsequently, they have become transnational, in line with hypothesis 2. The transnationalization of SGCC's innovation networks coincides with the international expansion of its business.

The rest of this paper is organized as follows. Section 2 argues that the chances of catching-up and leapfrogging in industries dominated by intellectual monopolies are slim. It extends the intellectual monopoly framework to include conditions that contribute to the emergence of a national intellectual monopoly and its later transition to a global intellectual monopoly. Section 3 presents some stylized facts related to SGCC's success in the context of China's innovation and energy policies. Section 4 describes the methodology used and section 5 presents our empirical findings. Section 6 discusses these results by referring to the originality of the SGCC case. Finally, section 7 concludes.

2. From catching-up to becoming an intellectual monopoly

2.1. The shortfalls of catch-up and leapfrogging under intellectual monopoly capitalism

Latecomer catch-up involves following 'the path of technological development of the advanced countries' while leapfrogging may involve skipping certain stages and/or creating their own paths (Lee and Lim, 2001, p. 460). According to Pérez and Soete (1988), leapfrogging is based on exploiting windows of opportunity resulting from shifts in technology generations. The authors argue that latecomers can adopt the new technology quickly whereas forerunners could be locked into existing technologies falling into the 'incumbent trap'. Lee, K. (2013) reinforced this argument by stating that short cycle technologies (that change rapidly) can offer greater chances to catch-up if latecomers have a certain level of absorption capabilities. Elaborating on this thesis, Lee, K. and Malerba (2017, p. 346) suggest that the higher cost of new technology may prevent the incumbents who are already obtaining the highest productivity from its adoption, opening such windows for latecomers.

However, as Lee, K. and Lim (2001) and Li et al. (2019) conclude, in industries with frequent innovation rhythms, catching-up opportunities are limited, especially for companies with scarce capabilities. This is precisely the case of industries led by global intellectual monopolies; innovation is systematic and rapid, which makes it impossible for latecomers to catch up. In addition, intellectual monopolies use patents (and, eventually, patent thickets) to limit competition and choose local suppliers with which they may share their technology, but capturing most of the resulting value (Coe and Yeung, 2015; Foley, 2013; Rikap, 2019; Yeung and Coe, 2015). This increased accumulation of intangibles (Corrado et al., 2009; Haskel and Westlake, 2018), particularly innovation, is a barrier to catching-up.

Also, both from an intellectual monopoly and a GVC perspective, outsourcing (of manufacturing and innovation) favors the global leaders and further limits the opportunities for latecomers because the extra costs associated with the adoption of a new production technique (and the uncertainty surrounding the development of new technology) can be diverted to other links in the network, such as the state (see also Mazzucato, 2015). This reduces windows of opportunity even more.

Furthermore, the window of opportunity argument assumes, implicitly, that the new technology was produced by some other than the current dominant firm and this latter will afterward decide about its adoption based on a cost-benefit analysis. The leading role of intellectual monopolies in -planning and organizing production and innovation networks- blurs the boundary between the producer and the user of the new technology. Eventually, it is the outsourced company, such as Foxconn in the case of Apple

(Dedrick et al., 2009; Kraemer et al., 2011; Rikap, 2018), that decides whether or not to adopt leader's new technological demands to remain as its supplier. Hence, when the segment of the production process that includes the innovation is outsourced, it is not the outsourcer that is challenged by the new technology; rather it is the latecomer firm that is the former firm's supplier.

Another limitation of catching up as a strategy for non-core countries is that, in many respects, China is an exception. Take, for instance, its position in the New International Division of Labor as both a huge market and a supplier with abundant cheap[1] and under-regulated labor and coal (Malm, 2012; Milberg and Winkler, 2013; Svartzman and Althouse, 2020). This has endowed China with huge economic and geopolitical strength, which, combined with China's flexible implementation of the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement, underpins the Chinese state's confrontations with intellectual monopolies from other countries, especially, in the ICT industry.

Therefore, although the chances of catching-up and/or leapfrogging tend, today, to be slim, China seems to be an exception. What distinguishes China's catching-up from previously studied cases considering that it is taking place in the context of intellectual monopoly capitalism? Addressing this question is beyond this paper. However, this paper contributes by analyzing the inception of SGCC as an intellectual monopoly in clean energy provision based on applying AI, an industry with no previous global intellectual monopolies -and offering a different explanation to that provided by traditional catching-up or leapfrogging narratives. We extend intellectual monopoly theory to distinguish between national and transnational or global intellectual monopolies and mobilize this framework to analyze SGCC.

2.2. Intellectual monopoly capitalism

Monopolizing innovation can be conceived as a persistent source of power in the relations among firms and can lead to globally unequal or asymmetrical market exchanges. As the process develops, differences in firms' innovativeness engender leaders that become intellectual monopolies (Durand and Milberg, 2020; Levín, 1997; Pagano, 2014; Rikap, 2018). Expanding Pagano's (2014, p. 1413) definition of an intellectual monopoly as a "legal monopoly over some items of knowledge, which extends well beyond national boundaries", even in the absence of a legal monopoly, access to knowledge can be monopolized if one company manages to maintain a pace of innovation that places it always ahead of its rivals. Intellectual monopolies innovate continuously in multiple technologies and, therefore, are constantly shifting the technological frontiers in different industries and fields, while also creating new industries. The systematic renewal of intellectual rents results in higher profit rates while resulting in lower profits for laggard firms that see their catch-up or leapfrogging opportunities diminish.

Intellectual monopolies deter R&D investment by other companies, which reduces firm-level catch-up opportunities. Noel and Schankerman (2013, p. 514) show that the adoption of a systematic patenting strategy by certain firms, diminishes the R&D investments, patenting activity, and market value of

[1] Even if this is no longer the case for urban wages when compared with those of near countries like Vietnam, they did contribute to attracting outsourcing and offshoring during many decades since China's reform.

technology rivals. More generally, it has been argued that GVC leaders profit from cheaper labor, worse labor conditions, and scarce regulation in the peripheries, which constrains country-level catch-up and leads to global poverty chains (Carballa Smichowski et al., 2020; Selwyn, 2019; Smith, 2016).

Latecomers might join production networks or GVC organized by an intellectual monopoly, but this would perpetuate the latecomer's technological dependence. In contrast, becoming an intellectual monopoly transforms the former latecomer into a technologically autonomous leader able to subordinate others. Understanding under which conditions the latter becomes a valid alternative is a central dimension of this paper.

When outsourcing, intellectual monopolies may not necessarily exercise direct control over subordinate enterprises. Entry to and mobility within GVCs are conditioned, among other things, by the leaders' capacity to set performance requirements and standards (Gereffi, 2014, p. 28). An active role in setting international standards is a sign of intellectual leadership. In the case of SGCC, its chairman indicated that the company went from being an adopter of International Standards to a situation where SGCC's technical standards increasingly became international standards.[2] Setting international standards reduces the costs of outsourcing because augmenting codifiability lowers the need to share product specifications (Strange and Humphrey, 2018).

Outsourcing is also a feasible alternative to in-house innovation. Since innovation is a cumulative activity that has economies of scale, imitation requires a certain level of knowledge (Antonelli, 1999; Dosi, 1988). Modularization or 'slicing' of the innovation process across distant locations is the object of Global Innovation Networks (GIN) (Ernst, 2009; Liu et al., 2013; Parrilli et al., 2013). GIN concentrate on the institutionalization of certain actors as regular or frequent R&D collaborators. An important aspect of GIN is that the production of knowledge is modularized, and the overall process is organized by the lead corporation. Intellectual monopolies outsource certain steps of their innovation processes and still collect most of the associated rents. This organization of innovation networks allows them to become multi-technology companies that control and orient the required R&D while preserving and extending their power (Rikap, 2021, 2020, 2019).

All things considered, given the capacity of intellectual monopolies to remain forerunners diverting the risks related to innovation to other parts of their innovation networks and collecting resulting rents, we argue that the chances of catching-up or leapfrogging in industries organized by intellectual monopolies will likely be slim. Exceptions include if the latecomer's state prevents global intellectual monopolies local operations (see for instance Lundvall and Rikap, 2022), and the latecomer finds ways to catch-up despite intellectual monopolies limiting technology transfer and reverse engineering. Alternatively, the firm could work to become an intellectual monopoly in an industry where there is no global leader monopolizing knowledge. To discuss this possibility, we draw on national and sectoral innovation systems.

[2] Retrieved from https://www.iec.ch/globalvisions/SGCC/ last access July 15, 2019.

2.3. National and sectoral innovation systems

Following Freeman's (1982) seminal work, the innovation system framework conceptualizes innovation as an interactive, uncertain, and cumulative process (Johnson and Lundvall, 1994). Knowledge, which is the basis of innovation systems, is conceived as interactive learning environments (Lundvall, 2017). Also crucial to the innovation system concept is that it combines two modes of learning and innovation: Science, Technology, and Innovation (STI) learning and an experience-based mode of learning by Doing, Using, and Interacting (DUI). STI is a science-based mode that connects science with technology; the latter involves tacit knowledge (Jensen et al., 2007).

Firms are seen as the core of the innovation system. However, work on National Innovation Systems (NIS), highlights that national innovation performance depends on the relationships among firms and firms' interactions with technological infrastructure innovations (Lundvall, 1992; Nelson, 1993). The focus on the national level is based on the assumptions that NIS differ in terms of their specialization and institutions and responds to the need to explain differences in national economic performance. Chaminade et al. (2009) show that this literature distinguishes between mature and emerging NIS and they make some specific policy recommendations to deal with their respective systemic problems. Emerging NIS are characterized by missing or weak links and components.

In the case of China, the literature generally highlights its impressive indigenous innovation activities in the 21st century and identifies an innovation-driven stage (Gu et al., 2016) and catching-up in patents and trademarks (Godinho and Ferreira, 2012). However, it also points to a dual or fragmented NIS with missing links and argues that technological catch-up remains limited to some enterprises from some industries (Ernst, 2020; Gu et al., 2016; Liu et al., 2017; Yu et al., 2017).

The notion of NIS includes an active role of the state in promoting innovation (Lundvall, 1992; Nelson, 1993). For instance, the state participates in the definition of norms and standards guiding innovation, provides the technological infrastructure, and integrates the system (Freeman, 1987; Lundvall, 1992).

At the beginning of the 1990s, this framework was extended to include among others, sectoral innovation systems (Breschi and Malerba, 1997). This concept refers to innovation systems built around specific sectors and is particularly relevant to the present study. It focuses on the actors and institutions involved in innovation in a particular sector. The sectoral innovation system may be more or less aligned with the NIS and Malerba and Nelson (2011) suggest that NIS and national institutional frameworks contribute developing sectors whose features are aligned to NIS characteristics. In Section 3, we show that this applies to China's NIS and its energy sectoral innovation system. In a successful sectoral innovation system, knowledge production and learning networks are interrelated.

However, the idea of a nationally bounded sectoral system of innovation has been challenged by globalization and global innovation systems (Martin, 2016; Rikap, 2019; Soete, 2009). It has been argued, also, that the NIS literature is overly-focused on links as opposed to actors, which overlooks the power relations within the innovation process (Rikap, 2018; Versino et al., 2012). Section 2.4 discusses the successive stages involved in the emergence of intellectual monopolies, which, conceptually, integrate national and sectoral innovation systems and the power relations in the innovation process, within and beyond national borders.

2.4. Stages in the inception of an intellectual monopoly

To illustrate the stages involved in establishing an intellectual monopoly, we build on Rikap's (2019) two-step model. In this framework, the wannabe intellectual monopoly does mainly in-house innovation and competes for technology with other wannabe or already established intellectual monopolies. If this company manages to establish itself as an intellectual monopoly, it may decide to outsource some innovation modules to subordinate companies or research institutions. This decision relies on the intellectual monopoly's planning capacity and knowledge modularity. Outsourcing diminishes the risks, which are even higher for innovation than for GVC production of already existing commodities. Furthermore, it has been suggested that, in the case of more generic knowledge modules, cooperation between intellectual monopolies can be a viable strategy that reduces the associated risks and increases the chances of success.

In this paper, we propose a model with an intermediate layer, which integrates the contributions of the national and sectoral innovation systems' literature in the (global) intellectual monopoly framework. This intermediate step represents the moment when the geographically close (national and/or sectoral) innovation system contributes to the inception and expansion of an intellectual monopoly. We propose that the initiation of an intellectual monopoly is an evolutionary process that relies on the organizations and policies of NIS, even if, eventually, the intellectual monopoly will go beyond those national boundaries.

Table 1 presents the three steps model. First, corporation 'A' decides to follow an intellectual monopoly strategy (this is t_1). If and only if 'A' manages systematically to monopolize innovation in a field or sector within its country of origin, it will eventually emerge as a national (or local) intellectual monopoly ($t_{1.5}$). Finally, if A manages to expand its monopoly transnationally, it becomes a transnational (or global) intellectual monopoly (entering t_2).

Table 1. Three-step behavioral model for becoming a transnational intellectual monopoly (IM).

	t_1 (Wannabe IM A)	**$t_{1.5}$ (National IM A)**	**t_2 (transnational IM A)**
Innovation Strategy	Systematic investment in in-house R&D	In house R&D complemented by outsourcing of innovation modules **at the national or local level**	In house R&D complemented by outsourcing of innovation modules **at the transnational level**
Associated risk	Mainly taken by the Wannabe IM A	Shared between IM A and other members of its innovation networks	Mainly taken by other members of IM A's innovation networks
Relations with other IMs (in its own or related sectors, if such IM exist)	Technological competition	Technological competition, especially with transnational IMs	Technological competition and **Technological cooperation**

Innovation rents	Profits from its own/internally triggered rents	Profits from its own/internally triggered rents, and appropriation of intellectual rents from its innovation networks.	Profits from its own/internally triggered rents, and appropriation of intellectual rents from its innovation networks.

Source: author's elaboration.

We focus on t1.5 -the formation of national intellectual monopolies-, which is the stage we added to Rikap's (2019) model. We argue that once the corporation starts accumulating innovation success, outsourcing of innovation will rely initially on nearby institutions which are easier to control, typically those within the corporation's sectoral innovation system/s (Malerba, 2002; Malerba and Orsenigo, 1997). In other words, one intellectual monopoly strategy involves reliance on the R&D capabilities and funding of geographically, culturally, and politically closer institutions. In line with Breschi and Lissoni (2001), proximity in terms of both geographical distances and cultural affinity contributes to developing social bonds and face-to-face encounters, which favor the circulation of knowledge. In line with Lundvall (2017, chap. 6), in the context of rapid technological change, face-to-face communication is necessary to define and, later, to solve problems.

Public research organizations (PROs), including public universities, can perform state-of-the-art R&D and the state can provide funds to complement the innovation activities of the wannabe intellectual monopoly. Historically, PROs do not seek to make a profit from their R&D. Therefore, it is easier for a wannabe intellectual monopoly to capture the intellectual rents from their joint activities. It is also easier for the firm to oversee the research if it is conducted by a geographically proximate organization. Furthermore, government support for public-private partnerships for R&D activities favors collaborations within its border. Although the firm might have overseas operations, it is generally more difficult for the wannabe intellectual monopoly 'A' to obtain public funding from a foreign country. This likely would apply to SGCC since the main western countries -especially the US- see China as a threat.

In more general terms, as the number of transnational intellectual monopolies increases, STI policies -including limiting those leaders' access- could play a key role in the emergence of national intellectual monopolies and their eventual transnationalization (Lundvall and Rikap, 2022). Still, this is a double-edged sword because intellectual monopolies appropriate value and intellectual rents from their production and innovation networks, thus leading to a heterogeneous catch-up at the country level.

In $t_{1.5}$, as long as a significant proportion of the R&D investment remains in-house, the innovation risks will be shared between the national intellectual monopoly and the members of its innovation networks. If the establishment of the intellectual monopoly is in line with state policy -as in the SGCC case-, we may expect the state will bear a significant share of the potential risk. In the case of already existing global intellectual monopolies, such as Alibaba and the Great Firewall (see for instance Foster and Azmeh, 2016)-, state protection may work to continuously raise the barriers to foreign companies, accelerating the pace of innovation in 'A' up to the point when 'A' is capable of competing with the global leaders on a more equal basis.

Competition under intellectual monopoly capitalism is based, mostly, on a perpetual technological race. Once 'A' establishes as a transnational intellectual monopoly, it will be in a permanent technological competition with other intellectual monopolies from the same or closely related fields. In this stage, continuous systematic innovation is required to maintain power. We can speculate that, in some cases or some market segments, this was the pattern followed by China's ICT leader firms, such as Huawei and Alibaba. These companies' caught-up, in part, based on their specific markets' conditions (Li et al., 2019). However, the overall process relied on the Chinese state who aimed to develop global innovation leaders (Lee et al., 2016; Lundvall and Rikap, 2022; Nolan, 2012; Wen, 2017; Wu and Gereffi, 2018).

Another specificity of $t_{1.5}$ is that 'A' is unable to enter technological collaborations with global intellectual monopolies on an equal basis; any attempt to do so would result in the global leader capturing most of the intellectual rents. However, as long as 'A' continues to innovate and as long as the state continues to provide protection (including limiting the activities of transnational intellectual monopolies in the country), 'A' will profit from the intellectual rents from its innovation efforts, which will support its t_2 aspirations.

The national intellectual monopoly will also fiercely compete for technology with global leaders to enter t2. When there is no other company innovating in closer or the same fields already in t_2, the self-expansion of A's intellectual monopoly power will not face such strong technological competition. However, entering t2 will require 'A' to develop *new to the world* innovations (Furman et al., 2002), which is a risky and uncertain activity. 'A' could divert risks and reduce uncertainty by relying more heavily on its national (and/or sectoral) innovation system which could compensate for the lack of technology transfer or reverse-engineering opportunities from forerunner firms. In any case, the latter becomes progressively more difficult for latecomers in industries with well-established global intellectual monopolies as incumbents.

We should add a final caveat. We are not suggesting that transition from t_1 to $t_{1.5}$ and from $t_{1.5}$ to t_2 is either assured or easy. It also does not involve a unidirectional process. To maintain its position of power as a transnational intellectual monopoly, the firm must innovate continuously; failure to do so means a downgrading to a national intellectual monopoly or the loss of its knowledge monopoly. Moreover, the limited capacity of peripheral states to prevent global intellectual monopolies from appropriating knowledge produced inside their borders should also be considered.

Overall, for $t_{1.5}$, we consider that there needs to be a stage of local consolidation before the intellectual monopoly tries to assume global power. In other words, geographical and cultural proximity, together with states' role in fostering NIS and particularly sectoral innovation systems at a local or national level, play a role in contemporary global intellectual monopoly capitalism. In the succeeding sections, we employ this framework to analyze the SGCC's experience.

3. Alignment between SGCC and China's innovation and energy policies

Becoming an innovation-driven country was a key goal in China's 13^{th} Five-Year-Plan (2016-2020). Following decades when patent applications to the China National Intellectual Property Administration were mostly made by foreign companies, between 2013 and 2016, more than 80% of patents were applied by Chinese enterprises, and this number reached almost 90% in 2017 (China Clarivate Analytics, 2018).

Some authors describe this as the *great transformation,* and refer to the accumulation of technological and organizational capabilities based mainly on imitation and greater efficiency, and, only in part, on innovating (Yu et al., 2017). Others describe Chinese firms as moving beyond imitation-driven towards innovation-driven (Gu et al., 2016) catching-up in patents and trademarks (Godinho and Ferreira, 2012). Nevertheless, Chinese organizations remained less successful than foreign firms in granted to applied patents' ratio and usually apply for patents only at China's patenting office (China Clarivate Analytics, 2018). Also, as Gu et al. (2016) explain, China's technological catch-up has been concentrated in some enterprises from some industries[3], while Luo et al. (2016) found a positive relationship between government subsidies and firms' innovation capability.

As identified by Majidpour (2012) when studying the heavy-duty gas turbine industries in Iran, India, and China, China's innovation policy is linked to its energy policy. According to Barbara Finamore, Asia director for the Natural Resources Defense Council, energy policy in China is driven by the state's aim to lead the clean energy transition.[4] China's top-ranking for gas emissions, combined with the strategical geopolitical positioning that would result from leading the energy transition, contributed to completely reversing China's initial position against global energy agreements. Since the 2005 Renewable Energy Law, the government and its State-Owned Enterprises (SOE) have been leading efforts to reduce emissions by changing China's energy matrix, replacing coal with clean energy (Gu et al., 2016; Lin et al., 2013; Mah et al., 2017; Schuman and Lin, 2012). In terms of results, China has committed that, by 2040, the country's main source of energy will be electricity. China is ranked first in the world for electricity production and is the solar photovoltaic, wind, hydro, and nuclear power leader (International Energy Agency, 2017).

China's position as a leader of the energy transition would further strengthen its geopolitical and economic power and, coupled with its focus on electricity (World Energy Outlook, 2017), explains the Chinese government's partnership with SGCC and the aim of making it a global leader. In the space of a few years, SGCC became the world's second most important corporation based on revenues (see the 2018 Fortune Global 500 ranking). In 2002, it was just a power supplier ranked 60th in the world for revenue. In 2019, due, in part, to the Chinese state's decision to cut utility prices for local industries[5], SGCC was ranked fifth in the Fortune Global 500 ranking for revenue, yet remaining as the world's largest utility company, with almost 1 million employees. Although much of SGCC's growth has been due to China's industrialization and promotion policies, there has also been a sharp rise in publications and patents, both of which are signs of its intellectual monopoly (Figure 1).

In 2017, SGCC invested USD 1.15 billion in breakthrough R&D in energy provision and other fields (State Grid Corporation of China, 2018). Until 2017 included, it had accumulated almost 17,000 granted patents

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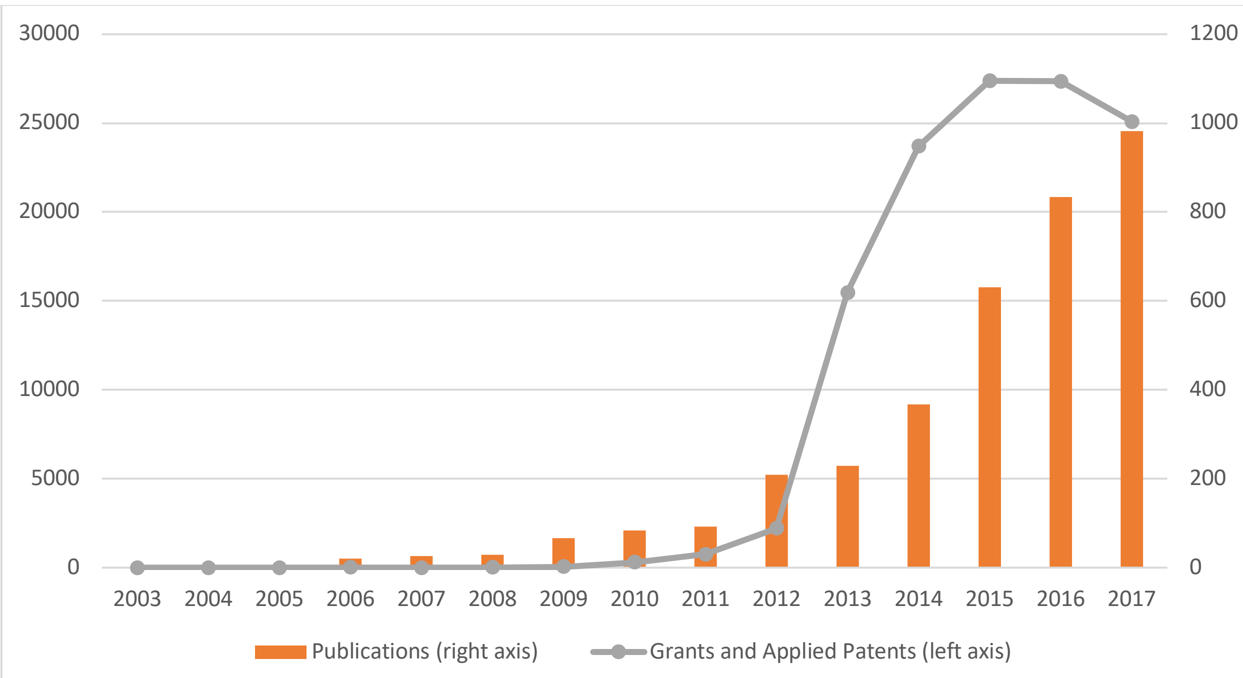
[3] In fact, these authors claim that industrial catch-up has not been accomplished and, combined with its persistent inequalities, this is hampering China's transition to a high-income country.
[4] Retrieved from https://www.politico.eu/article/us-china-climate-renewable-energy-sustainability-leadership-investment/ last access September 2, 2019.
[5] Retrieved from https://www.ft.com/content/0bb37c2e-3755-11ea-a6d3-9a26f8c3cba4?segmentId=b0d7e653-3467-12ab-c0f0-77e4424cdb4c last access March 9, 2020.

and had over 100,000 patent applications. This impressive evolution allowed SGCC to integrate the top 100 Chinese innovators (China Clarivate Analytics, 2017). In terms of publications, from 1 scientific publication in 2003, in 2018 it was responsible for almost 1,000 papers (Figure 1). The company's web page states that, for the last seven years, it has been ranked first among Chinese SOEs for patent ownership and inventions. It received

> 69 National Awards for Science and Technology, (…) 91 China Patent Awards, including 7 Chinese Patent Gold Awards and 25 China Standards Innovation and Contribution Awards, in which 7 are First Prizes. Besides, the company has also obtained 597 China Power Science and Technology Awards, including 59 First Prizes.[6]

Figure 1. SGCC's annual scientific publications and patents



Source: Web of Science and Derwent Innovation.

In the rest of this paper, we provide evidence supporting that these stylized facts indeed correspond to an intellectual monopoly. Based on the model presented in Section 2.4, we argue that SGCC initiated the transition from national to transnational intellectual monopoly. Section 4 describes our methodological approach.

[6] Retrieved from http://www.sgcc.com.cn/html/sgcc_main_en/col2017112700/column_2017112700_1.shtml last accessed January 4, 2021.

4. Methodology

We use big data techniques (network and cluster analyses and text mining) to depict SGCC's innovation networks and its most relevant fields of R&D. SGCC's publications were retrieved from the Web of Science database and applied and granted patents from Derwent Innovation.

We employed network analysis techniques to proxy SGCC's innovation networks. By mapping the resulting networks, we can provide a visual account of the complex set of social relations within different innovation systems, taking into account the links among the participating institutions as well as the frequency of co-authorship with SGCC.

We combined network analysis with clustering, a big data technique that groups the closest entities forming communities within networks (Fortunato and Hric, 2016). These big data techniques allow tracking the positions (central/bridging or marginal) of local and foreign organizations in SGCC's co-publishing and co-patenting networks. An individual organization might publish only a few papers with SGCC, but if it connects SGCC with multiple other -especially foreign- organizations, it will be vital for SGCC's intellectual monopoly expansion.

We used SGCC's network of co-authoring organizations to proxy its innovation networks (hence its institutionalized R&D partnerships). To be considered an intellectual monopoly, SGCC must organize innovation networks involving multiple organizations and profit more than these other organizations from the associated innovations. To that end, it will mostly not share ownership of resulting patents, ignoring the role of other participating organizations. Moreover, inventorship only registers the final steps of an innovation process, thus potentially leaving aside multiple organizations that only participate in the early stages. All things considered, scientific publications provide an accurate depiction of: i) the variety of stakeholders, ii) their position in SGCC's innovation networks, and iii) the geographic scope of those innovation networks.

We retrieved all SGCC's scientific publications up to and including 2018 (4,192 publications). We split the corpus into two periods (2003-2010 and 2011-2018) to get a sense of the evolution of SGCC's innovation networks. The data were processed using CorText.[7] CorText allows the construction of network maps[8] based on specific algorithms that associate terms (in this case affiliations of SGCC's co-authors) according to their frequency of co-occurrence within a chosen corpus of texts (Barbier et al., 2012). To construct these maps, we followed Tancoigne et al. (2014), including their proposed methodology for corpora cleaning. In the resulting maps, the nodes represent research organizations (universities, PROs, firms, etc.) and the node size represents co-authorship frequency with SGCC. To focus on SGCC's most frequent partners, thus, its institutionalized innovation networks, we built networks with the top 101 research organizations for each period (SGCC plus its top 100 partner organizations). In the first period, SGCC co-authored papers with 79 institutions. The corresponding map depicts the 76 institutions that surpassed a minimum proximity threshold (0.1). These maps provided evidence, also, of the national or transnational

[7] CorText is an open platform used to perform bibliometric and semantic analysis. It can be accessed online at: https://www.cortext.net/

[8] All the network maps in this paper follow chi-square metrics, which is a direct local measure, meaning that it considers actual co-occurrences between entities (Tancoigne et al., 2014, p. 40).

scope of SGCC's intellectual monopoly by considering the position and number of foreign co-authors in its co-authorship networks.

We also conducted a lexical analysis of the abstracts, keywords, and titles of SGCC publications to proxy its R&D priorities. As discussed in section 2, intellectual monopolies use their internal and outsourced R&D capabilities to keep innovating and tend to become multi-technology corporations, which explains our interest in analyzing the content of SGCC's publications.

We used text mining to extract the 500 most frequent phrases of up to four terms. Monograms were excluded to avoid words whose frequency responds to their grammatical function ('and', 'or', etc.). The resulting list was also refined to avoid phrases unrelated to the field and whose frequency was related to the level of grammaticalization in the scientific genre (e.g. 'main reason', 'case study', 'proposed model', 'main factors', etc.). Using the resulting list of the 276 most frequent phrases, we built a network map for the whole period (2003-2018) privileging the most frequently connected phrases. We followed the procedure used for the research organizations' network maps but, here, the nodes represent phrases. The resulting network depicts the top 100 phrases by frequency of co-occurrence within the corpus. Hence, the network map can be considered a compelling depiction of the main science-based technology developed by SGCC. As explained in section 2.2, intellectual monopolies innovate systematically (in-house and through their innovation networks) in multiple technologies. Hence, if SGCC is an intellectual monopoly, the network map depicting the privileged content in its publications should give an account of these diverse developments.

Intellectual monopolies also appropriate most of the intellectual rents derived from their innovation networks. To determine the extent to which SGCC shared potential intellectual rents with the organizations in its innovation networks, we retrieved SGCC's applied and granted patents from all patent offices until 2017 included (122 296 records). The data correspond to 25 different patent offices. However, 99% (120,937) of SGCC patent applications and patent awards corresponded to the China National Intellectual Property Administration, followed by WIPO (0.62%, 758 records) and USPTO (0.24%, 295 records). We discuss these figures later in the paper.

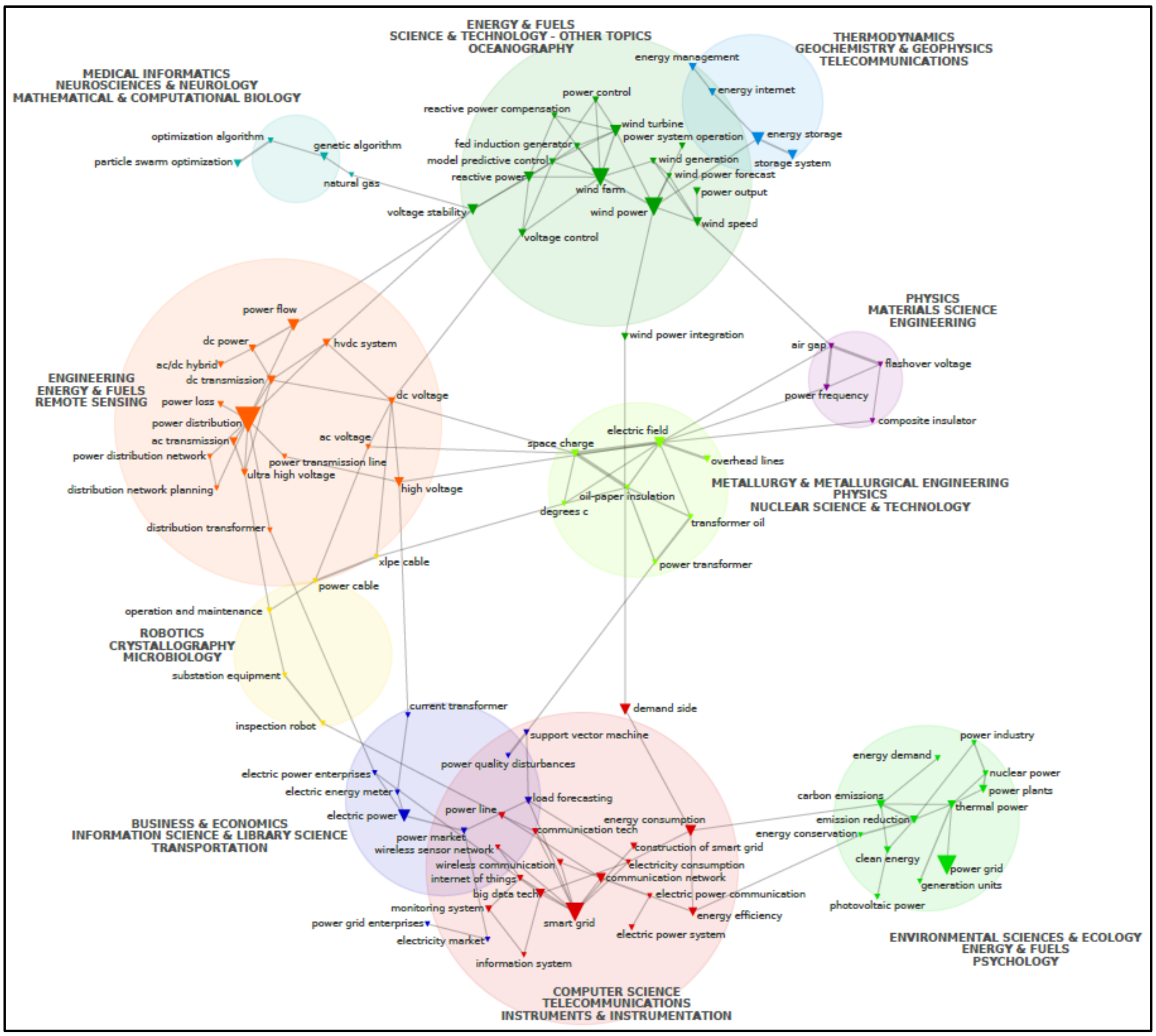
5. SGCC: on the way to becoming a transnational intellectual monopoly

In this section, we provide evidence related to the two interrelated hypotheses of this paper. First, that SGCC is an intellectual monopoly. This means that it concentrates knowledge turned into intangible assets (such as patents, see Figure 1), that this process results in a multi-technology company, and that SGCC captures intellectual rents from its innovation networks. Second, that SGCC is a national intellectual monopoly that is advancing towards becoming a global intellectual monopoly. To provide evidence supporting these hypotheses, we study SGCC's scientific publications to check the scope of its R&D and depict the evolution of its innovation networks. We argue that initially its innovation networks mostly involved Chinese organizations, emerging as a national intellectual monopoly ($t_{1.5}$ in the model in section 2.4) but that it then extended its collaborations to include more foreign organizations, which points to a transition to a transnational intellectual monopoly (between $t_{1.5}$ and t_2). We also analyze SGCC's patent portfolio. We differentiate between members of SGCC's innovation networks (proxied by its co-publication networks) and the beneficiary of the associated intellectual rents (proxied by patent co-ownership), which shows that SGCC is an intellectual monopoly. Finally, we discuss SGCC's business and market results.

5.1. The content of SGCC's scientific publications

Figure 2 shows SGCC's privileged research topics, based on the text mining described in section 4We interpret each cluster as an SGCC's R&D priority. Clusters are weakly connected within, plotting a network of multiple different topics investigated simultaneously by SGCC, which is in line with the multi-technology condition of an intellectual monopoly.

Figure 2. Network map of the most frequent topics in SGCC's publications.



Source: Author's analysis based on data extracted from the Web of Science.

The clusters in Figure 2 focus on structural aspects of the power industry, in particular, Ultra High Voltage (UHV) technologies. The SGCC intellectual monopoly project was based on becoming the leader in these technologies. No other single player was close to mastering them and SGCC was able to rely on heavy state support. Among others, the state transferred to SGCC different research centers that had belonged to the Ministry of Electric Power and provided the company multiple R&D grants (Yi-chong, 2017, chap. 7).

The lexical analysis also shows that new technologies including big data, robotics, and IoT are also central.[9] Some of the multi-terms that refer to these technologies are connected to the multi-term ’smart grid', which is evidence that SGCC's ultimate goal became the development of a smart grid[10] based on AI (Lin et al., 2013). While many countries were working on such a project, none had achieved a frontrunner advantage when, in 2009, SGCC officially launched its R&D project to complete a smart grid by 2020. This initiative included the establishment of the Smart Grid Research Institute, which in addition to its Chinese facilities, has branches in California and Berlin.[11]

SGCC has become a global leader in AI applications for the energy sector. In WIPO's 'Tech Trends 2019: Artificial Intelligence' report, it is the only Chinese company in the top 20 patenting organizations (World Intellectual Property Organization, 2019). According to interviews with experts, three reasons explain the recent rapid increase in SGCC's AI research and patenting, all related to SGCC's capacity to harvest and analyze data: 1) big data gathered from grid operations 2) SGCC big data include full life-cycle data on its massive assets, and rich user and operations data for various regions and across time, and 3) "SGCC has a clearly defined project management system, and its AI projects are managed with strict quantitative evaluation indicators" (China Institute for Science and Technology Policy at Tsinghua University, 2018, p. 29). In a similar vein, an article published on the Chinese website Aibizweek.com in 2019 stated that among the four main requirements of AI (algorithms, computing power, data, and application scenarios), SGCC had advantages in data and application scenarios. The article goes on to explain that SGCC is applying AI technology to power grid control, power distribution networks, intelligent distribution transformers, renewable energy and inspection robots, all of which are used in its smart grid which is supposed to be a ’ubiquitously powered internet of things' capable of reducing blackouts, automatic identification of breakdowns, and provision of plans to handle them.[12]

SGCC's smart grid developments are aligned with the Chinese government's aims. Lin et al. (2013) identified 57 innovation policy tools aimed at the development of a smart grid, 26% were related to SOEs, followed by policies for scientific and technical development which also frequently involved SGCC (23%).

Another of the clusters in Figure 2 linked to the cluster that includes the term 'smart grid' focuses on robotics and research into areas beyond power distribution such as microbiology and crystallography. SGCC is also prioritizing carbon emission reductions and the development of new forms of clean energy.

[9] Based on numbers of patent applications, China is the leader in AI; it overtook the US in 2015 and has increased its lead since, with more than 1,000 patent applications in 2017 compared to just over 400 for the US (China Clarivate Analytics, 2018).

[10] "By definition, a smart grid is a digitally enabled electrical grid that gathers, distributes, and acts on information about the behavior of all energy or power suppliers and consumers in order to improve the efficiency, importance, reliability, economics, and sustainability of electricity services" (Lin et al., 2013, p. 120).

[11] Retrieved from https://www.geirina.net/ and http://www.geiri-eu.com/ last accessed, 10 September, 2019.

[12] Retrieved from https://zhuanlan.zhihu.com/p/79702863 last accessed, 28 February, 2020.

Figure 2 plots a cluster dedicated to these topics at large and another cluster, detached from the former, where wind power occupies a central position.

Overall, among SGCC's research focus, AI to enable clean energy stands out. This is in line with SGCC's patenting activity which shows its global leadership in AI applications for energy management (World Intellectual Property Organization, 2019). A special report on AI, conducted by Tsinghua University, notes that the energy systems have been a neglected area of AI application that, through SGCC's lead, is being fulfilled (China Institute for Science and Technology Policy at Tsinghua University, 2018). SGCC is not only patenting but also publishing on these topics (see Figure 2), which highlights its in-house scientific capabilities. In this respect, SGCC shows some similarities with Huawei in that both companies are global leaders in complex product systems where the STI learning mode is paramount. This is a central reason why it is relevant to study -as we do here- its STI outcomes, such as Joo et al. (2016) did for Huawei.

Moreover, our results are in line with SGCC's view of the electrical power industry as 'going through a period of emerging technical innovations' and, according to SGCC's chairman, the company is a 'cutting edge global research organization in areas such as ultra-high voltage DC transfer, Smart Grid, large scale renewable energy integration, and electric vehicle charging networks'.[13] Although Figure 2 does not include the multi-term 'electric vehicle', according to Ree and Kim (2019), SGCC is leading the race in this R&D area, with 14 patent applications related to electric charging technologies.

Summing up, SGCC's technological diversification, exemplified by its expanded technology base (Granstrand, 2000) as shown in Figure 2, has been crucial to its emergence as an intellectual monopoly. Bysucceeding in innovation in multiple fields, SGCC augments potential intellectual rents and increases its intellectual monopoly power.

5.2. SGCC's innovation networks proxied by its scientific publications' co-authorship network

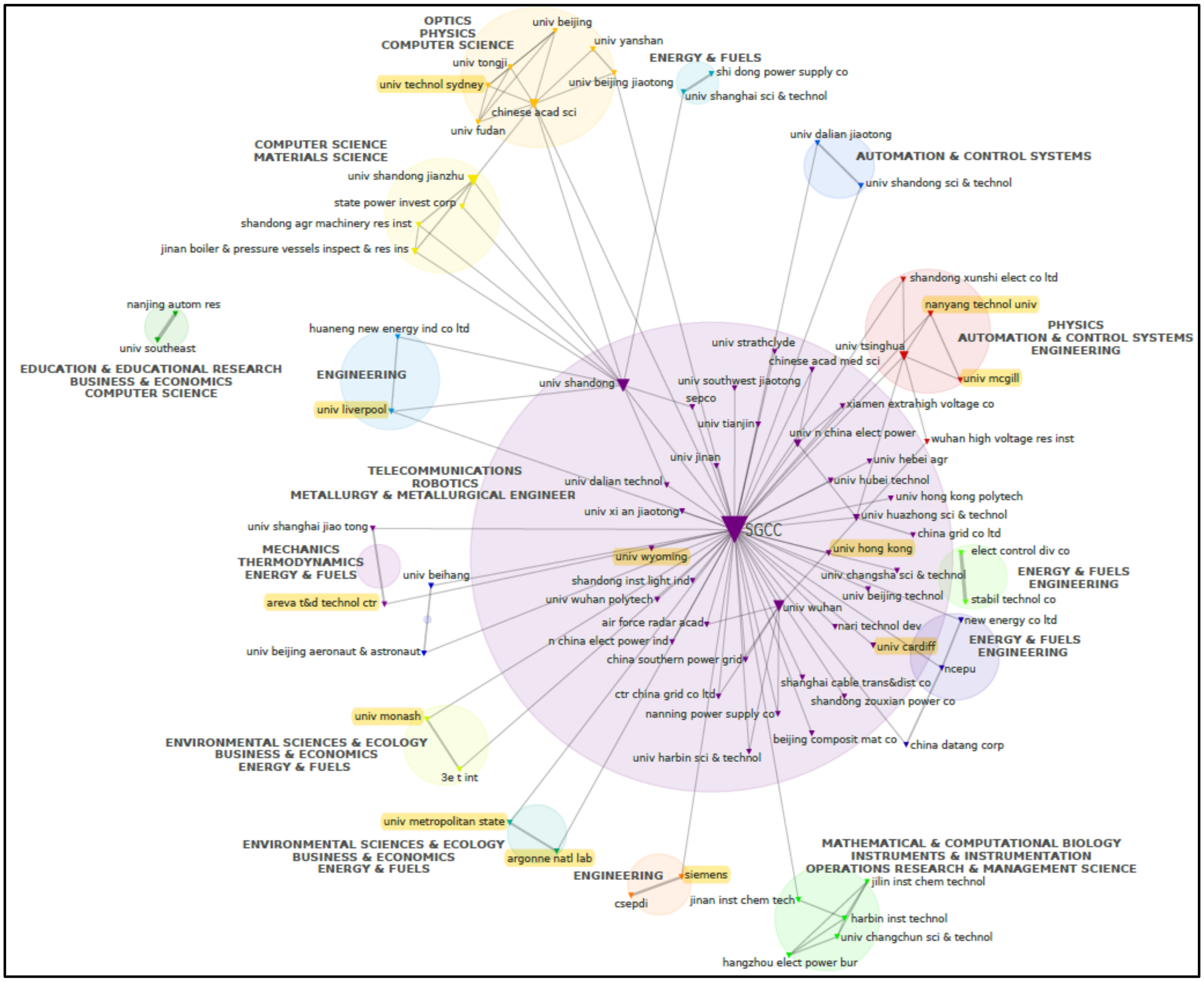
Being an intellectual monopoly also entails the organization of innovation networks, capturing associated rents. We consider SGCC's publications network to be a reasonable proxy for its innovation networks. In sub-section 5.3, we compare SGCC's expanding innovation networks to its patent co-ownership, suggesting that it is mostly SGCC that profits from the innovations produced in these networks. This result is in line with hypothesis 1 that the SGCC is an intellectual monopoly. Moreover, our innovation networks' proxy will allow us to test our second hypothesis (that SGCC is a national intellectual monopoly showing signs of transnational/global expansion). While SGCC's innovation networks initially relied mostly on local actors (Figure 3), they are now clearly expanding beyond China (Figure 4).

As discussed in Section 2.4, there are two main differences between national ($t_{1.5}$) and global intellectual monopolies (t_2). First, national intellectual monopolies rely mostly on R&D capabilities and geographically, culturally and politically close institutions, while global intellectual monopolies organize transnational innovation networks. Second, while national intellectual monopolies mainly compete over technology with established transnational or global intellectual monopolies, global intellectual monopolies also

[13] Retrieved from https://www.iec.ch/globalvisions/SGCC/ last accessed 4 August, 2019.

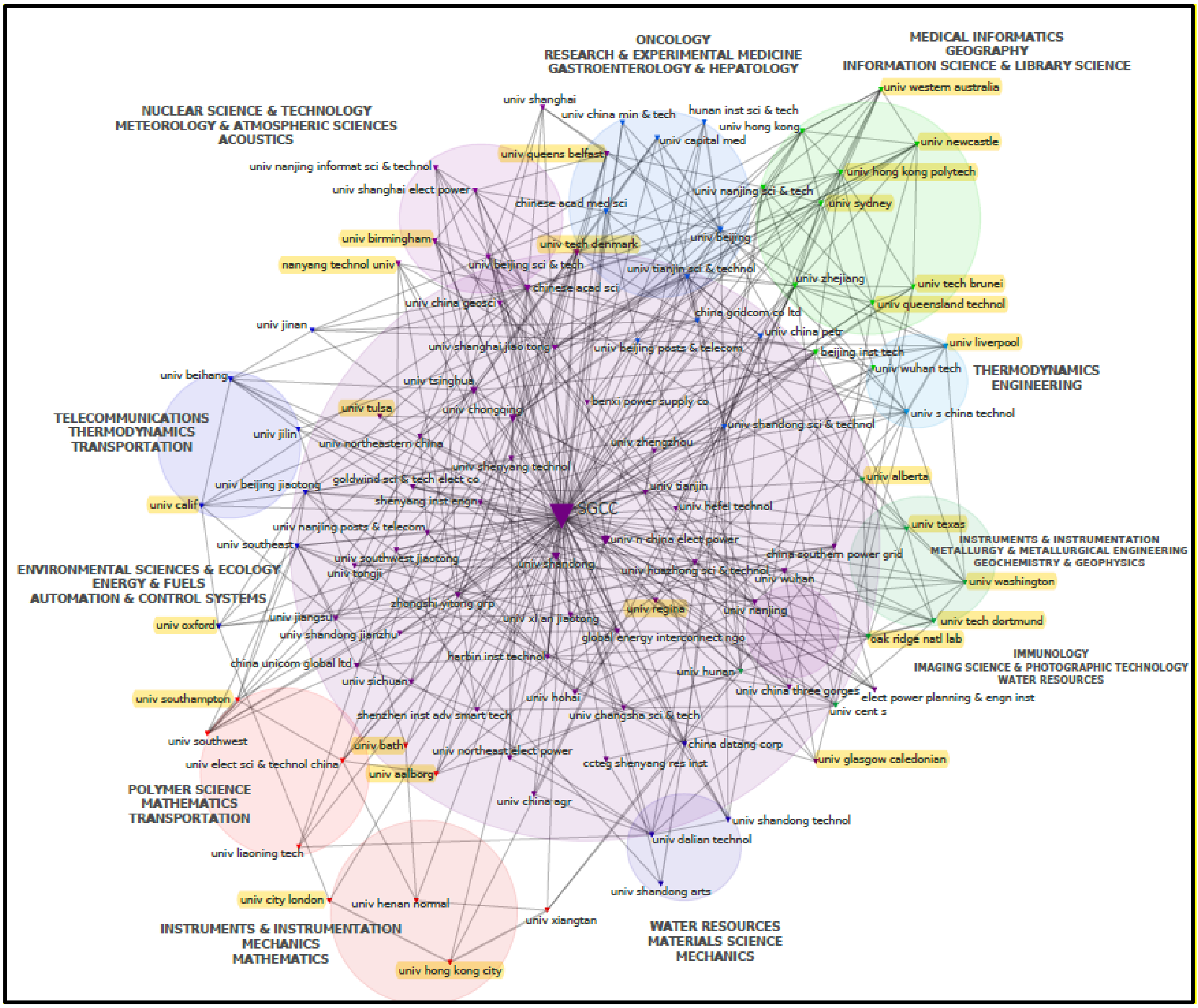
cooperate over technology and share the resulting intellectual property. If SGCC is transitioning from being a national to becoming a transnational or global intellectual monopoly, we should see signs of global networks rather than mostly local or national innovation networks and we should be able to identify technological collaborations with other intellectual monopolies in the second period.

Figure 3. SGCC's co-publications network(2003-2010)



Source: Author's analysis based on data extracted from the Web of Science.

Figure 4. SGCC's co-publications network (2011-2018)



Source: Author's analysis based on data extracted from the Web of Science.

In terms of the first difference, a comparison between Figures 3 and 4 points to a transition from mostly national to more transnational innovation networks. In the first period (2003-2010), SGCC was connected to 12 foreign institutions; 2 multinational corporations (Siemens and Areva) and 10 universities. These 12 organizations came from seven different countries and represented 16% of SGCC's partners. In the second period (2011-2018), the number of top foreign institutions increased to 26 (117% increase), all universities from 10 different countries. These results show that, over time, SGCC has been extending its innovation networks beyond China, to both nearby and core western countries.

In both periods, there were some other institutions in central positions, connecting the network. The Chinese Academy of Science connects its cluster with that of SGCC and other (mainly) national clusters. Shandong University has also been a key partner for SGCC in a twofold way: co-authoring 8.6% of SGCC's publications, and as a bridging institution, among others connecting SGCC to two clusters with foreign institutions in each period. As explained by Choi et al. (2011, p. 768), '(b)ridging organizations promote new connections to catalyze information flows and to create innovation opportunities'. These links are probably responsible for the significant increase in foreign co-authors. During the second period, even some foreign universities became bridging institutions. The Technical University of Dortmund connected SGCC with Oak Ridge National Laboratory, the University of Texas, and Washington University, albeit being only SGCC's 83rd co-author in frequency in this period.

In network analysis, bridges act as mediators between otherwise indirect links. In our case, indirect links between SGCC and other organizations, which implies that SGCC's co-authored publications include both the third organization and the bridging organization and, also, that SGCC has other publications co-authored with the bridging organization. Bridging organizations are particularly relevant if they connect the SGCC's main cluster to other clusters that include foreign organizations; thus contributing to SGCC's expansion and transition from a national to a transnational intellectual monopoly. An example is Zhejiang University in Figure 4.

One of the most obvious differences between periods is the total number of co-authors, which rose from 79 to 864. Some of this increase is related to the general increase in SGCC's R&D activities, as reflected in its publications' growth (see Figure 1 in section 3). However, it is due, also, to the expansion of SGCC's innovation networks increasingly beyond China's national innovation system.

Additionally, between 2011 and 2018, there is no single institution co-authoring more than 8.5% of SGCC's papers, whereas in the first period its two main partners -Shandong University and Wuhan University- co-authored 14.8% and 13.9%, respectively. This happened albeit SGCC's 10-fold increase in publications' frequency with each of them. Depending less on a few institutions is a sign of the extension of SGCC's innovation networks both within and beyond China. This greater independence contributes to reducing the influence wielded by a single partner over the content and distribution of profits from SGCC's research projects.

Chinese public policies and funding have also influenced SGCC's transition from a national to a transnational intellectual monopoly. Among them, in 2009, China's central government launched the Technological Innovation Project, which incentivized strategic alliances and technological cooperation with universities and other research institutions (Yi-chong, 2017, chap. 7). SGCC's publications record is also evidence of strong state support. During the whole period, the SGCC's most frequently declared funding source was the National Natural Science Foundation of China (funding 30% of its publications), , and 7% acknowledge funding from China's National Key Technology Research and Development Program. A few publications acknowledge support from the National Program for Science and Technology '863' (5%) and the National Basic Research Program of China '973' (4%). SGCC's heavy dependence on public funds suggests that it has not completed the transition to a global intellectual monopoly.

Based on the model presented in section 2.4, when comparing between periods, we consider SGCC's links with other possible intellectual monopolies. Figure 3 includes Siemens and Areva. However, based on the content of their joint publications, we could verify that they refer to general power supply aspects, not related to SGCC's main innovations which enabled its rise as an intellectual monopoly. In the second period, neither of these companies was an important partner (Areva was not involved in any co-authorships) (see Figure 4). This suggests that SGCC is not engaged in institutionalized technological cooperation with these companies and collaborated with them for projects unrelated to the technologies that led to its intellectual monopoly.

Interviewed SGCC engineers and other experts explained that Siemens and Areva provided technical assistance in the corporation's early days (Yi-chong, 2017, chap. 7, 2012, chap. 6). These interviewees also explained that, initially, SGCC had contacted several multinationals, including Siemens and Areva, to develop core new technologies for UHV lines. However, all of these companies wanted to retain the resulting intellectual property rights, leading to SGCC's decision to innovate without them, which it managed within two years (Yi-chong, 2017, chap. 7). This experience could be seen as exemplifying SGCC's reluctance to collaborate with already established intellectual monopolies that did not consider SGCC an equal partner. From the standpoint of companies like Siemens -which could be considered a transnational intellectual monopoly- this was reasonable because by then SGCC was far from being an intellectual monopoly. By rejecting Siemens and other multinationals' offers, SGCC won the chance to become itself an intellectual monopoly.

All in all, SGCC is moving towards more transnational innovation networks but still relies on its NIS for joint R&D with universities and financial support from the state. Comparison with other intellectual monopolies shows that it needs to make more efforts to achieve transnational intellectual monopoly status. For instance, fewer than 5% of Roche's and Novartis's top 150 co-authors are located in Switzerland, while around 50% of Pfizer's top 150 co-authors are based in the US (Rikap, 2019). Compared to these companies, the SGCC's innovation networks are only marginally transnational and, considering China's specificities, may never include as many global partners.

5.3. SGCC's patent portfolio

To test our first hypothesis, that SGCC is an intellectual monopoly, we compare SGCC's co-publication shares and networks (described in the above section) with its share of co-patenting to account for SGCC's capacity to capture intellectual rents from its innovation networks. We follow the method used by Rikap and Lundvall (2020) who investigated this aspect for global intellectual monopolies in the digital industries. To provide further evidence to our second hypothesis, we analyze the degree of transnationalization of SGCC's intellectual monopoly by considering the level of internationalization of its patent portfolio.

Previous research shows that SGCC's innovation strategy relied heavily on public universities (Yi-chong, 2017, chap. 7), but our results show evidence of those collaborations only at the level of publications. Our results suggest that SGCC captures intellectual rents from its innovation networks, in particular from public universities and other PROs, as shown by the comparison between its vast and dense co-publications' network (Figures 3 and 4) and the small share of patents co-owned with other actors (Table 2).[14] For instance, the North China Electric Power University co-authored 8.5% of SGCC's papers but is an applicant on only 1.5% of SGCC's patents. This university is SGCC's most frequent patent co-owner, followed by

[14] Given that SGCC refused to resign from the property of innovative results from projects with multinationals, it is likely that this also applies to collaborations with less powerful organizations, which makes unlikely that some other organization will own the exclusive rights to the intellectual property related to SGCC's other innovations.

companies and other universities sharing less than 0.5% of SGCC's patent portfolio. Among SGCC published papers, 78.5% have at least one co-author organization, but only 21.4% of its applied and granted patents are co-owned with other organizations.

These results are in line with Yi-chong's (2017, chap. 7) findings, based on interviews with university researchers that collaborated with SGCC. The interviewees claimed that SGCC requires universities and other research institutions to sign a 'one-size fits all' adhesion contract which assigns all potential patent rights to SGCC. Some of the interviewed university researchers complained that SGCC exploited universities' need for funding to set unfair conditions.

Table 2. Top co-owners on SGCC's applied and granted patents.

Entity	Distinct Patents	Share in SGCC's patents	Share in SGCC's publications	Type of organization
North China Electric Power University	1792	1,5%	8.5%	University
Sanchuan Electric co ltd	442	0,4%	-	Chinese corporation
Tsinghua University	417	0,3%	6.84%	University
Xi'an Jiaotong University	327	0,3%	3.85%	University
Southeast University	320	0,3%	1.83%	University
Shanghai Jiaotong University	288	0,2%	1.83%	University
China Electric Power Eng Consulting	280	0,2%	-	Chinese corporation
Wuhan University	268	0,2%	4.55%	University
Zhengzhou Huali it co ltd	255	0,2%	-	Chinese corporation
Chongqing University	234	0,2%	5.43%	University
Hohai University	210	0,2%	1.12%	University
Beijing Guodiantong Network Tech co	210	0,2%	-	Chinese corporation
Huazhong Science Tech University	175	0,1%	3.31%	University
Lin Xiaoming	154	0,1%	-	Individual
Lin Shuyan	154	0,1%	-	Individual
Northeast Dianli University	152	0,1%	1.02%	University
Hon Hai Prec Ind Co Ltd	112	0,1%	-	Foreign corporation

Source: Author's analysis based on Derwent Innovation data.

Our patent analysis allows further examination of SGCC's strategy concerning foreign collaborators, which is an indication of the extent of its intellectual monopoly. Almost all SGCC's applied or granted patents are owned by Chinese actors, followed by 0.11% owned by Taiwanese players (see Table 3). Taiwan's share is almost exclusively explained by patents co-owned with Hon Hai Precision Industry (Foxconn), the giant Taiwanese electronics manufacturer, which is based in China (see Table 2). Hence, while SGCC is enlarging its innovation networks beyond China (see Figures 3 and 4), inventions (and their potential intellectual rents) are owned mainly by SGCC and, in a relatively few cases, other Chinese organizations. Arizona State University is the first foreign university to share patents with SGCC, and it only shares 4 applied or granted patents. Thus, although there is increasing participation of foreign actors in SGCC's innovation networks, they mostly do not benefit from potential intellectual rents. Besides the countries shown in Table 3, 27 other countries have co-authored with SGCC without sharing any applied or granted patent. They range goes from Australia, which co-authored 1.6% (67) of SGCC's publications, to Greece with only 1 co-authored publication.

Table 3. Origin of patent assignees (either people or institutions)[15]

Country	Number of distinct patents	Share in total SGCC's patents	Share of the country in total SGCC's publications
China	122169	100%	100%
Taiwan	136	0.1113%	Not differentiated from China in the data base
United States	13	0.0106%	4.2%
Germany	8	0.0065%	0.6%
Hong Kong	5	0.0041%	Not differentiated from China in the database
Japan	3	0.0025%	0.6%
United Kingdom	2	0.0016%	3.6%
Singapore	1	0.0008%	0.3%
Bulgaria	1	0.0008%	0%

Source: Author's analysis based on data extracted from Derwent Innovation and the Web of Science.

Furthermore, SGCC's patent portfolio provides insights on the internationalization of its intellectual monopoly. Regardless of its role in setting international standards (see section 2.2) and the increase of foreign actors in its innovation networks, almost all its applied and granted patents (99%) correspond to the China National Intellectual Property Administration. This patent office is now recognized worldwide, but, generally, transnational intellectual monopolies apply to several international patent offices, which is a sign of the higher quality of their innovations.

Finally, there is a question related to SGCC's capacity to effectively appropriate economic returns from innovations. It has long been known that value extraction from innovation is difficult to measure (Harabi, 1995). There are no available data on SGCC's appropriability, but China's statistical yearbook includes science and technology indicators by registration status, which allows us to compare SOEs with other types of firms. Considering that for the last seven years SGCC has ranked first among SOEs in patent ownership and invention[16], we can assume that the figures for SOEs are aligned with those of SGCC. Table 4 compares expenditure on new product development with revenue from sales of new products by firms' registration status for medium and large-sized firms for 2018. Compared to other types of firms, SOEs profit the most from expenditure on new products; their revenue from sales of new products is over 15 times higher than investment in new product development. We also compared 2018 figures with those of previous years and results hold, SOEs profit more than different types of private sector firms from their expenditure on

[15] 482 patents included "undefined" among its assignees' countries of origin.
[16] Retrieved from http://www.sgcc.com.cn/html/sgcc_main_en/col2017112700/column_2017112700_1.shtml last accessed January 4, 2021.

new products. This points to the capacity of SOEs to profit from innovation and we can assume that this applies, also, to SGCC given its leading innovator role among SOEs in China.

Table 4. Expenditure and revenues related to the development of new products by Chinese-based firms (2018)

Type of firm by registration status	Expenditure on new products development (10 000 yuan)	Sales revenues of new products (10 000 yuan)	Share of sales of new products in total expenditure on new products
Total	**149872196**	**1970940694**	**13.15**
State-owned enterprises	841252	12834758	15.26
Limited liability corporations	48431587	573408674	11.84
Shareholding corporations	21885257	300572095	13.73
Private enterprises	45017359	547795829	12.17

Source: Author's analysis based on China statistical yearbook 2019 data.

Overall, patent analysis shows that foreign co-owners are marginal and that local co-owners are relatively less important than actual collaborations, based on scientific publications' co-authorships. Furthermore, considering SOEs' greater capacity to profit from innovation *vis-à-vis* other types of Chinese-based firms, our findings point to SGCC profiting from its innovations. Therefore, SGCC can be considered an intellectual monopoly that mostly exclusively profits from the knowledge developed in its innovation networks, which supports hypothesis 1. Our analysis also suggests that SGCC is a national intellectual monopoly with the potential to become a transnational intellectual monopoly, hence between t1.5 and t2 in the model in section 2.4 and in line with hypothesis 2.

5.4. SGCC's market and business results

Finally, we are interested in whether the establishment of the SGCC's intellectual monopoly and the start of its upgrading to a transnational intellectual monopoly coincided with similar market and business expansions. As already mentioned, SGCC is the world's biggest utility company in terms of revenue; between 2002 and 2018, it moved from 60^{th} to 2^{nd} place for revenue in the Fortune Global 500 ranking. The size and recent growth experienced by China is not the only explanation for SGCC's economic growth. The available data suggest that the SGCC is globalizing both its intellectual monopoly and its business.

According to Standard & Poor (2019), SGCC is the world's largest regulated utility company measured by assets and revenue. The report identifies SGCC as outstanding for financial metrics vis-à-vis most of its peers. A particularly distinctive feature is its strong cash generation ability, which is explained partly by the injection of government capital for China's rural network and partly, and relevant to our study, government funding for technology innovation.

SGCC serves 88% of China's territory and, in 2018, owned USD 65.5 billion in overseas assets (SGCC, 2018). As SGCC was developing its intellectual monopoly and expanding beyond national borders, it has steadily increased its overseas business. SGCC's total overseas investment was USD 1.9 billion in 2005, USD 8.2 billion in 2007 and USD 21 billion in 2018 (a 990% increase compared to 2005) (SGCC, 2018, 2007).

SGCC has expanded globally despite international scrutiny of China's global expansion, fueled by conflict with the US, and a slowdown in expansion in Western countries including failure to buy stakes in European electricity companies.[17] In 2020, SGCC had offices and/or subsidiaries in more than 20 countries and its power transmission and transformation business had reached nearly 40 countries in Asia, Africa and Latin America. SGCC exports equipment to more than 100 countries.[18] Also in 2020, SGCC was investing in and operating energy networks in nine overseas locations.[19] Its overseas business also includes greenfield power transmission projects in Brazil and Pakistan and it has plans to export wind and thermal power to Germany, India, Pakistan, and Myanmar using China's Belt and Road Initiative.[20] In terms of its global business expansion, SGCC has been active in building transnational transmission lines with proximate countries, including Russia, Mongolia, and Kyrgyzstan, and is currently working on similar projects for China-Nepal and China-Korea.[21]

Interestingly, SGCC's global business is based in countries that do not necessarily coincide with the home countries of the foreign organizations participating in its innovation networks. For instance, the US, the UK, and Denmark are relevant when it comes to the latter (see Figure 4) but do not host SGCC businesses. In other cases, SGCC's foreign direct investment strategy has contributed to the expansion of foreign R&D partnerships. When SGCC purchases companies that already have institutionalized collaborations with local universities, SGCC inherits those links. For instance, SGCC bought a controlling stake in CPFL Energia, Brazil's largest power distributor, inheriting its established R&D cooperation with the University of Campinas.[22]

6. Discussion

The main argument in this paper is that SGCC has become a national intellectual monopoly with the potential to become a global intellectual monopoly based mostly on China's NIS instead of technology transfer from forerunners. Comparing this case with the experience of other national champions highlights the empirical contribution of this paper.

SGCC's smart grid is an example of a Complex Product System (CoPS) (Hobday, 1998). CoPS were defined as 'high cost, engineering and software intensive products, systems, capital goods, networks and constructs, produced in projects or small batches' (Hobday and Rush, 1999, p. 618) and, historically, have

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[17] Retrieved from https://www.economist.com/briefing/2020/09/17/americas-domination-of-oil-and-gas-will-not-cow-china last accessed 10 January, 2021.

[18] Retrieved from http://www.sgcc.com.cn/html/sgcc_main_en/col2017112821/column_2017112821_1.shtml?childColumnId=2017112821 last accessed 5 January, 2021.

[19] Retrieved from http://www.sgcc.com.cn/html/sgcc_main_en/col2017112817/column_2017112817_1.shtml last accessed 5 January, 2021.

[20] Retrieved from https://www.ft.com/content/68cdef50-f66a-11e5-803c-d27c7117d132 last accessed 10 August, 2019.

[21] Retrieved from http://www.sgcc.com.cn/html/sgcc_main_en/col2017112826/column_2017112826_1.shtml

[22] Retrieved from http://www.saopaulo.sp.gov.br/ultimas-noticias/comitiva-chinesa-visita-unicamp-para-estreitar-parcerias-em-pesquisas/ last accessed 10 March, 2020

been an area of key competitive advantage of developed countries, where not even emerging East Asian economies (including China) were catching-up (Davies, 1997; Ren and Yeo, 2006). However, several recent studies consider catch-up by firms in developing countries.

A frequently studied case is Huawei's catch-up in telecommunication networks (Fan, 2011; Guo et al., 2019; Hawes and Chew, 2011; Joo et al., 2016; Li et al., 2019; Li and Cheong, 2017; Wen, 2017). Huawei's catch-up is particular in that it only initially relied on a forerunner (Ericsson) as its knowledge source. It then developed and relied mostly on its internal R&D capabilities and leapfrogged to become the global leader (Joo et al., 2016).

Other considered cases include Lee, J. & Yoon (2015), who studied military aircraft development by three SOEs: Embraer from Brazil, Korea Aerospace Industries, and Aviation Industry Corporation of China. The authors found that foreign forerunner partners influenced technology acquisition in different ways.

The catch-up literature also includes cases from the energy industries. Gosens and Lu (2013) analyze catch-up by China's technology innovation system in turbine manufacturing for wind power. Binz et al. (2017) also studied wind turbines in China, but in a comparative study of solar panels and biomass power plants. They evaluated the different policy mixes and catching-up specificities according to differences in these technologies' lifecycles.

In the case of emerging economies, Kwak and Yoon (2020) conducted a longitudinal analysis of South Korea's catching-up in nuclear power. The authors show that its success relied on the endogenization of an exogenous window of opportunity following nuclear accidents, which harmed the forerunner's legitimacy.

Common to all these cases is that the interaction with foreign forerunners was a determinant of local firms' catching up. Even in the case of Huawei, technology transfer initially played a role. In other words, technology transfer or co-development of technology with forerunners would seem to be a prerequisite for the development of indigenous capabilities. Access to foreign (advanced) knowledge is a common feature of all the successful cases of catch-up in Malerba and Nelson (2011). They study multiple cases from six different sectors and found that lack of access to foreign know-how coincided with failed catch-up. Similarly, a review of the literature on latecomer catch-up in CoPS shows that successful cases relied on technology transfer from lead firms (Park and Ji, 2020).

What is unique about SGCC is that it had no forerunner firm on which to rely for technology transfer, but still emerged as an intellectual monopoly ranked 1st for patenting in AI for energy applications. It could not rely on technology transfer because there was no forerunner in the technologies it committed to master. Figure A.1 in the appendix depicts the patent portfolio of the other major world utility companies; they are not intellectual monopolies and comparison with the SGCC's patent portfolio highlights the impressive evolution of the Chinese corporation. The most striking feature of the SGCC's development is the decision to cut any ties to and reject partnerships with multinationals in its bid to become an intellectual monopoly and focus on developing and patenting new core technologies.

However, the SGCC's experience and the experience of the other cases analyzed in this section have something in common. As two literature reviews on catching-up in CoPS show, the role of the state stands out (Park and Ji, 2020; Safdari Ranjbar et al., 2018). Furthermore, our results are in line with Liu et al. (2016) who found that the Chinese state preferred SOEs for large R&D projects. In 2013, SOEs received over 20% of government R&D funds, with private funding accounting for only 10.9% of their total expenditure on R&D. The funding sources acknowledged in SGCC's publications are evidence of strong state support for R&D.

Finally, in terms of university-industry linkages, our results differ from those in Gosens and Lu's (2013) study of wind power turbines and Ernst's (2020) findings for AI R&D, but are similar to the finding for the case of China in Lee, J. and Yoon (2015) who studied military aircraft in Brazil and found that PROs were crucial for Embraer's technological catching-up. Chinese PROs seem to be similarly vital in SGCC's innovation networks. This is particularly the case of bridging institutions (see section 5.2).

To sum up, SGCC's success is distinguished by its lack of reliance on technology transfer and reverse engineering from forerunners to develop the technologies that are the foundation of its intellectual monopoly. This paper reinforces the relevance of the NIS in explaining the emergence of a (global) intellectual monopoly because SGCC's success relied, at least in part, on China's NIS, especially, on the R&D capabilities of PROs and on public policies including direct R&D funding.

7. Final Remarks

We have argued that the windows of opportunity for catching-up and leapfrogging are narrowing due to the emergence of intellectual monopoly capitalism. In this context, technology transfer and reverse engineering are curtailed, so latecomers need to find alternative strategies to overcome technological and market subordination. Our main theoretical contribution was to explain that catching-up under intellectual monopoly capitalism implies the establishment of intellectual monopolies and, to that end, national (and sectoral) innovation systems play a central role. We suggested that between a firm's attempt to become a global intellectual monopoly and its eventual success, there is a stage where it becomes a national intellectual monopoly. As such, the company profits mostly from its home state's R&D funding, benefits from home country policies and reaps intellectual rents from its national innovation networks.

The empirical contribution of this paper was to mobilize this framework to analyze SGCC's experience. Since its intellectual monopoly is based strongly on STI learning, we scrutinized its publications and patent portfolio to provide evidence of SGCC as an intellectual monopoly and identify its stage of development. We found that SGCC indigenously became the global leader in AI applications for the energy sector. Its intellectual monopoly focuses on clean and smart energy, both patenting and developing underlying science and technology. We showed that SGCC's case is unique compared to past examples of national champions from developing or emerging countries whose catch-up relied on technology transfers from technology forerunners.

SGCC is continuing to develop its intellectual monopoly by organizing innovation networks with other organizations, mostly PROs and universities. In line with the intellectual monopoly framework, we showed that it appropriates most of the resulting innovations. Over time, these networks (and SGCC's business) have become more transnational but were originally mostly integrated by Chinese institutions. This is evidence of a transition from a mostly national towards a global intellectual monopoly. However, SGCC still relies mainly on the Chinese state funding for R&D and national policies which privilege its activities; also, 99% of its patents are registered at the Chinese patent office. All these factors suggest an incomplete transition to a global intellectual monopoly.

This case also suggests that if a firm (or a group of firms) becomes an intellectual monopoly, this individual success will not necessarily trickle down to its country of origin on an equal basis. SGCC collects intellectual rents from its interactions with Chinese universities and smaller firms but seldom shares the resulting intellectual property. Although the empirical evidence in this paper needs to be complemented by qualitative studies and gathering empirical data on patent licensing and internal use of SGCC's patented inventions, our results suggest intellectual rent predation. The emergence of such leaders increases firms' heterogeneity, deepening capital's technological differentiation and, thus, polarization even if SGCC has privileged local suppliers (Yi-chong, 2017, chap. 7), potentially contributing to developing technical capabilities in these companies. At the geopolitical level, SGCC seems to be playing a key role in China's capital accumulation.

More generally, our study and findings open a discussion on the role of the state in fostering the emergence of intellectual monopolies. While these intellectual monopolies are seen as national champions, their knowledge monopoly limits the other (local and foreign) firms' catching-up.

All in all, this paper has contributed to acknowledging that intellectual monopolies' inception is a process where geographical, political, and cultural proximity as well as public policies encouraging national innovation systems, in particular sectoral innovation systems, contribute to establishing national intellectual monopolies from which it is possible to embark on a transnationalization strategy. Additionally, as the SGCC's case shows, becoming an intellectual monopoly requires huge R&D investment, which, in this case, were covered, at least in part, by the Chinese state. All in all, we have advanced the debate on the complementarities between two apparently contradictory explanations of innovation dynamics, that is, those focused on the systems within a country (NIS) or a localized environment and global innovation networks, which highlight the transnational and hierarchized features of the innovation process.

Future research should further elaborate on appropriability measures for intellectual monopolies from China and other countries. This research would extend our knowledge on the effects of intellectual monopolies' appropriation of intellectual rents.

Concerning SGCC, a limitation of this study is that we did not complement the quantitative analyses with qualitative methodological instruments. However, this shortcoming was offset, in part, by previous work involving interviews with SGCC experts and university researchers who collaborated with SGCC (China Institute for Science and Technology Policy at Tsinghua University, 2018; Yi-chong, 2017). Moreover, our focus on STI outcomes -in the same vein as Joo et al. (2016) -, also involved a novel methodology to examine catching up processes that could shed further light on other cases.

To conclude, this study leaves some open questions that delineate a long-term research agenda. First, the overall specificities of China's catching up compared, for instance, to those of Japan and Korea. China is catching-up under intellectual monopoly capitalism, which means that access to foreign knowledge is limited. The absence of a global leader to catch-up with could be an advantage. In our case, there was no global intellectual monopoly to hamper the SGCC's indigenous innovation efforts. Second, the dynamics between (global) intellectual monopolies and their home states could be conceptualized as part of the interplay among corporate and political powers. Our findings also suggest that more work is needed on the consequences of the spread of (global) innovation networks, led by intellectual monopolies, for other organizations that lose most of those networks' associated rents. The main consequences go beyond limiting these organizations from capturing associated innovation rents; at the society level, intellectual monopolies could be hampering innovation.

8. References

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Appendix

Table A.1. Applied and granted patents of major utility companies in market capitalization

Corporation	Grated and applied patents	Granted patents	Industry ranking in market value (May 2019)
Duke energy	27	12	1
Engie (ex GDF Suez)	944	355	2
National Grid (UK)	67	14	3
NextEra	48	21	4
EDF	1 932	756	5
Enel	1 179	536	6
Dominion Resources	150	34	7
Iberdrola	192	77	8

Source: Derwent innovation