International Business Review 32 (2023) 102140

Contents lists available at ScienceDirect

International Business Review

journal homepage: www.elsevier.com/locate/ibusrev

The Tech Cold War: What can we learn from the most dynamic patent classes?

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ARTICLE INFO

Keywords:
China
US
Catching up
Tech Cold War
Patenting

ABSTRACT

This research assesses key aspects of the Tech Cold War between the World's two largest economies, the US and China. We focused on the patenting performance in four most dynamic patent classes at both the EPO and the USPTO in the period from 2000 to 2019. The data shows that China has had a very fast catching up in terms of patent counts, and was ranked no lower than #5 in all of those patent classes, in both the EPO and the USPTO in 2019. However, an assessment of patent quality shows that a significant gap still remains between the Chinese firms and their counterparts in the US and in other most developed economies. Despite that qualitative disadvantage, the patent data that was analysed also indicates that the quantitative catching up has to a reasonable extent been based on endogenous R&D effort and learning dynamics, a finding which is confirmed by the weak involvement of the major Chinese firms in patent co-ownership networks in the overviewed patent classes. In the now unlikely scenario of no significant changes in the global competitive environment, including in the WTO and TRIPS rules, China becoming the global technological leader before the end of the 2020s would have been a possibility with a reasonable likelihood. However, the political economy of the Tech Cold War has made difficult any linear extrapolation of recent trends.

1. Introduction

China's entry to the World Trade Organisation (WTO) in 2001 was to a large extent envisaged from the West as being a highpoint of *Pax Americana*, which would advance economic globalisation further and foster change in China's domestic governance. Twenty years later, the mood in US-China relationships is quite different. Cooperative wishes, trust,[1] and the perception of common interests have been replaced by policy controversies, mutual allegations of unfairness and reciprocal feelings of increased conflict (The Economist, 2019). A "bifurcated world order" (Petricevic & Teece, 2019), or a "fracturing of the global economy" (Buckley, 2022) appears to be emerging now, as a result of moves made by both sides.

Although volatility, uncertainty, complexity and ambiguity (VUCA) conditions were heightened with the Covid-19 pandemics, the optimistic expectation was that certain common threads on both the economic and the environmental fronts would still hold firm to support cooperation and avoid complete decoupling (Buckley, 2020; Acemoglu, 2021; Grosse, Gamso, & Nelson, 2021). However, the perception that the World has entered a "Tech Cold War" is becoming widespread (The Economist, 2019; Segal, 2020; Tung, Zander, & Fang, 2021). This new type of cold war is grounded on technological rivalry and is driven by the quest to achieve dominance in trend-setting technologies, ranging from semiconductors, artificial intelligence, 5 G telephony and smart cars through to quantum computing, bioscience and blockchain technologies. At the root of this confrontation is a struggle for worldwide dominance (Witt, 2019).

From the perspective of the most developed nations, one expectation behind the creation of the WTO and the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) was that labour-intensive manufacturing activities would continue to be transferred to lower cost locations, while developed countries would retain and trade in higher value-added products and services, boosted by the intellectual property rights (IPR) granted to domestic firms. As information- and knowledge-intensive firms required protection on a global scale, the WTO introduced further harmonisation in international trading conditions, namely in terms of the dominant IPR regime (Athreye, Piscitello, & Shadlen, 2020). These developments paved the way for streamlining

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[1] Though it was mostly a "hyphenated" trust (Williamson, 1993).

https://doi.org/10.1016/j.ibusrev.2023.102140
Received 1 September 2021; Received in revised form 21 March 2023; Accepted 27 March 2023
Available online 11 April 2023
0969-5931/

the ICT-mediated International Value Chains (IVCs)[2] that significantly developed during the first decade of the 21st century.

However, some of the initial expectations of the most developed nations were not fully met, namely as the widespread access to the internet opened new opportunities for data transmission and knowledge sharing processes. Furthermore, the upgrading of the innovative capacity in certain developing countries brought about an increasing erosion of the hegemony previously enjoyed by developed countries firms (Buckley, Strange, Timmer & De Vries, 2020). The most outstanding example of this shift in paradigm was China, whose efforts to catch up enabled it to become a relevant hub in IVCs (Degain, Meng, & Wang, 2017; Mao, Tang, Xiao, & Zhi, 2021). The geographic redistribution of production and advanced technological capabilities have led to a gradual change of the institutional framework of international trade from the free trade, globalising paradigm, to the current emerging techno-nationalisms (Petricevic & Teece, 2019; Luo, 2022; Zhang, Zhao, Kern, Edwards, & Zhang, 2022).

In this context, which has been labelled a Tech Cold War, there is a need to assess what exactly is China's (and Chinese firms') innovative power, how much it has been growing, and how it can foreseeably expand in the near future given the current trends, as well as the degree of involvement of Chinese firms in international cooperation networks. For this purpose, we use patent data regarding the patenting activity in the USPTO and the EPO for the four most dynamic patent classes from 2000 to 2019. Our approach is in line with the observations of Teece (2021) about technological leadership.

In this article we specifically address three research questions, namely: 1) how has the geography of patent ownership (and invention) evolved in those two specific patent offices over the last two decades? 2) how much different is the quality of patents originating from different geographical locations? and, 3) how far are Chinese top-level firms involved in international patent co-ownership networks? The first question will allow to track how fast Chinese firms have been gaining ground in the most dynamic technologies and compare them with US- and other developed countries-based firms, as well as to assess how much Chinese-owned patents rely on foreign inventors. The second question is intended to gauge whether Chinese-originated innovation, which previously has been assumed to be relatively inferior (Petricevic & Teece, 2019; Teece, 2021), is currently of a higher or lower quality than innovation originating in the US and in other developed economies. The third question addresses the need to investigate the level of key Chinese players' participation in international technology networks.

The theoretical framework of this contribution is inspired by a combination of Schumpeterian dynamics of creative destruction with the International Business (IB) literature on innovation by multinational enterprises (MNEs). We draw from the ideas of Cantwell and Santangelo (2000) regarding the increasing multinational dimension of innovative activities and the patterns and challenges of internationalisation in the information age (Alcácer, Cantwell, & Piscitello, 2016). Such a framework acknowledges both the relevance of institutional features and the interaction between domestic and foreign players in shaping new capabilities through co-evolutionary learning processes (Alcácer et al., 2016; Cantwell, Dunning, & Lundan, 2010; Lundan & Cantwell, 2020) within the broader context of the evolution of national systems of innovation (NSI) (Bazavan, 2019; Freeman, 1995; Liu & White, 2001; Lundvall, 1992), sectoral systems of innovation (SSIs), and catching up policies (Lee & Malerba, 2017; Malerba, 2002; Malerba & Nelson, 2011). Such a combination provides the theoretical thread to understand the development and competitive upgrading of firms from emerging countries, especially China (Anand, McDermott, Mudambi, & Narula, 2021; Luo & Tung, 2007 and 2018; Mathews, 2006).

The main contributions of our research to the IB literature, and more specifically regarding the Tech Cold War issue, are four-fold. First, we provide a long-term compared view of performance in the most dynamic patent classes, which are at the core of the Tech Cold War, highlighting an under-researched theme in IB. Second, we show that Chinese patent applicants (and inventors) have been able to engage in a fast technology catching up process, to the degree that by 2019 China was among the main sources of patenting in the most dynamic classes. Third, we found that the performance in terms of patent count is not matched by patent quality, as there is still a considerable gap between the quality of US and Chinese patents. Fourth, the involvement by Chinese players in patent co-ownership networks is still limited, and they do not hold central positions in such networks. In sum, we found that China is catching up fast in key high-tech fields and does not depend considerably on patent co-ownership networks led by foreign firms, although it is still lagging in terms of patent quality.

This article is structured in seven sections, including this introduction. Section 2 analyses the literature on NSIs, SSIs, and the roles played by MNEs, both within and by enabling connections between such systems. It also includes an approach to the cultural foundations underpinning China's catching up, its evolving IPR framework, and a brief assessment of the evolution of Huawei, a key Chinese technological firm. This leads to a set of propositions in Section 3 regarding China's patenting performance in the four selected patent classes. The methodological approach is presented in Section 4. Next, the results of the quantitative analysis of patenting trends and from the qualitative assessment of patents are addressed in Section 5. The main findings are discussed in Section 6. The article closes with the conclusions and the suggestions for further research.

2. Literature review

2.1. The United States, China and international trade

China entry in the WTO was perceived as being a highpoint in the US-led globalisation process (Witt, 2019). According to Athreye et al. (2020), TRIPS, which is part of the WTO founding treaty, was championed by information- and knowledge-intensive industries to enable market expansion along with IPR protection. China's acceptance into the WTO implicitly assumed that Chinese firms would become integrated into business networks led by MNEs based in the most developed countries.

However, as integration through IVCs progressed and was amplified by ICT advancements (Athreye et al., 2020; Degain et al. 2017), the assumption that leading players would keep their positions unchallenged did not hold (Awate, Larsen, & Mudambi, 2015). Chinese firms followed a committed learning path and the institutional and policy framework set up by China strengthened the NSI and promoted investment in research and development (R&D), thus accelerating catching up and the upgrading of technological capabilities in certain key high-tech industries (Bazavan, 2019; Buckley, Strange, Timmer, & de Vries, 2020; Luo & Tung, 2007 and 2018). Such a process was further leveraged by Chinese culture, especially holistic thinking and the capacity to deal with conflicting tensions. The next sub-sections are dedicated to detailing these developments.

2.2. The influence of Chinese culture

China's catching up process cannot be fully understood without taking Chinese cultural traits into consideration. The way the Chinese envisage life and behaviour is holistic, dynamic and dialectical (Fang, 2012). Peng & Nisbett (1999) stressed that Chinese thinking is based on the principles of change, contradiction and relationship, derived from Taoism and Confucianism. This mindset endorses an integrative perspective, which can be described as a "middle way" approach (Chen,

[2] We use International Value Chains instead of the more common label of Global Value Chains, in order to better express the reality, since many value chains operate in a regional or sub-regional context, rather than in a global one (see for instance Verbeke, Coeurderoy, & Matt, 2018, and Verbeke (2020)).

2002), in the search for harmony and the ability to deal with paradoxes and dualities (Fang, 2012; Li, 2016; Stahl & Tung, 2015).

Arguably, these cultural underpinnings enable Chinese managers to adopt a holistic perspective and develop a compositional capability (Redding, 2023). Empirical research confirms such suggestions (Luo & Rui, 2009; Ren, Fan, Huang, & Li, 2021). Based on four case studies, Luo and Rui (2009) show how Chinese MNEs are able to simultaneously attain four dimensions of ambidexterity: co-orientation (balancing short-term survival with long-term growth), co-competence (combining transactional and relational capabilities), co-opetition (simultaneously pursue cooperation and competition), and co-evolution (combining adaptability to environmental conditions and the capacity to influence such conditions). The observations of Faure and Fang (2008: 206) regarding the process of cultural change in China provide a blueprint to understand how technological change has unfolded and how Chinese firms learn: it encompasses the collection of new technological elements, "sedimentation of those elements within the Chinese system, then digestion and finally re-use within the Chinese metabolism".

2.3. National and sectoral systems of innovation, learning processes, and catching up

China's process of technological upgrading *cum* innovation has taken place in the context of a distinctive institutional framework. Institutional conditions, including rules and demands set by the government, have been adapted to drive innovation, combining inward investment and participation in IVCs with domestic firms' strategic intent (Luo & Rui, 2009; Luo & Tung, 2018). Direct and indirect State influence on firms' ownership and foreign linkages have been used to promote R&D commitment and support persistent learning and innovation paths (Boeing, 2016). China's industrial and R&D policies have been instrumental in fostering productivity growth in globally-emerging high-tech industries (Mao et al., 2021). This is consistent with the Schumpeterian view of innovation being a tool to achieve temporary monopolistic advantages under conditions of technological uncertainty (Cantwell & Santangelo, 2000). The recent shift in the Chinese government's role, from direct actor towards being mainly a platform creator, facilitator and strategy-setter (Bazavan, 2019), is in line with the perspective of the emergence of co-evolutionary processes between the country's environment and policies and MNEs' activities and capabilities (Cantwell et al., 2010).

By applying the IDAR (Introducing, Digesting, Absorbing and Reinnovating) model, China was able to attain the leading edge of technology (Cheung, 2014; Buckley, 2020). Chinese players have followed Schumpeterian processes to master and recombine key inputs and products and to also design and develop their own innovations and set up China-led IVCs. Such processes involved acquisitions abroad to access technological, organisational and managerial capabilities, and the capacity to bundle them with in-house local knowledge (Hennart, 2009; Luo & Tung, 2007). Many acquisitions followed a strategic asset-seeking approach (Dunning, 1993) with the objective to get R&D skills, upgrade technological capabilities, and foster innovative advantages (Luo & Tung, 2007, 2018). Although this process was not easy, especially with regards the mastering of certain knowledge-intensive activities (Buckley et al., 2020; Malerba & Nelson, 2011), many Chinese players have climbed up the ladder in terms of technology and innovation (Athreye et al., 2020), with China now offering unique concentrations of highly specialised firms offering expertise and quality along different supply chains (McGee 2023b). From China's WTO entry until the early 2010s, the imbrication between America and China's value chain hubs kept growing, but afterwards the strength of linkages started to wane (Degain et al., 2017; World Bank, 2020). The launch of the Belt and Road Initiative, of 'Made in China 2025' and also of the "dual circulation" strategy can be envisaged as initiatives towards an increasing autonomy of Chinese interests and, ultimately, congruent with a decoupling perspective (Buckley, 2022; Foroohar, 2022a; Herrero, 2021; Shi & Merlo, 2022).[3]

In line with Cantwell and Santangelo (2000), Mao et al. (2021) found that the uncertainties involved in anticipating the direction of technological change opened windows of opportunity for catching up. This seems to be especially true for high-tech industries placed at the technological frontier, where emerging economies such as China are able to benefit from R&D investments unhindered by past trajectories and consequently achieve "rapid technological catch up" (Mao et al., 2021: 14; Zhang, Xu, & Robson, 2022). Nevertheless, different industries present specific requirements for catching up, leading to distinct outcomes. For instance, China has been very successful in the automotive and telecommunication equipment industries, albeit not so much in other industries so far, such as semiconductors (Malerba & Nelson, 2011; Herrero, 2021; Miller, 2022).

2.4. The changing landscape of multinational enterprises and the internationalisation of Chinese business interests

The above-described developments have led to significant changes in worldwide FDI patterns, with China becoming a top source and recipient of FDI. Simultaneously, the global geography of MNEs' headquarters has changed significantly. While in 2000 US firms corresponded to 38% of *Fortune*'s Global 500 and Chinese firms accounted for just 2%, by 2020 this ranking had been reversed, with Chinese firms accounting for 25%, followed by US firms with 24% (Statista, 2021).

These changes in the location pattern of the world's largest firms demand a closer analysis from an IB perspective. By taking a long-term view of those changes, we were able to identify four relevant aspects.

First, there is a systemic nature in the interaction between inward and outward flows. Up until the turn of the century, Chinese policy placed the emphasis on the selective attraction of FDI. The often-compulsory joint-venturing with Chinese partners had a two-way learning effect. It enabled foreign MNEs to become acquainted with Chinese business practices and demand patterns to enter China's markets, yet simultaneously it provided local firms with opportunities to learn about modern technology, marketing and managerial practices (Li & Shenkar, 1997; Luo & Tung, 2007, 2018).

Second, Chinese firms took advantage of their partnerships with foreign players to bundle different types of assets. The acquisition by Lenovo of IBM's personal computers division in 2005 enabled it to combine IBM specific advantages in PC technology and marketing with Lenovo's efficiency, frugality, and low costs (Liu, 2007). This has been an important instrument for Chinese firms to achieve higher technological capabilities and leverage their brand image, while drawing on their local market knowledge and distribution channels (Hennart, 2009 and 2012).

Third, Chinese firms have ventured abroad following a strategic asset-seeking logic (Li, Li, & Shapiro, 2012; Piscitello, Rabellotti, & Scalera, 2015). This was intended to access missing technology, marketing and management resources and skills. The capacity to venture into acquisitions abroad and to combine them with firms' home-country assets is a key element of what Luo & Tung (2007 and, 2018) called "springboard MNEs".

Fourth, Chinese firms' international competitiveness has increased significantly, with Chinese firms venturing abroad and challenging incumbent leaders (Luo & Tung, 2018; Buckley, 2020). The 2007–2009 crisis contributed to leverage this move. Chinese MNEs started to be identified as strategic rivals by the US and other Western countries, Huawei being the most evident case (Zhang et al., 2022).

[3] As we will see below, several important initiatives on the US side in the most recent years also reveal another techno-nationalism (Luo, 2022) in the rising. Those policy initiatives stem from a strong bipartisan agreement on how to restrain the catching up of China and are congruent with the possibility of the decoupling scenario.

2.5. China's IPR governance

In the early 2000s, China was perceived as offering weak IPR protection (Zhao, 2006). However, this changed from the 2000s onwards to the 2010s, as increased IPR protection facilitated China's imports of tech-intensive products (Awokuse & Yin 2010a) and helped to stimulate inward FDI (Awokuse & Yin, 2010b). This was part of broader changes in the country, as "the institutions for the planned economy were mostly rationalised while regulatory institutions in many domains have been established or reconfigured to suit a more market-driven and globally inter-connected economy" (Yang, 2018: 26).

Despite the tightening of IPR rules, China's persisting lack of enthusiasm to meet US IPR demands has been interpreted as a rational response (Peng, Ahlstrom, Carraher, & Shi, 2017). The advantages of such a flexible approach were confirmed by a modelling exercise whose assumption was that optimal IPR enforcement is stage-dependent, concluding that such a dynamic pattern was in line with China's IPR protection policies (Chu, Cozzi, & Galli, 2014). Patent subsidy programmes have been found to significantly contribute to patenting performance (Dang & Motohashi, 2015; Lin, Wu, & Wu, 2021).

The ascendancy of China to become the #1 patenting country since 2011 can be accounted for by the fact that an extensive margin of growth for Chinese firms taking up patents previously existed, together with Chinese firms adapting more strategic IPR practices, as "non-innovation related motives for acquiring patents may have played an important role in the patenting surge" (Hu, Zhang, & Zhao, 2017: 107). It has been questioned whether the fast growth of Chinese patenting will generate proportional economic returns, as China's NSI may still need further development in order to fully internalise those returns (Godinho & Ferreira, 2012).

2.6. Huawei's rise and the new challenges it is facing

The role of Huawei as a leading global innovative firm and patent owner has often been highlighted over the last decade (Godinho & Ferreira, 2013; Kang, 2015; Luo & Rui, 2009). It has benefited from international cooperation and spread to learn and upgrade its capabilities (Chang, Ho, Tsai, Chen, & Wu, 2017; Schaefer, 2020), while espousing a duality perspective and a 'wolf' spirit (Liu, 2015). Huawei gained notoriety as a supplier to the telecommunication systems industry, especially since 2012, when it overtook Ericsson in terms of sales.

Based on patent data, it has been shown that Huawei developed different technologies to those of Ericsson, with a stronger reliance on scientific knowledge (Joo, Oh, & Lee, 2016). Huawei's catching up trajectory towards the global technological frontier was based on building an overall innovation capability ahead of its core innovation capability (Guo, Zhang, Dodgson, & Gann, 2019). The decision to locate multiple R&D centres worldwide testifies to Huawei's quest for learning (Rui & Yip, 2008; Shaefer, 2020). It has been considered to be an ideal case study for the advancement of the theory of routines and dynamic capabilities to change routines (Wu, Murmann, Huang, & Guo, 2020).

However, the US Administration decision to blacklist the firm was a serious blow to Huawei's growth strategy (Congressional Research Service, 2022; The Economist, 2020). Furthermore, US pressure led to decisions not to accept Huawei as 5 G supplier by other Western countries, namely the UK.[4] The US Chips and Science Act, to support US chip firms and "counter China" (The White House, 2022) and the export controls, both enacted in 2022, further restrain trade, licensing, and the employment of Americans by Chinese firms with regards components with supercomputer and semiconductor manufacturing end uses (Department of Commerce, 2022). Huawei's response to such challenges to date appears to be three pronged: 1) spin off its Honor mobile phone division; 2) boost investment in R&D even more; and 3) diversify towards providing technology services to a variety of industries (Financial Times, 2022; The Economist, 2022b). In an internal memo, Ren Zhengfei wrote that Huawei was in a fight for survival (The Economist, 2022b). However, despite being too early to anticipate the consequences of these US decisions on Chinese chipmakers and especially on Huawei's fate, they may indeed even act as a further boost for R&D and technological development by Chinese players (The Economist, 2021; Zhang et al., 2022).

[4] Huawei's "legitimacy defeat" by the UK press is analysed in detail by Zhang et al. (2022).

3. A patent-based perspective of the Tech Cold War: a set of propositions

The recent developments regarding the confrontation between the US and China, and the race for world dominance (Witt, 2019) have led to claims that the world is facing a Tech Cold War (Tung et al., 2021). A little-researched approach to address the issue is the analysis of patenting performance. A longitudinal analysis of patenting will certainly be helpful in providing relevant evidence about the dynamics of China's technological catching-up, as well as the extent to which Chinese firms are challenging their competitors from the most developed countries.

China's catching up has demonstrated a distinctive sectoral pattern (Malerba & Nelson, 2011; Mao et al., 2021), with some fast-growing industries and technologies being distinctively targeted to leverage the process. Accordingly, the focus of this research is centred on four patent classes which have proved to be particularly dynamic along the current century, namely: Computer processing (G06F), Semiconductors (H01L), Digital communication (H04L), and Wireless communication (H04W). These classes correspond to the main grounds on which the Tech Cold War is fought.

Teece (2021) argued that "patent counts are noisy and biased indicators of value and generally should be ignored for business and commercial purposes" (Teece, 2021: 25). However, he recognised that some noise might be eliminated by drawing on forward citation counts, for example. To minimise such noise, we use a battery of different indicators to assess patent quality, as explained in Section 4. In line with the literature on patents (Boeing & Mueller, 2015; Hall, Thoma, & Torrisi, 2007; Song & Li, 2014; Squicciarini, Dernis, & Criscuolo, 2013), the reliance on composite indicators enables one to get an appropriate assessment of patent quality, providing a sound basis for weighing the relative technological capabilities of China and Chinese firms against international benchmarks.

Following this line of reasoning, we submit and empirically address three propositions regarding China's technological performance. The first one is geared to providing a longitudinal picture of the behaviour of top-patenting Chinese firms in terms of both patent ownership and inventive performance, as well as of where they stand in the international context. While recognising the limitations of patent indicators, we consider that by charting the evolution of the geography of patenting it is possible to provide a perspective about two important research issues, from a Tech Cold War perspective, namely: (1) how fast have Chinese firms been emerging and gaining ground in the most dynamic technologies and then compare them with US- and other developed world-based firms; and (2) whether Chinese-owned patents are mostly invented at home or whether Chinese firms are tapping extensively from inventive capacity abroad, drawing from international technology linkages. The following propositions are therefore put forward:

Proposition. 1A: Chinese firms have been gaining increasing importance in the international geography of patent ownership in the most dynamic classes.

Proposition. 1B: Chinese-invented patents have been gaining increasing importance in the international geography of inventiveness in the most dynamic classes.

As argued above, the basic information about patenting performance needs to be combined with a finer-grained analysis that takes into consideration patent quality patterns. Teece (2021) pointed out that in general the quality of patents originated in China lags behind their competitors. Nevertheless, it appears that along this century there has been a significant recovery by Chinese players (Prud'homme, 2014 and 2019), which may lead to question Teece's (2021) position. By the same token, the very concern with the Tech Cold War may be interpreted as suggesting that China is already at the technological forefront in relevant fields. Referring to 5 G technology, Teece (2021: 28) stated that "China is unlikely to be in a global leadership position – at least not yet". These considerations lead us to advance that:

Proposition 2. The quality of patents held by Chinese firms is now similar to that of their most developed countries' competitors in the most dynamic classes.

Adopting the Tech Cold War lens and the related arguments regarding the decoupling of Western and Chinese areas of influence (Buckley, 2020 and 2022; Petricevic & Teece, 2019; Witt, 2019), a related issue concerns the density and strength of technological links between Chinese firms and those based in the most developed countries. Drawing on the literature on acquisitions by Chinese firms to access more sophisticated knowledge (Hennart, 2009; Li et al., 2012; Luo & Tung, 2007 and 2018) and to bolster their participation in IVCs (Anand et al., 2021; Awate et al., 2015), it can be argued that closer linkages have been fostered between Chinese and most developing countries' firms over the first two decades of this century. Chen, Vanhaverbeke, and Du (2016) showed that reliance on different types of external knowledge linkages in combination with internal R&D capabilities enhances innovation performance. This leads to our final proposition:

Proposition 3. Chinese firms are now fully integrated in worldwide patent co-ownership networks in the most dynamic classes.

4. Methodology

We use patent data as a close proxy of innovative activity and capability, although we are well aware of the limitations of patents (Griliches, 1990; Pavitt, 1985; Torrisi et al., 2016). We know that patents protect inventions and not innovations, and that not all innovations are patented. Furthermore, we know that patent propensity varies both across sectors and according to the characteristics of firms. We also know that patents are often used for strategic ends, in order to increase stock market value and to keep competitors at bay in critical areas of knowledge.

Nevertheless, despite the concerns expressed above, not only has previous research suggested that patents are highly correlated with innovation (Hagedoorn & Cloodt, 2003), but patent data has also continued to be prized as a resource for assessing innovative performance (Dziallas & Blind, 2019), especially when looking at the long-term trends for persistent growth in the volume of patent applications and grants (Granstrand, 2018).

4.1. Assessing the quantitative dynamics

In this article we track both patent applications and grants at both the United States Patent and Trademark Office (USPTO) and the European Patent Office (EPO) over the 20-year period of 2000–2019. These two offices were selected on the basis that they: (i) offer patent protection in the world's largest economic areas; and (ii) provide reliable patent data for time spans of several decades.

Our data was extracted from ORBIS IP, a proprietary database. Our dataset comprises yearly information for the period of 2000–2019, with the data referring to the moment of patent publication. We limited the analysis to 2019, as the 2020 data had not been consolidated yet when we accessed ORBIS IP in February 2021. We mainly compare an initial sub-period (2000–2004) in our quantitative analysis with a more recent sub-period (2018–2019), in order to capture the long-term trends over the two decades we are looking at. The results presented are based on fractional counting, i.e., applications with more than one inventor (or applicant) are divided equally among all applications and subsequently among their countries, to avoid double counting.

We detail the quantitative patenting dynamics in Section 5.1, where we specifically identify the behaviour of Chinese-originated patents to address Proposition 1. As mentioned above, the focus of our analysis is on four IPC subsectors of high-tech competition, namely: Electric digital data processing (G06F); Semiconductor devices (H01L); Transmission of digital information, e.g. telegraphic communication (H04L); and Wireless communication networks (H04W). Our selection follows the recent work of Confraria, Ferreira, and Godinho (2021) which identifies the "most dynamic patent classes" worldwide.

These four patent groups have a very significant and increasing share in total patent filings. While they correspond to less than 1% of the 594 International Patent Classification (IPC) subsectors, they account for a disproportionate amount of all patent filings at the EPO and at the USPTO. When we compare the two sub-periods of 2000–2004 and 2018–2019, these four classes exhibit annual compounded growth rates (ACGR) of 7.3% at the USPTO, and 6.2% at the EPO. These figures compare with overall growth rates for all patent applications in the two offices of 4.9% and 3.8% respectively, which clearly reveals the dynamic nature of the four classes. As an outcome of this growth, the relative weight of those four classes together increased from 23.2% to 34.6% at the USPTO, and from 14.0% to 20.8% at the EPO between the two above-mentioned sub-periods.

4.2. Assessing the qualitative dynamics

To address Proposition 2 , we propose two composite measures of patent quality, labelled respectively Q4 and Q5. Q4 is the aggregation of four separate indicators, where each one highlights different aspects of patent quality, whereas Q5 is composed of the same four indicators, plus a fifth one. The indicators aggregated in Q4 and Q5 were normalised, limiting their variation to the range 0–1. In Q4 each of them has a weight of 25%, while in Q5 each has a weight of 20%, with the aggregate measures varying between 0 and 1.

Q4 includes the following indicators: Grant rate (grants/applications); Survival rate (active granted patents/grants); Family size (the number of family members sharing a given priority date); and Forward Citations (the number of citations received by a published application). Grant rate reflects how patent examiners assess whether applications meet the standard patentability criteria of novelty, industrial application, and non-obviousness. Survival rate concerns the assessment firms do, by paying or not paying maintenance fees, about whether they should keep their patents active. A patent family is a collection of patent applications with similar technical content, with all of them being related to each other through a common priority (i.e., an initial application). Family size refers to the number of such inter-related applications across different patent offices; it mirrors the degree of internationalisation of the initial patent application, with a larger number of family members reflecting the patent holder's belief that the invention merits the extra investment required to apply for protection in a large number of patent offices. Forward citations regard the recognition of the contribution made by previous patents towards new patents (Teece, 2021). All these attributes of patent quality are in line with those identified in the literature (Boeing & Mueller, 2015, Confraria et al., 2021; Hall et al., 2007; Prud'homme, 2014; Song & Li, 2014; Squicciarini et al., 2013). The fifth indicator, added in Q5, is the log measure of patent applications, which is a quantitative measure designed to reveal how much a country (or firm) is involved in the patenting business. In this case, the underlying assumption is that the greater the degree of such involvement, the greater will be the degree of specialised knowledge retained by the respective country (or firm) regarding patenting activities, with such knowledge impacting positively on the quality of the country's (or firm's) patent applications.

Q4 and Q5 were computed for four different years, being respectively 2004, 2008, 2012, and 2016, which enabled carrying out an assessment of how different patent cohorts behave. These four years were selected taking into consideration the lifetime dynamics of patents, as many patents are abandoned before the 20-year limit of legal protection, and the number of citations tends to grow as time goes by (Andrade & Viswanath, 2017). In principle, most applications submitted in 2016 should have already been examined, and therefore grant rates were also considered for this year. Only USPTO data were used in the computation of Q4 and Q5, as we were unable to gain access to the required EPO data to compute our indicators.

The values of each of these aggregate measures are not directly comparable across periods. For example, earlier patents are likely to have a higher number of citations than more recent patents, and the latter have a much higher probability of still being active than earlier ones. Nevertheless, the relative positioning in the rankings of countries (or firms) stemming from such measures are comparable across periods.

When using data from a given patent office, we need to be aware of the home bias, as the resident firms of that jurisdiction will have a greater propensity to patent locally than those from elsewhere. We should also expect that countries or firms without a significant track record in patenting may be relatively less recognised than their competitors, leading to their patents receiving less citations on average.

Despite the recognised limitations in the analysis of patent data and the acknowledgment of forces which often pull in different directions, our approach to measure patent quality seems sensible, especially as we take the aggregate measures Q4 and Q5 to be merely indicators of patent quality, rather than exact measures of the patents' actual quality, and even less of patent value.

4.3. Assessing co-ownership networks

To address Proposition 3, we identified patent co-ownership networks by using R Software (R Core Team, 2021). The following three-step routine was performed to create such networks: cleaning up the data; construction of a co-ownership matrix containing each interaction between multiple owners; and creation of a network graph based on the matrix.

For the first step, we chose all published patents from 2000 to 2019, broken down by class (both primary and secondary) and patent office. Data were filtered by cases in which a given published patent application had more than one owner. To better identify each individual owner, a name clean-up exercise was conducted, assigning a unique ID which is provided by ORBIS IP, and we then normalised their names. In the same process, data were aggregated at corporate level (though in a few cases such aggregation came across some database inconsistencies). For the second step, a matrix containing every possible interaction between pairs of owners was constructed and then they were weighed accordingly, based on the number of interactions displayed by each owner. Further filtering was then carried out by only displaying networks that had at least one owner among the top 70 overall owners by the number of patent applications for each respective class. Finally, an interactive web-based visualisation of the network graphs was created using visNetwork (Almende, 2019), enabling the visualisation of each network and the weight of each owner in their respective network. Co-ownership networks for each class (G06F, H01L, H04L, H04W) and for the two patent offices (USPTO and EPO) were then identified.

5. Results

5.1. The quantitative performance

By taking in consideration the nationality of patent applicants, the rise of China as a patenting power over the first two decades of this century is fully confirmed by observing both the EPO and USPTO patent data for 2000–2004 and for 2018–2019.[5] Despite China being already among the top 25 geographic origins of patents at the EPO in 2000–2004, it never had more than 100 applications over those 5 years in any one of the four patent classes, with the best ranking being #15. By 2018–2019 the situation became rather different, with China holding #1 in H04W, #2 in H04L, #3 in G06F, and #5 in H01L. For the USPTO, the ranking of China was also quite modest in 2000–2004, only featuring in the top 25 geographic origins in classes H01L, H04L, and H04W. However, similarly to that which occurred at the EPO, China's standing experienced a pronounced increase, attaining positions #4 in all the three classes of G06F, H04L, and H04W, and #5 in H01L in 2018–2019. Additionally, China's more recent standing in these same rankings might be further reinforced if applications from Chinese firms without a head office address in China were also to be accounted for.

The analysis of the top patenting firms in each of the four patent classes confirms the degree to which Chinese firms have emerged over the first two decades of this century as leaders or important players at both the EPO and the USPTO. Concerning the most recent sub-period (2018–2019), Huawei is #1 in patent applications in H04W for both offices: #1 at the EPO, and #2 at the USPTO in H04L, and #4 at the EPO, and #12 at the USPTO in G06F. The ascendency of Huawei is not an isolate case, as, for example, BOE Technology Group (also known as Jingdongfang), a Chinese firm focussed on interface devices and smart Internet of things (IoT) systems is #2 at the EPO, and #4 at the USPTO in H01L, while it is in the top firms' rankings in both patent offices in G06F. Furthermore, ZTE, a partially state-owned technology firm specialising in telecommunications, is #7 at the EPO, and #14 at the USPTO in H04W, and also belongs to the top 25 in both patent offices in H04L, and is additionally #21 at the EPO in G06F; in this latter class at the EPO, three other Chinese firms were also ranked in the top 25 in 2018–2019.

These results fully confirm Proposition 1A. Such inference is further corroborated by the data in Table 1 on the country distribution of the top patenting firms in both offices, which shows that China has recently (2018–2019) become one of the most frequent sources of leading firms in the four patent classes, just after the US and Japan. China's ranking is still reinforced by several Chinese firms (including Tencent and Alibaba) providing the Cayman Islands as their address for patent applications. Additionally, the presence in the top patentees' rankings of firms headquartered in South Korea, Taiwan or Hong Kong (Lenovo) further underpins the presence of East Asian firms in the most dynamic patent classes.

With regards the geography of patents, it also makes sense to assess the countries of the inventors, as their geographic distribution may not necessarily coincide with the applicants' geographic distribution. Firms from a given nationality might rely on foreign R&D manpower, while the inverse situation can also occur, where some countries having an inventors' share in excess of that of their patent applicants may be serving as a R&D basis for foreign firms.

Table 2 provides a snapshot of the geographic distribution of inventors and applicants for the four patent classes at both the EPO and the USPTO for 2018–2019. The discernible pattern in Table 2 for the aggregate of the four classes is not particularly dissimilar to that which occurs for each individual class.

It is evident that while some countries are relatively balanced in terms of their weight for applicants and inventors, other countries attract inventors who are located elsewhere (that is the case of the US, or especially Sweden); in contrast, there are countries that provide inventors for foreign-based firms (that seems to be case of India, the UK, and also, to a certain extent, China). Indeed, the data in Table 2 show that the Chinese weight for inventors at the two offices is higher than the respective weight for applicants during 2018–2019. Even though part of

[5] Detailed information, not provided in the Tables below, is available from the authors upon request.

Table 1
Geographic origin of top 25 companies at the EPO and the USPTO in 2000–2004 and 2018–2019.

EPO 2000–2004								EPO 2018–19							
G06F		H01L		H04L		H04W		G06F		H01L		H04L		H04W	
JP	9	JP	13	US	10	US	7	US	11	JP	12	US	12	US	12
US	9	NL	4	JP	8	JP	6	JP	8	KR	6	JP	6	JP	8
DE	2	US	4	SE	1	CA	2	CN	5	US	6	CN	4	CN	4
NL	2	DE	2	NL	1	KR	2	DE	2	DE	3	DE	3	TW	3
FI	1	FI	1	KR	1	SE	2	KR	2	KY	2	FR	2	FR	2
KR	1	KR	1	FR	1	CN	1	CA	1	NL	2	KR	2	KR	2
SE	1			FI	1	DE	1	FI	1	AT	1	CA	1	CA	1
				DE	1	FR	1	FR	1	BE	1	CH	1	DE	1
				CA	1	HK	1	GB	1	CN	1	FI	1	FI	1
						IT	1	KY	1	FR	1	GB	1	GB	1
						NL	1	NL	1			KY	1	SE	1
								SE	1			NL	1		
USPTO 2000–2004								**USPTO 2018–19**							
G06F		H01L		H04L		H04W		G06F		H01L		H04L		H04W	
US	14	JP	11	US	13	US	13	US	14	JP	9	US	16	US	10
JP	8	US	6	JP	7	JP	5	JP	4	US	4	JP	3	JP	6
DE	1	KR	2	FI	1	CA	2	KR	3	CN	3	CN	2	CN	2
HK	1	TW	2	KR	1	KR	1	CN	2	KR	3	KR	2	KR	2
KR	1	AE	1	NL	1	FI	1	DE	1	AE	1	FI	1	CA	1
		CA	1	SE	1	NL	1	HK	1	AT	1	SE	1	DE	1
		DE	1	SG	1	SE	1			CA	1			FI	1
		NL	1							DE	1			SE	1
										NL	1			TW	1
										TW	1				

Source: Own calculation.
Note: We identify next in alphabetic order the countries or territories (and their two-letter abbreviations) listed in Tables 1 to 3: Austria (AT); Belgium (BE); Canada (CA); Cayman Islands (KY); China (CN); Finland (FI); France (FR); Germany (DE); Great Britain (GB); Holland (NL); Hong Kong (HK); Japan (JP); Singapore (SG); South Korea (KR); Sweden (SE); Switzerland (CH); Taiwan (TW); United Arab Emirates (AE); and United States (US).

Table 2
Geographic distribution of applicants and inventors and inventors/applicants balance for top patenting countries, 2018–2019.

EPO				USPTO			
Country	Inventors	Applicants	Inventors/ /Applicants	Country	Inventors	Applicants	Inventors/ /Applicants
AU	0.4%	0.3%	1.38	AU	0.4%	0.2%	1.96
CA	2.6%	1.7%	1.59	CA	2.2%	1.3%	1.72
CH	0.6%	0.9%	0.76	CH	0.5%	0.4%	1.10
CN	17.7%	16.6%	1.06	CN	8.4%	7.2%	1.16
DE	6.2%	5.4%	1.14	DE	2.8%	2.3%	1.25
FI	1.7%	2.3%	0.75	FI	0.6%	0.7%	0.96
FR	3.7%	4.0%	0.90	FR	1.3%	1.1%	1.17
GB	2.7%	1.5%	1.89	GB	2.0%	1.0%	2.00
IE	0.2%	0.4%	0.67	IE	0.4%	0.3%	1.04
IL	1.0%	0.6%	1.68	IL	1.9%	0.9%	2.21
IN	1.2%	0.3%	4.14	IN	2.7%	0.5%	5.04
IT	0.6%	0.4%	1.55	IT	0.4%	0.2%	2.22
JP	13.5%	14.3%	0.95	JP	12.6%	13.0%	0.97
KR	10.0%	10.8%	0.93	KR	9.0%	9.7%	0.93
NL	1.3%	1.6%	0.84	NL	0.4%	0.7%	0.62
SE	3.8%	5.3%	0.72	SE	1.3%	1.8%	0.74
SG	0.6%	0.5%	1.10	SG	0.4%	0.8%	0.50
TW	1.4%	1.4%	1.01	TW	4.7%	4.6%	1.01
US	28.8%	29.7%	0.97	US	46.7%	53.4%	0.87

Source: Own calculation.
Note: For the country codes see the note to Table 1.

this imbalance possibly stems from certain Chinese firms applying from addresses located outside China, it is clear that China is doing quite well in terms of inventors' performance, thus confirming Proposition 1B.

5.2. *The qualitative performance of patenting countries and firms*

We computed the Q4 and Q5 quality measures for the 18 countries with higher application performance in 2016 at the USPTO in the four most dynamic technology classes. Table 3 shows the values of Q4 and Q5 for the aggregate of the four classes in 2004, 2008, 2012, and 2016, with the 18 countries ranked in accordance to their Q5 values in 2016. The most important finding is that patents with a Chinese origin (CN in the table) on average have a much lower quality than those of US registered firms. While the US ranks #2 in Q5 in 2016, China ranks #16 out of 18 countries in the table for the same year. Furthermore, for the Q4 measure, which does not contemplate the quantity effect, China ranks as #18 in 2016.

While the relative performance of China as measured by Q4 and Q5 has improved from 2004 to 2016, it does not account yet for a catching up in terms of patent quality, at least in relation to the US, whose relative performance on the two aggregate quality measures also improved over the same time-period.

Table 3
Top countries' Q4 and Q5 performance in 2004, 2008, 2012 and 2016.

Q4				Q5				
2004	2008	2012	2016	2004	2008	2012	2016	Country
0.33	0.41	0.65	0.67	0.41	0.48	0.66	0.68	KR
0.46	0.51	0.62	0.58	0.56	0.61	0.70	0.67	US
0.40	0.40	0.49	0.72	0.43	0.42	0.45	0.63	NL
0.37	0.56	0.53	0.66	0.35	0.50	0.45	0.56	CH
0.38	0.56	0.53	0.56	0.40	0.55	0.52	0.53	CA
0.44	0.66	0.55	0.58	0.42	0.60	0.50	0.52	IL
0.27	0.37	0.37	0.44	0.40	0.48	0.46	0.51	JP
0.59	0.57	0.51	0.53	0.55	0.53	0.48	0.51	SE
0.46	0.66	0.53	0.55	0.46	0.62	0.50	0.51	GB
0.28	0.46	0.48	0.48	0.35	0.49	0.49	0.48	DE
0.34	0.28	0.35	0.45	0.41	0.36	0.41	0.48	TW
0.43	0.53	0.68	0.50	0.44	0.51	0.61	0.46	FI
0.42	0.59	0.40	0.46	0.34	0.47	0.35	0.44	KY
0.32	0.53	0.58	0.47	0.33	0.49	0.52	0.44	SG
0.29	0.45	0.45	0.44	0.34	0.47	0.45	0.43	FR
0.28	0.25	0.29	0.34	0.25	0.29	0.33	0.39	CN
0.45	0.30	0.35	0.39	0.37	0.27	0.32	0.35	IN
0.53	0.59	0.26	0.38	0.46	0.49	0.21	0.30	HK

Source: Own calculation.
Note: For the country codes see the note to Table 1.

Table 4, which just focusses on the US and China, provides detailed information for the five indicators that were used in the computation of the aggregated measures. The results for the two earlier years are less consistent, as they are based on a narrower set of patents, but whatever year is taken in consideration, it is clear that China is doing less well in Grant rate and in Forward citations, while it scores marginally better in Survival rate and Family size.

Following on from the analysis of patent quality across countries, we turn now our attention to the analysis of the patent quality of the top-performing firms. These firms declare head office addresses not only in China and the US, but also in Japan, South Korea, Taiwan, Hong Kong, several European countries, and the Cayman Islands also. Table 5 provides information for Q5 regarding the aggregate of the four patent classes in 2004, 2008, 2012, and 2016, with the firms ranked according to their Q5 performance in 2016. When one considers the firms' head office address (last column), the results are in line with our findings for the top 18 countries. Firms from the US and South Korea are in the top ranks, along with two firms from Japan and Taiwan. The Chinese top patent performers are placed from mid to bottom of the ranking, the best of them being Huawei. As in the previous analysis of countries' data, we

Table 4
US and China performance on the indicators used in Q4 and Q5.

Country	US	China
Total 2004	30891	59
Total 2008	39367	824
Total 2012	65082	3909
Total 2016	95793	10427
Grant rate 2004	60%	42%
Grant rate 2008	52%	23%
Grant rate 2012	49%	26%
Grant rate 2016	52%	38%
Survival rate 2004	36%	46%
Survival rate 2008	51%	50%
Survival rate 2012	70%	77%
Survival rate 2016	84%	94%
Average Number of family members 2004	3.6	4.8
Average Number of family members 2008	3.3	5.1
Average Number of family members 2012	4.8	5.8
Average Number of family members 2016	4.9	5
		.6
Average number of forward citations 2004	47.8	15.5
Average number of forward citations 2008	27.2	17.4
Average number of forward citations 2012	17.4	8.5
Average number of forward citations 2016	5.9	28

Source: Own calculation.

Table 5
Top companies' Q5 performance in 2004, 2008, 2012 and 2016.

2004	2008	2012	2016	Owner	Country
0.50	0.74	0.66	0.78	APPLE INC.	US
0.40	0.53	0.69	0.73	LG ELECTRONICS INC.	KR
0.53	0.58	0.65	0.61	ALPHABET INC.	US
0.46	0.47	0.47	0.61	SEMICONDUCTOR ENERGY LABORATORY CO. LTD.	JP
0.52	0.62	0.61	0.60	ORACLE CORP	US
0.44	0.50	0.53	0.59	SAMSUNG ELECTRONICS CO. LTD.	KR
0.48	0.47	0.58	0.58	MICROSOFT CORPORATION	US
0.38	0.46	0.52	0.57	TAIWAN SEMICONDUCTOR MANUFACT. CO. LIMITED	TW
0.37	0.51	0.54	0.56	LG DISPLAY CO. LTD.	KR
0.57	0.52	0.50	0.55	QUALCOMM INC	US
0.45	0.49	0.51	0.54	INTEL CORP	US
0.37	0.50	0.56	0.54	SAP SE	DE
0.39	0.45	0.44	0.53	SONY GROUP CORPORATION	JP
0.50	0.44	0.47	0.52	ERICSSON (TELEFONAKTIEBOLAGET NL) AB	SE
0.39	0.55	0.49	0.52	MICRON TECHNOLOGY INC	US
0.33	0.43	0.49	0.51	HUAWEI INVEST CONTROL CORP. LABOR UNION COM.	CN
0.43	0.47	0.53	0.48	NOKIA OYJ	FI
0.38	0.46	0.47	0.45	UNITED MICROELECTRONICS CORPORATION	TW
0.33	0.40	0.42	0.45	NEC CORPORATION	JP
0.60	0.22	0.43	0.44	GUANGDONG OU JIA CONTROL CORP. LABOR UNION COM.	CN
0.40	0.44	0.45	0.44	LENOVO GROUP LIMITED	HK
0.39	0.42	0.50	0.44	INFINEON TECHNOLOGIES AG	DE
0.35	0.43	0.36	0.41	CANON INCORPORATED	JP
0.35	0.33	0.35	0.41	ZTE CORPORATION	CN
		0.33	0.38	TENCENT HOLDINGS LIMITED	KY
	0.43	0.32	0.37	BOE TECHNOLOGY GROUP CO. LTD.	CN
0.40	0.38	0.39	0.35	INTERNATIONAL BUSINESS MACHINES CORP	US
0.35	0.37	0.35	0.34	FUJITSU LIMITED	JP
0.36	0.45	0.27	0.32	TCL TECHNOLOGY GROUP CORPORATION	CN

Source: Own calculation.
Notes: The existence of blank cells has to do with the absence of patent applications in those years; higher values in the earlier years may be related with a small number of applications. For country codes see the note to Table 1.

cannot draw again any strong inference about individual firms' catching up in terms of patent quality.

Accordingly, it becomes clear that Proposition 2 is neither confirmed for the aggregate national data, nor for the individual firms' data.

5.3. Network Analysis

As mentioned above, a set of patent co-ownership graphs, broken down by class and patent office (USPTO and EPO) was developed to respond to Proposition 3. These graphs are depicted in Figs. 1 to 4, which concern USPTO data only, since our main focus is on the US versus China.[6]

The main finding from the analysis of these Figures is the rather limited participation of Chinese firms in the networks. For all classes, they seldom behave as hubs of patent co-ownership networks. Indeed, most Chinese firms emerge as isolated players (e.g., China Information and Technology Group, Guangdong Oujia Control Corp., and Lenovo in H04W), or have scarce links with other players (Ningbo Joyson Electronics, Shanghai Infotech Co, and China Mobile), even inside their own groups, as is the case of ZTE. There are two main exceptions to this pattern: Lenovo, which portrays some linkages in classes G06F (EPO e USPTO) and H04L (EPO); and Huawei, which behaves as a mini hub in class H04W (USPTO), with links to Nokia, Porsche, and China Mobile.

These findings are at odds with Proposition 3. In fact, in contrast to the proposition, Chinese firms are not fully involved in international co-ownership networks. This behaviour is clearly distinct from that of firms based in Japan, South Korea, the US, or in the EPO region.

These findings are consistent with the results presented in Section 5.1 regarding the geographic distribution of inventors and applicants, which show that China's share in the geography of inventors is higher than that of applicants (about 12% versus 10%). This suggests that Chinese firms do not rely disproportionally on R&D manpower which is located elsewhere, including in subsidiaries abroad. However, the figures might well be biased, as the applications of some Chinese firms use head office addresses outside China, including the above-mentioned cases of Alibaba and Tencent, which provide Cayman Islands addresses. It thus seems that the integration of Chinese firms in international invention networks is limited, at least in the dynamic patent classes under study, with technology development and invention activities appearing to be mainly concentrated in China.

6. Discussion

The findings of this research suggest that China has indeed achieved a remarkable progress in its catching up process over the two decades since 2000. Such progress has been evident in China's innovation performance, as demonstrated, for example, by the successive progression of China in the Global Innovation Index, which attained #11 in this ranking's 2022 edition (GII, 2022), as well as in its scientific performance too, with China now leading "the world, both in the number of scientific research papers as well as the most cited papers" (Matsuzoe, 2022). A study of the Australian Strategic Policy Institute released early in 2023, focusing on 44 critical scientific research fields related to defence, space, energy and biotechnology, showed that China is leading in 37 of them (Gaida, Wong-Leung, Robin, & Cave, 2023). Furthermore, the density, complexity, reliability and flexibility of the industrial fabric in China now are, in many fields, much higher than in the US (BCG/SIA, 2021; McGee, 2023a and b).

Our results, which show China's increasing share of patent applications in the most dynamic classes, in both the USPTO and the EPO, provide evidence of a fast catching up. Naturally, these results only reflect part of China's broader drive to increase the innovation and competitiveness capabilities of the country and the main Chinese firms. This process has been anchored with a combination of access to foreign knowledge and a committed effort to upgrade domestic R&D capabilities, including in high-tech sectors (Boeing, 2016; Luo & Tung, 2007 and 2018; Mao et al., 2021; Piscitello et al., 2015). Upstream, China has been successful in attaining a significant level of technological capacity which has resulted in avoiding an over-reliance on foreign sources and rapidly developing its domestic capabilities. Downstream, Chinese MNEs, such as Huawei, Lenovo, ZTE, and Alibaba, have experienced sustained growth and became daunting competitors, which provides support to the merits of springboard strategies (Luo & Tung, 2018).

China's catching up in terms of patenting is even more remarkable when we analyse the most dynamic patent classes at the core of the Tech Cold War, namely: computer processing, semiconductors, digital communication, and wireless communication. China's positive behaviour in such high-tech fields confirms Schumpeterian approaches to developments under conditions of technological uncertainty (Cantwell & Santangelo, 2000), as well as the role of industrial policies in promoting the exploration of opportunities at the technology frontier (Mao et al., 2021). In terms of patents counts, China has successfully been closing the gap with the most developed countries. From this standpoint, China has become a patenting powerhouse, suggesting that it has sufficient impetus to catch up with the US and other developed countries in the near future and that it seems to be fully capable of fighting a Tech Cold War.

The results regarding patent quality show that, even for 2016, the quality of Chinese patents still lags behind South Korea or the Netherlands, and especially the US. Although China's patent quality has been increasing and is therefore likely to catch up and eventually overcome US levels in the future, the fact is that a qualitative gap still holds. Even Huawei, the leading Chinese high-tech contender, has only an average performance in terms of patent quality. However, one needs to consider that our qualitative analysis was based on USPTO data only, where an implicit bias against China may happen.[7] Indeed, the use of data from other patent offices might well have led to different results.

An explanation for the quality gap might be that quantitative catching up occurs faster than the qualitative catch up. The latter may require more time and effort to bring about a gradual process of accumulation of sophisticated technology which will only be achieved over a longer time span. This reasoning is consistent with the Schumpeterian evolutionary perspectives, both in general (Cantwell & Santangelo, 2000), and also from a sectoral perspective (Malerba & Nelson, 2011; Lee & Malerba, 2017).

The results regarding Proposition 3, on the involvement of Chinese firms in patent co-ownership networks, are somewhat surprising. Chinese firms were expected to have forged stronger international linkages. The extant literature shows that Chinese firms have extensively drawn on the cooperation with, and the acquisition of, foreign firms (Hennart, 2009; Luo & Tung, 2007 and 2018; Piscitello et al., 2015). Our results also seem to diverge from Chen et al.'s (2016) findings of the relevance of relying on different types of cooperative linkages to achieve technological upgrading.

One should be careful in the inferences drawn from the observation of the network graphs, as they refer strictly to patent co-ownership. Other kinds of inter-organisational alliances and linkages are not captured in our approach. Accordingly, although the results are clear in showing that the level of participation of Chinese firms in patent co-ownership networks is weak, they should be taken at their face value.

[6] The graphs for EPO data are available from the authors upon request.

[7] This argument is based on two considerations, drawing on cognitive psychology, namely: "humans are unreliable decision makers" (Kahneman, Rosenfield, Gandhi, & Blaser, 2016); and "whether the patent office grants, or rejects, a patent is significantly related to the happenstance of which examiner is assigned the application" (Kahneman, Sibony & Sunstein, 2021: 213). We thank an anonymous referee for raising a question in this regard, which led us to research the issue in more depth.

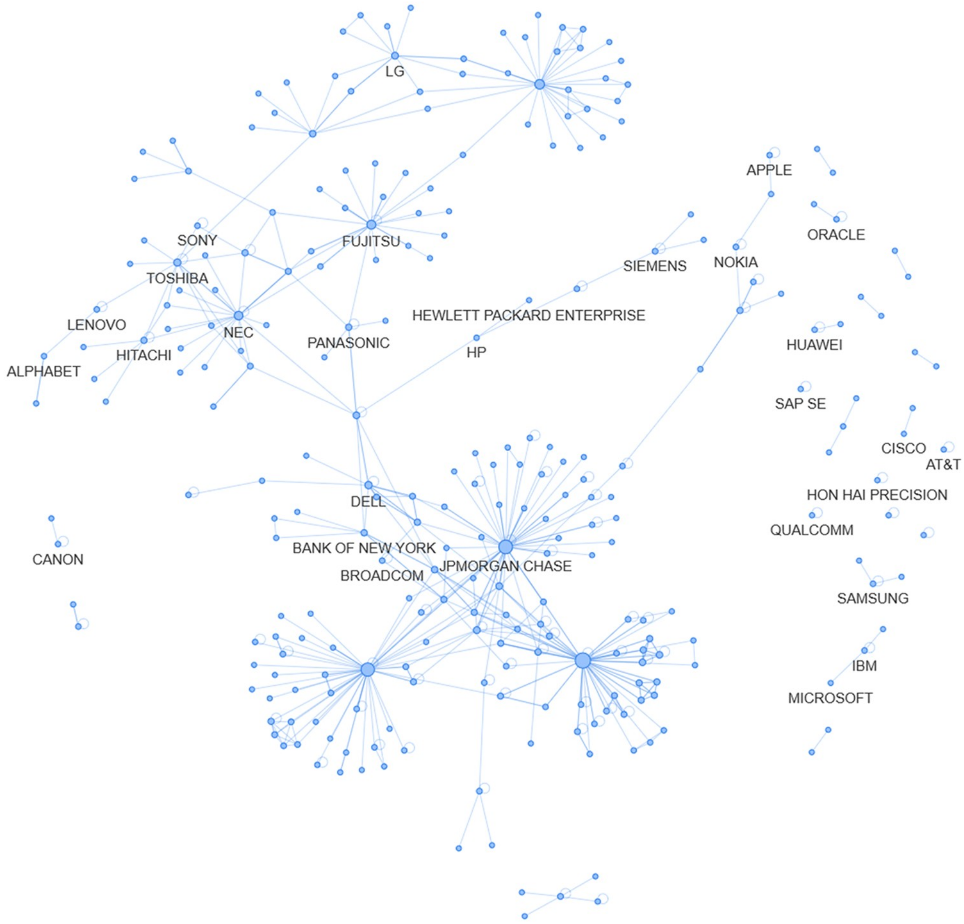

Fig. 1. Co-proprietorship networks: GO6F at USPTO, 2000–2019.
Source: Own calculation. Note: For the sake of intelligibility, only those companies that belong to the patent rankings in 2000–2004 or 2018–2019 show up in the graph.

Two possible complementary explanations can be put forward to try to account for these results. Firstly, following the springboard logic, Chinese firms have acquired access to foreign knowledge and capabilities to further develop and re-invent around, unconstrained by the give-and-take balances that are inherent to alliances. Secondly, firms based in the most developed countries may well be somewhat afraid of partnering with Chinese players in R&D alliances in high-tech sectors. We are not in a position to assess the validity of these two possible explanations, which require a research approach that is out of this article's scope.

Related to this topic is the finding that Chinese firms do not rely disproportionately on researchers located abroad. Once again, this appears to be a counter-intuitive finding, as the literature on MNEs' knowledge management would suggest that Chinese firms draw on their subsidiaries abroad to gain an insider position in worldwide dispersed knowledge pools (Alcácer et al., 2016; Cantwell & Mudambi, 2005). Schaefer (2020) shows how Huawei relies on worldwide talents. However, our results suggest that this does not necessarily happen for most of the patenting originating in China, since China's share in patents' inventors is higher than the equivalent share in patent applications. This may indicate that, in contrast to Huawei's approach, most R&D-performing Chinese firms concentrated their research laboratories in China, either for cost or organisational reasons. Our results also show that, in relative terms, the reliance of foreign MNEs on R&D activities carried out in China is higher than Chinese MNEs' reliance on similar activities in their subsidiaries abroad. This should not be interpreted as downgrading the relevance of R&D abroad by Chinese MNEs. There are two further reasons for our findings. First, the sheer size and distinctiveness of the Chinese market demands that foreign subsidiaries carry out R&D in China, geared to respond to such a market. Second, the level of R&D costs in China has been significantly lower than that of the most developed countries over most of the period under analysis (and still is nowadays, albeit to a lesser extent). This entails a preference for locating R&D in China, in subsidiaries and/or through subcontracting.

Overall, what do our findings tell us from a Tech Cold War perspective?

Our findings highlight that, from a quantitative standpoint, Chinese firms are not at disadvantage regarding their rivals, including those based in the US, despite the same not being true in terms of patent quality. Nevertheless, this should not be envisaged as being a stagnant situation, as over time the quality of Chinese patents has shown signs of improvement, suggesting that also in this respect it is just a matter of time before China catches up (Zhang et al., 2022). The low dependence of Chinese firms on patent co-ownership networks suggests that, in general terms, they may have little to fear should a decoupling take place.

Taken from a longitudinal catching-up perspective, our results also underpin forward-looking implications. The prevailing techno-nationalist mood will spur further investment in R&D by both US and

Fig. 2. Co-proprietorship networks: H01L at USPTO, 2000–2019.
Source: Own calculation. Note: For the sake of intelligibility, only those companies that belong to the patent rankings in 2000–2004 or 2018–2019 show up in the graph.

China,[8] together with a reassessment of companies' geography of patenting. One may anticipate a decline in the growth of Chinese patenting in the US. This stems directly from the increasing feeling of distrust as well as from the regulatory measures already taken. It cannot be eschewed that Chinese firms will also refrain from patenting in the US, simply because that market may become relatively less important for their high-tech exports. By the same token, an increasing patenting by MNEs, both Chinese and Western, in East Asian patent offices might be anticipated as some MNEs may take a decision to split their business networks in the face of an overwhelming gulf between the US and China. This context is also prone to a significant decline in international standardisation, while regionally-based standards will coexist. The outcome will be an increased R&D overlapping and distinct technological approaches on both sides of the conflict.

7. Conclusions

We have assessed various key aspects of the Tech Cold War between the US and China by focussing on patenting performance in the four most dynamic patenting classes at both the EPO and the USPTO. These

[8] R&D investment in China has already been growing fast in recent years. For the period between 2017 and 2021, McKinsey (2023) compared the 136 biggest Chinese companies that disclosed their R&D spending with the 129 non-Chinese Fortune 500 companies that did the same. The conclusion was that over that period the Chinese "firms' R&D spending grew three times as quickly as the MNCs' global R&D spending".

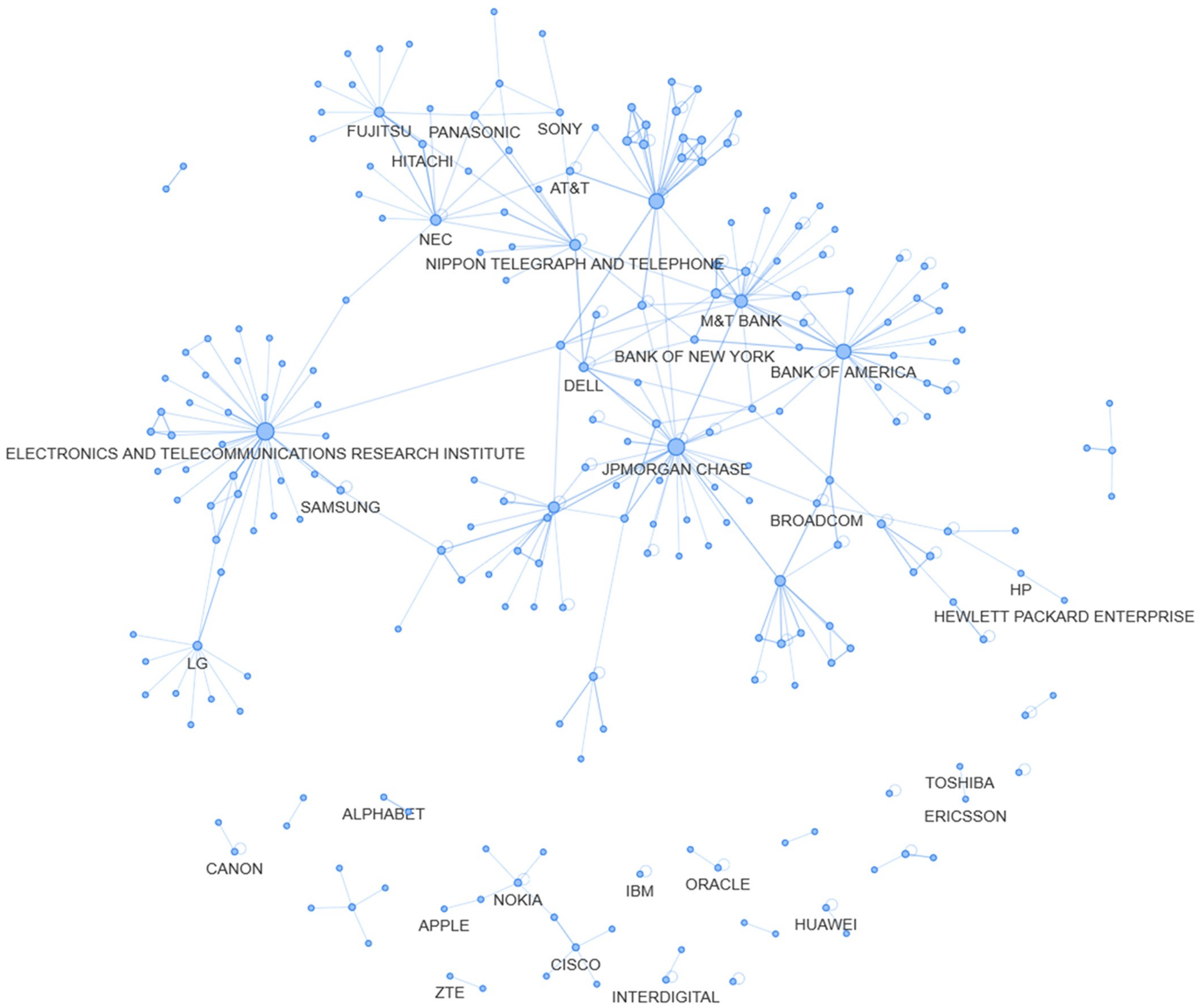

Fig. 3. Co-proprietorship networks: H04L at USPTO, 2000–2019.
Source: Own calculation. Note: For the sake of intelligibility, only those companies that belong to the patent rankings in 2000–2004 or 2018–2019 show up in the graph.

four classes of computer processing, semiconductors, digital telecommunications, and wireless telecommunications technologies, are all characterised by their high-tech nature and by the fact that they attract an increasing share of all patent applications. Indeed, by 2019 they represented more than one-fifth of all patent applications at the EPO, and more than one-third of all patent applications at the USPTO.

The first of the three research questions that we formulated was “how has the geography of patent ownership (and invention) evolved in those two patent offices over the last two decades?” We confirm that during the period of 2000–2019, China emerged as one of the main sources of high-tech patents worldwide, rivalling the US and few other countries, including Japan and South Korea. From a very low patenting base 20 years ago, China has caught up with the most developed economies in terms of the number of total patent applications. China is ranked no lower than #5 in all of the four most dynamic high-tech patent classes at both patent offices in 2018–2019, even reaching #1 in H04W (Wireless communications networks) at the EPO.

The second research question we put forward was “how different is the quality of patents originating in different geographical locations?” The intention was to investigate whether the qualitative and quantitative performances of Chinese patents were at a similar level during the period under analysis. The conclusion was that in qualitative terms, Chinese firms still lag behind its main competitors, with China being particularly disadvantaged in terms of two critical indicators, namely: grant rate and number of forward citations. Nevertheless, the evolution of the aggregate quality measures provides an indication that the quality of Chinese patents has been improving.

The third research question was "how far are Chinese top firms involved in international patent co-ownership networks?". In this respect, our analysis indicates that Chinese firms are not fully involved in international patent co-ownership networks. This behaviour is clearly distinct from that of Japanese and South Korean firms, not to mention Western firms. Furthermore, the balance between applicants and inventors who provide addresses in the People’s Republic of China confirms that Chinese patents do not rely extensively on foreign inventors. This is not the same as to say that China’s catching up in terms of innovation has been strictly a domestic affair, as Chinese firms have resorted to using other channels, especially joint ventures, FDI abroad, and technology intelligence activities to tap into foreign technology sources. Either way, the evidence suggests that endogenous learning

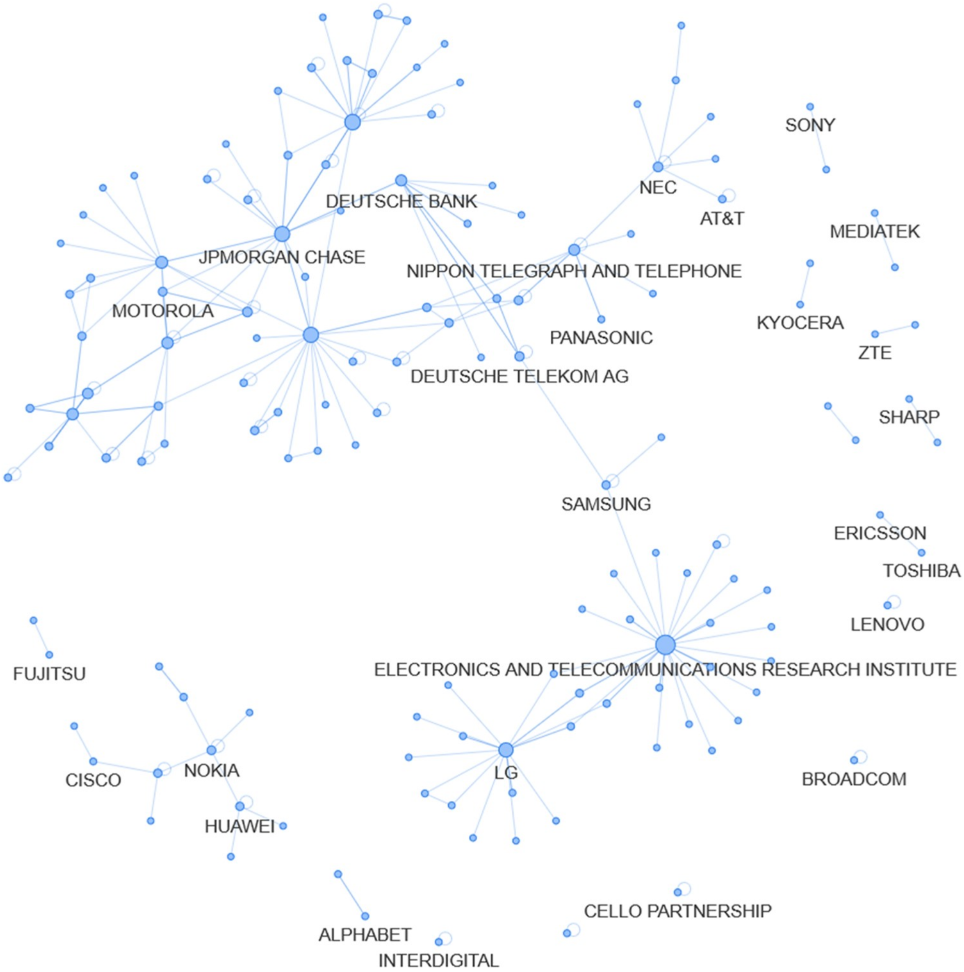

Fig. 4. Co-proprietorship networks: H04W at USPTO, 2000–2019.
Source: Own calculation. Note: For the sake of intelligibility, only those companies that belong to the patent rankings in 2000–2004 or 2018–2019 show up in the graph.

activities within China's NSI have been significant.

The relevance of such activities is bound to increase in the future as a response to critical technological weaknesses, including in the production of semiconductors (Miller, 2022; The Economist, 2022a). This will especially be the case after US decisions on sanctions against Huawei, the approval of the Chips and Science Act, and US export controls in this area (Congressional Research Service, 2022; The White House, 2022; Department of Commerce, 2022).[9]

Zhang et al. (2022) show that in the context of the Tech Cold War, at least one Chinese firm has been able to attain the leading position in a key technological area. Our analysis also indicates that a number of China-based firms have become, or are becoming leaders in some of the most advanced technological fields, with meaningful patenting activities in both the US and in Europe. These firms have already overcome the initial threshold of being active in foreign technology markets, and now reveal a definite IPR strategy aimed to establish commanding patent portfolios at a worldwide level. Furthermore, while on average the quality of Chinese patents appears not to be very high yet, it seems to be improving, with at least the case of Huawei's patents starting to rival leading US- and other developed economies-firms in terms of quality.

Teece (2021) asserted that there was no leader in 5 G, albeit recognising that China (and India) would become relevant players in the future. What our research has shown is that China is already a leading technological power in several key patent classes, at least in terms of patent counts. There is still a qualitative lag. However, given the fast quantitative catching up, and the fact that the quality measure we used is based on an average calculation, there are grounds to think that it might not take long for at least the leading innovative Chinese firms being able to match their rivals of the most developed economies. At least, that would be an outcome with a very high probability of occurrence in the now unlikely scenario of no significant changes occurring in the global competitive environment (Buckley, 2022).

In recent years, China has put forward the so-called "dual circulation" strategy (Tang, 2020; Herrero, 2021), where the country should rely further on its domestic market, instead of the export-oriented strategy followed during the previous decades. This has been confirmed by President Xi Jinping, who clarified that China will "gradually form a new development model in which domestic circulation plays a dominant role" (quoted in Leng, 2020). The "dual circulation" strategy has been formally included in China's five-year plan for 2021–25, with this new orientation confirmed by the publication of an Exports Control White Paper on December 2021 (Shi & Merlo, 2022). It has been pointed out that "Beijing's so-called dual circulation plan is a decisive step away from WTO rules and multilateral agreements orchestrated by technocrats from the US and Europe, prioritizing self-reliance, indigenous innovation and the use of all strategic resources to shape a world where the US no longer calls most of the shots"

[9] According to the press, company incentives provided under the Chips and Science Act are contingent upon refraining from expanding capacity in China for ten years (Sevastopulo, 2023).

(Foroohar, 2022a).

These recent developments on the Chinese side of the Tech Cold War suggest that decoupling is envisaged as a realistic possibility. China's reliance on its huge domestic market, plus the possibilities opened by the Belt-and-Road initiative, will combine to keep providing the necessary demand to foster Chinese-originated innovation. In such a scenario, while patenting in the USPTO and EPO areas will not grow at the same rate as before, there is no reason to anticipate that improvements in Chinese firms' patent quality will not occur. With regards the innovation supply-side, our results provide evidence that China has sufficient domestic resources to keep expanding its innovation capacity, even in the face of the weakening or even the lack of certain international linkages in which the country has invested in recent decades. Furthermore, industrial policy will carry on being very active, promoting initiatives related to semiconductors, industrial automation, AI, and the metaverse. It is within this context that the recent regulation and demands imposed by the U.S. upon the Chinese tech giants should be interpreted. The new framework seems to be oriented towards keeping Chinese firms away from trivial innovation, drawing them into investing in strategically-relevant technology, aligned with a national interest in areas such as security, defence, space exploration, and industrial capability. However, given the limitations imposed on accessing advanced foreign knowledge in critical areas, some observers have cast doubts on the ability of China to close the gap quickly in sectors such as semiconductors, biotech, agricultural science, fine chemicals, industrial software, medical equipment, and aircraft engine production (Pao, 2022). A more forward-looking question is whether an institutional setting that is centred on self-reliance will be, in the longer term, conducive to nurture all the necessary ingredients that are typically required to make innovation happen in frontier areas and which tend to generate the next wave of radical innovations.

Despite the many signs that both contenders are preparing for a possible scenario of decoupling, the political economy of the Tech Cold War poses significant challenges to any linear extrapolation (Foroohar, 2022b; Luo, 2022). It has been observed that the huge interdependence between the US and Chinese economies may require decades for a complete decoupling to occur. For example, the manufacturing hubs on which Apple relies for the production of its smartphones in China cannot be easily replicated elsewhere. Some analysts found that the shift of value chains for other locations, namely India, is fraught with difficulties (McGee & Reed, 2023), and anticipate that "Apple will shift just 10 per cent of iPhone production outside of China by 2030, or at most 20 per cent if it moves aggressively" (McGee, 2023b), from the current 70% of iPhone production that comes from China (Horwitz, 2022). Western-based MNEs rely on the huge Chinese market for placing their exports too (McKinsey, 2023). At the same time, China attempts to stimulate domestic consumer-led growth have not been fully effective so far, with the country still depending on exports to the US and other foreign markets (Foroohar, 2023).

In relation to the specific contents of this article, despite providing some key findings of interest, we recognise that the analysis carried out has also some limitations. The first is derived from the patenting data under analysis, as they refer to a period that just goes up to 2019, which historically was just before the escalation of the negative climate associated with the Tech Cold War. The second has to do with the fact that the qualitative analysis was only carried out using USPTO patent data, which implies that future research should attempt to integrate data from other patent offices. Third, the qualitative appraisal refers mainly to the technical aspects of the patents, with our measures not being designed to fully capture the legal or economic value of patents. Our quality measure should be further object of a sensitivity analysis, by testing, for example, different weighting schemes, or by proceeding to aggregation through other statistical methods, including PCA.

By providing a patent-based perspective of technological rivalry, we hope to have contributed to highlighting a key dimension of the Tech Cold War. Further research in this particular area would be most welcome, and it would likely provide fresh evidence-based insights to address a key issue in the present geo-political, economic, and managerial context.

Declaration of interests

None

Data Availability

Data will be made available on request.

Acknowledgements

The authors thank the helpful comments from the Editor and the reviewers, that significantly contributed to improve the quality of the article. We wish also to thank the dedicated and competent research assistance of João Pedro Magalhães. Financial support by FCT (Fundação para a Ciência e a Tecnologia), Portugal is gratefully acknowledged. This article benefited from project PTDC/EGE-ECO/30690/2017 and from grants UIDB/04521/2020 and UIDB/05069/2020 from FCT. Any remaining error is ours.

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