Fraunhofer
ISI

Fraunhofer ISI Discussion Papers *Innovation Systems and Policy Analysis* No. 73

China's Changing Role in Global Science and Innovation

Henning Kroll, Rainer Frietsch

Karlsruhe, March 2022

Responsible for content

Henning Kroll, Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany; Institute of Economic and Cultural Geography, Leibniz University Hannover, Germany
Rainer Frietsch, Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany

Recommended citation

Kroll, H.; Frietsch, R. (2022): China's Changing Role in Global Science and Innovation, Discussion Papers Innovation Systems and Policy Analysis No. 73. Karlsruhe: Fraunhofer ISI.

Published

March 2022

Contents

Figures

1 Introduction

In the past four decades, China has re-evolved from a backward, post-socialist country into a thriving hotspot of research and innovation. Over the years, the nation's capacities have grown not only in terms of numbers but also in terms of quality and international relevance (Kroll et al. 2020 and 2021, Liu et al. 2018, Boeing et al. 2016). While China remained in a learning position within global knowledge networks throughout the 1990s and much of the 2000s, it has long since reached eye level with established leaders in science and innovation. In selected, often digital fields, the process has even partly been reverted, in particular since the mid-2010s China has become a role model. For the moment, the nation claims to remain technologically dependent and continues to lack technological sovereignty on a number of integral hardware components (BBC News 2019, Foreign Policy 2020, TechSpot 2021). That said, more and more of its end products have come to match their Western, Japanese or Korean counterparts.

The Chinese market has grown very rapidly and is the lead market in many sectors; from mobile phones, electronic devices to electric vehicles and investment products like machines or instruments. The market power, at the same time, coupled with massive demand and governmental regulation, has led to a scaling up of Chinese companies, which still mostly focus on the national market. However, several companies have taken the next step and have entered the world market. At the same time, 'from China to the world' does not refer to the world's workbench anymore, but it now often means that new technologies and innovations start off in China and are brought to the rest of the world. In consequence, the technology and innovation cycles in China are driving the world and not the other way around. For many years the latest technologies were not brought to the Chinese market, due to fears of unintended knowledge and technology leakage. International companies can hardly afford to keep this strategy.

As a result of these changing dynamics, China's role in the global network of science and innovation related exchanges has shifted – not only with a view to scientific and technological collaboration, but also with a view to external trade and investment. As an aspiring scientific leader, its collaborations with international partners have increased; following the logic that the best should collaborate with the best to mutually inform each other (Wang et al. 2020). In the scientific domain, collaborating with the finest is seen as an achievement. For the moment this still largely applies to most disciplines, irrespective of political concerns. At the same time, self-reliance has become an increasingly relevant paradigm of Chinese economic and technology policy. Since the 2006-2020 Medium- and Long-term Development Plan of Science and Technology (Schwaag Serger and Breidne 2007), Chinese leaders have emphasised the role of 'indigenous innovation' (Suttmeier 2005, Ernst 2011, Yang 2015), i.e. autonomy, even if not necessarily autarky, in the innovation process; and have been heavily criticized for it (Wilsdon 2007, Nakayama 2012, Cunha 2015, Suttmeier 2014, Koleski and Salidjanova 2018). The 12th FYP (2010-2015) already foresaw a strengthening of the national market and further technological and economic independence from other countries. The political leaders justified this by the lessons learnt from the worldwide financial and economic crisis of the previous years. The same line of argument has prevailed in the 13th and seemingly also in the 14th FYP. The efforts of the past US-administration to cut off China from certain technological supplies, which have not been fully revoked, have further fuelled this process. From the perspective of the Chinese government, they amount to the unacceptable attempt to 'keep China down' (Global Times 2019) which has led to an ever stronger attempt to achieve technological independence, going as far as to purge foreign technologies from official use (Financial Times 2019). In parallel, developing internal capacities makes the country more and more independent from international collaboration. Accordingly, China's inclination to collaborate internationally on matters of technology has lessened notably, unless to assert its position in existing areas of strength or to source specific technologies where that is still needed (Prud'homme et al. 2018). In relation to that, we have also witnessed a parallel effort of Chinese firms going international themselves and seeking targeted investments in the West (ten Brink, 2015).

One further central reason why China's international positioning has changed is that its domestic capacity to exploit own knowledge resources has improved substantially in the course of the past decade. Up until the early 2000s, China's national system of science-industry-collaboration was characterised by the legacies of a largely dysfunctional Post Soviet model (Gu 1999, Liu and White 2001, Liu and Jiang 2001). At the time, the university and the enterprise sector remained largely separate domains that, beyond dynamic islands of entrepreneurialism, hardly communicated with each other (Walcott 2003, Kroll and Liefner 2008, Kroll and Schiller 2010). This lead to a somewhat distorted picture in which a high share of formal, yet largely irrelevant invention activities cumulated in the public sector (Kroll 2011). However, the majority of Chinese technology enterprises de facto learned from the intensive study of competitors abroad, through re-engineering, or from their joint venture partners within China (Fan 2011, Liefner et al. 2013, Si et al. 2013, Yang 2014). In short, learning from international examples prevailed over domestic learning from knowledge institutions (Cao 2004, Liefner et al. 2013, Wei 2014).

More recently, however, this has substantially changed at different levels (Chen and Kenney 2007, Chen et al. 2016, Tang et al. 2020, Conlé et al. 2020). First, the entrepreneurial spin-off ecosystem around leading universities has evolved, reaching a level of dynamism that outpaces Europe and almost matches the US West coast (Europäische Kommission (EASME) et al. 2021, Hyun et al. 2020, AsiaTechDaily 2020, Hemmert et al. 2019). At the same time, these universities have become global leaders in scientific discovery in e.g. information and communication technologies, so it is less necessary to consult foreign partners. In particular, the Chinese market is awash with public seed finance and subsidies in areas of national interest (Nirei et al. 2021, TechSpot 2021) which, in the meantime, also appear fairly effective in triggering innovation (Ma et al. 2021, Zhang et al. 2021). Second, a new generation of academics and researchers has found better ways to communicate on issues of technology transfer in comparison to ten years ago (Crupi 2020, Kaiji et al. 2021). On the one hand, this is a cultural matter, as the cognitive divide between academia and industry has diminished. On the other, it is facilitated by the fact that many companies' increased technology orientation has increased their absorptive capacity (Cohen and Levinthal 1990) and made academic input more relevant for them. Third, the Chinese government has taken active measures to complement more business-oriented regions' entrepreneurial dynamics with academic capacities. This was relevant in particular for Guangdong, a region once close to being devoid of large-scale academic establishments. It is now thriving with top universities' subsidiaries and purpose-built regional research institutions (Xu and Qiao 2018, Conlé et al. 2020, Conlé et al. forthcoming).

While individual contributions to each of the abovementioned dynamics exist, the literature currently provides little by means of integrating them into a consistent picture of where China is heading. Given its government's highly strategic approach on most scientific and technological build-up matters, it however seems obvious to assume that such an overarching blueprint de facto exists – in both the domain of planning and that of tangible action. Despite all this idiosyncrasy, it therefore seems reasonable to consider currently observed trends and orientations in China's scientific and technological collaboration as far more than an empirical reflection of arbitrary or unconnected trends, driven by individual actors. Instead, we are witnessing a substantive, consistent self-empowerment of an entire nation, which we have yet to understand fully. In particular, it results in a natural continuity of the past two decades' developments while it is, at the same time, accelerated by a political paradigm shift towards global self-assertion.

Against this background, this paper seeks to cast different empirical perspectives on China's international collaborations in the domain of science and technology as they developed in the course of the past 15-20 years. At the same time, it will seek to trace domestic developments of scientific and technological capacities and collaborations within China, in order to improve our understanding of its international repositioning. Eventually, this should allow us to better gauge which of the recent changes in China's international posture could follow naturally from the country's de facto developments and which must be considered to be the result of recent geopolitical shifts. Bearing in mind this differentiated assessment, we will put forward an evidence-based outlook on possible future developments.

Conceptual Section

In development theory, it was traditionally assumed that countries follow the path of leaders to – ideally – eventually catch up with them with regard to technological expertise and economic capacity (Akamatsu 1962). As most of the related models' imagery and analogies suggested, however, there was a strong implicit assumption that further players would enrich the established world order. While existing ones caught up, whereas the "lead goose" itself was not really predestined to change (Kasahara 2004, Ozawa 2006). China, however, took a different approach to development from the outset of its reform and opening up policies in the late 1970s by aspiring towards reestablishing the leading position that it had historically held. While recognising its then backwardness, its ambition has in principle always been to once more become a global leader in research and innovation, however far the road towards that end might prove to be. From a Western perspective, that ambition was, if not actively derided, at least insufficiently incorporated into theoretical models, most likely, as it was considered far too unlikely to materialise.

Modernisation theory also foresaw only one way to the aim, namely to aspire to the position of the leader by competing on the same grounds (Rostow 1960, Berger 1996, Berger 2000). This was sometimes even linked to the political or at least the economic system (Fukuyama 1992). The history of the past 150 years showed some successful examples, but even the industrialisation of Japan and Korea was not based on traditional grounds, namely new leading-edge technologies like microelectronics or optical technologies. Furthermore, productivity increases were based on quality control, bringing the second and third industrial revolution to perfection. China, however, decided to go along similar tracks at the beginning, but always stressed that it pursued the 'Chinese Way', both in economic and political terms.

From the early beginning, China's strategic approach to national development was aimed at leapfrogging (Brezis et al. 1993), i.e. relinquishing or at least moderating the ambition to catch-up in existing technologies. Instead China waited for the opportunity to become the leader in new ones, that would eventually supersede the existing ones. First, this proved successful in specific areas of industrial design, e.g. in the mobile phone industry, when first Chinese products pushed incumbent Western solutions out of the market (Liu et al. 2015, Dong and Flowers 2016). Later it gathered full momentum in the course of the digital transformation into which China had invested substantially ahead of time and continuously thereafter (Segal 2003, Lindtner 2014, Sheehan 2018). Today, the country is reaping the benefits of long-term investments, not only into microelectronics design and assembly but, more specifically, into new aspects of the digital transformation such as artificial intelligence, robotics, and big data related applications (Europäische Kommission (EASME) et al. 2021, Roberts et al. 2021, Liu 2021). With a view to mobility transformations, a third attempt based on e-mobility replacing combustion engines may be currently underway, at least on the blueprints of Chinese strategists (Tagscherer and Frietsch 2014).

This situation, in which the technological lead of established Triad nations is no longer structurally "given", has so far not been sufficiently conceptualised in development theory. This theory suggested that the order of leading and lagging nations would hardly structurally change. Even if, the catching-up countries would enter the established pathway, including market/capitalist economic orders and eventually also adopt democracy as their political system (Fukuyama 1992). Since China has joined the global competition for innovation as an increasingly strong player, global technological leadership has become more contested and ephemeral. Today, some formerly lagging nations have become agile first movers in key enabling technologies, ahead of all China. In consequence, the established networks of collaboration, built on a leader-follower constellation, will invariably change. For international relations, this is relevant in particular as this process of contesting structural leadership has political repercussions as well (de Graaff et al. 2020, Weinhardt and ten Brink 2019). Leading nations would consider catch-up development beneficial rather than being offended by it. However, they would necessarily staunchly object – and likely react – to the notion of being replaced as leaders in the international scientific, technological and economic domain (BBC News, 2019). Very likely, under these conditions it will not be up to the contesting nation alone to design and shape its collaborations at different levels, in particular those in strategic fields. It seems that the perception in the Triad nations has changed and that the original idea of placidly watching other nations catch up while sharing with them an ever bigger cake has been replaced by concerns of getting outperformed and losing out in a world of increasingly limited resources. In parallel, economic relations once held together by mutual benefit have been detrimentally affected by systemic rivalry that undermines trust and puts a political burden on all collaboration and exchange. In consequence, economic opportunity may no longer be sufficient to trigger and sustain international collaborations. In many cases, ambitions to limit the flow of knowledge to politically competing nations may restrain what could in principle emerge and fuelled a renaissance of notions of technological sovereignty – in Europe, the US as well as in China itself.

Against this background, it becomes conceptually indispensable to distinguish between those changes and trends, which result directly and organically from the dynamic development and eventual measuring up of the contesting nation and those that follow indirectly from the political repercussions of this dynamic. While the former have to be considered as natural trends with no specific trigger or concerted agency behind them, the latter can and will be shaped by the government actions on either side. They can be traced back to decisions over which specific actors have defined control.

In any case, different options and possible scenarios may result from the abovementioned dynamics. First, a new "lead goose" could replace the old one, relegating the incumbent to second rank (as is, in fact, common practice among real geese in nature). Second, it could draw level with the incumbent, without either of them assuming clear leadership, or leadership differing by field, creating a potentially unstable system. Third, the formation could break, giving rise to two formations with a new, respective leader, heading in diverging directions – as is already alluded to in recent literature (Negara and Suryadinata 2021).

Furthermore, different domains follow different logics worldwide. Science is generally considered a positive-sum game in which collaboration brings benefits and advances to all, while it is sufficiently removed from practical application to affect strategic interests. Technological development, on the contrary, is a highly contentious and strategic field with direct implications for individual and, in consequence, national competitiveness. Accordingly, different nation's actors will collaborate in these matters only if they have to (as they cannot achieve certain aims alone) or because they are institutionally connected across borders anyway (as in the case of prevalent foreign direct investment). In the domain of trade, finally, additional, substantially unrelated, aspects come into play with a view to international wage differentials, resource endowments as well as specific hub functions in the worldwide web of logistics. Conceptually, these aspects constitute a third, cross-cutting layer which has to be considered in order to ascertain a correct interpretation of China's international repositioning across the past decade.

Finally, all domestic statistics, even when drawn from international sources, reflect a very specific institutional setting, which has to be interpreted with care. In many cases, terms like 'state-owned company', 'private company', 'public research institution' or even university have different functional meanings in China than in Western economies (Liefner 2014, Chen 2015). While the set-up is no longer that of a traditional post-Soviet innovation system (Radosevic 1998, Xu 2011), it has, against expectations, not converged against any known Western configuration either (May et al. 2019, Roberts et al. 2021). In the Chinese system, both public research and companies can to a much larger extent be politically directed towards collaboration and this orchestrated collaboration remain one fundamental aspect and driving factor of recent developments in domestic science-industry collaborations (Liefner et al. 2016, Naughton and Tsai 2015, ten Brink 2019, Nölke et al. 2020). That said, there have always been a large number of bottom-up dynamics in the Chinese innovation system as well, in particular in its dynamic Eastern and Southern areas around the Yangtze and the Pearl River Delta (Fu et al. 2012, Liefner and Wei 2014, Liefner and Kroll 2019, Kroll and Liefner forthcoming). These, too, however, evolve under a very different and – with regard to limitations – in part much more rigid framework than in the West (Liefner et al. 2016, May et al. 2019, ten Brink 2019). At the same time, the amount of available state aid for issues and themes considered strategic is often by an order of magnitude higher than in Western economies, even when it comes to the individual recipient organisation (Kroll and Schiller 2014, Boeing 2016, Techspot 2021). Given the substantive amount of public resources available, Chinese policy makers need to focus less on short-term efficacy than their peers in liberal market economies, but can focus on effectiveness and on building fundaments from a strategic perspective.

In sum, these considerations lead us towards four propositions that we will seek to corroborate by developing new analytical perspectives based on a number of already existing sources of microdata. First, that China's rise with a view to both quantity and quality of its scientific output has increased. In principle the country's options to collaborate internationally have also increased as it has become a more relevant partner at eye level for many. Second, this rise has, at the same time, in itself reduced the country's dependence on international technology. This on its own will have triggered a decreasing de facto reliance on external knowledge sources at large. Third, there is evidence that China's domestic system of science industry collaboration and technology transfer has improved notably across the last decade, further reducing the country's motivation to collaborate internationally. Fourth, the geopolitical paradigm from collaboration to contestation between at least the U.S. and China has left a notable imprint on collaboration patterns. This goes beyond what the abovementioned trends would have, by themselves, suggested. Subsequently, we will consider the findings on these four main propositions in the synopsis and integrate them into a broader discussion and conclusion.

Data and Method

To investigate the accuracy of the abovementioned propositions, this paper will apply a differentiated analysis of bibliometric and patent data. Bibliometric data is relevant as it provides insights into nations' and organisations' capacity for knowledge production. Due to the recent tide of publications in China, it is required to work with a database that sets certain international standards and quality thresholds. A few databases fulfil this criterion Elsevier's SCOPUS is one of them. A broader coverage of the social sciences and humanities, as well as broader coverage in Asia and Europe (see for example Michels and Schmoch 2012, Stahlschmidt et al. 2019) makes this database an attractive and useful source. In general, co-publications are interpreted as reflecting the extent of resulting person-to-person or also organisation-to-organisation linkages – and thus knowledge-bridges. In the cooperation domain, it reflects processes of mutual learning and collaborative development of knowledge flows in the realm of science – not yet industrial application or market competition. By its very nature, moreover, published knowledge is freely available to all. In consequence, scientific collaboration reflects a rather uncontested, mostly positive sum game.

Patent data is relevant as it provides insights into nations' and organisations' capacity to generate inventions and technological solutions (Grupp 1998, OECD 2018, Frietsch et al. 2010, Frietsch et al. 2014). Technically, the most established source of global patent data for scientific and analytical purposes are the EPO's biannual releases of the PATSTAT database, which contains patent filings from more than 80 offices worldwide and reflects the vast majority of technological knowledge supply and of technology markets globally. In line with the situation for publications, however, there is an analytical need to focus on those patents that are of actual relevance for the international competitiveness of nations. To that end, this paper will consider only 'transnational patents' (Frietsch and Schmoch 2010), i.e. patents filed with the ambition to address diverse global markets (through patent families with at least a PCT filing or an EPO filing).

In contrast to publications, where knowledge flows and collaborations between different affiliations are considered, co-patents – defined as co-inventions of inventors from different countries – reflect on technological knowledge flows between different R&D locations, however mostly within the same multinational enterprise. For strategic reasons or reasons of simplification co-applications in terms of two distinct companies or enterprises filing a patent together is in reality a rather unusual case, even more so across national borders. Information on the international cross-ownership of internationally invented intellectual property rights will be established following a methodology proposed by Guellec and van Pottelsberghe (2001) which draws on information available at the level of individual patents of the PATSTAT database. Guellec and van Pottelsberghe suggested two indicators that reflect knowledge flows and control of knowledge issues across borders, namely the shares of nationally owned, but foreign invented patents versus nationally invented, but foreign owned patents.

2 Results

A) International Integration

Scientific Collaboration

With a view to scientific collaboration, our analysis finds that, despite the significant overall surge of publications at an international level (having increased by more than factor 3 since 2005), China's inclination to internationally collaborate has been on the rise as well. Overall, the share of international co-publications in all academic publications increased from below 15% in 2005 to close to 25% in 2018. That said, it is noteworthy that China's overall share of co-publications remains notably below those of the US (~40%), let alone Germany or the UK (~55-60%). Even Japan and Korea reach higher shares with about 30% each. Only India ranks lower with about 20% while Russia and Iran remain at similar levels to China.

China's largest collaboration partner by far remains the United States, accounting for close to 45% of all co-publications. This is followed by the United Kingdom, Australia, Canada, Germany and Japan. Over the past two decades, notable increases in collaboration can be observed for Australia as well as the US and the United Kingdom. Towards the end of the list, relative increases in collaboration can also be detected for other European countries (IT; NL; SE; ES) as well as some regional partners from the developing world, such as Pakistan. In consequence, the relative share of some traditional partners like Canada, Germany, France, Singapore, Korea, Taiwan, and, most dramatically, Japan has decreased. Both geographical proximity and similar disciplinary profiles promote scientific collaborations across borders (Frietsch et al. 2008, Hoekman et al. 2010, Ahlgren et al. 2013, Frietsch et al. 2017). Size effects also play a role, researchers/organisations in larger countries are more likely to find a national partner, whereas researchers in smaller countries consequently have a higher propensity to collaborate internationally (Frietsch et al. 2016). In addition, it seems that scientifically developed countries tend to seek collaborations with scientifically developed countries for an eye-level scientific exchange (Frietsch et al. 2018).

With a view to disciplinary orientation, it is noteworthy that the share of co-publications in all publications is highest in the social sciences, economics (35-45%), followed by the humanities, ecology, climate and geosciences but also reach notably above average shares in informatics, mechanical engineering and medical technology. In contrast, the lowest number of co-publications is found in nuclear research, different areas of chemistry and electrical engineering although it remains above 15%.

Technological Collaboration

With a view to technological collaboration, our analysis finds that, in parallel to the significant overall surge in patenting (having increased by factor 12 since 2005), China´s inclination to internationally collaborate has substantially decreased. Overall, the share of co-patents in all transnational patent applications from China decreased from about 15% in 2005 to a mere 5% in 2018. Even in developed nations, this share would typically stand around 15%, such as in the US, Germany, France or Taiwan. In highly integrated countries like the UK and Canada or smaller countries like Denmark or Singapore, it commonly reaches 25-35%. We find lower values of between 2-3% only in Japan and Korea. On the contrary in developing nations, where high shares can be read as a proxy for technological dependence, it ranges between 30% (Malaysia, India) and above 50% (Vietnam, Philippines, Indonesia).

Even more dominant and unipolar than in the case of academic collaborations, China's key partner in the technological domain are the United States with an above 50% share of all co-patents. Japan and Germany follow with around 10% shares while no other country's share exceeds 5%. Unlike the academic domain, collaboration with Japan is increasing while collaborations with Germany and Great Britain are decreasing. Slight increases, in contrast, are visible for Sweden, Australia, France, India and Korea, but all at a relatively low level. The only country that saw a relative increase among the overall decreasing trend of international collaboration is Sweden, which, however, in 2018 once more reached its level of 2005.

With a view to the thematic orientation of China's technological collaboration, the analysis reveals a picture that is in part inverse from that identified in the scientific domain. The main areas, which still display relatively high collaboration rates of around 10% are chemistry and pharmaceuticals, closely followed by the fields of digital communication, surface technology (materials) and biotechnology. Overall, collaboration is weakest in the areas of optics, computer technology, semiconductors, and audio-visual technologies. In short, technological cooperation seems to be more prevalent in traditional or non-digital enabling technologies.

Cross-Ownership of Intellectual Property

Beyond mere cooperation, a further relevant perspective considers the international ownership of intellectual property developed by inventors of a particular country, in other words, organisations of a country own intellectual property developed abroad (Guellec and van Pottelsberghe 2001). This perspective is relevant in particular, as, by proxy, it provides an insight into international investment and targeted technology-sourcing relations. As a tendency, domestically owned foreign inventions are either inventions made in foreign subsidiaries of domestic firms, or rights lastingly acquired by such firms. Foreign-owned domestic inventions, on the contrary, tend to be inventions made in domestic subsidiaries of MNEs that subsequently have been applied legally by these corporates' headquarters abroad.

In line with China's opening up yet then lagging technological capacity, we see a sharp increase of both foreign-owned Chinese inventions and Chinese-owned foreign inventions in the early 2000s, up until about 2003/04. This is a double reflection of the then ongoing surge of foreign investment in technology-oriented sectors and the fact that China did not yet develop many transnational patents independently. Remarkably, however, the share of foreign-owned Chinese inventions peaked notably higher (at around 35%) than the share of Chinese-owned foreign inventions (at below 25%). At the time, the control of a large share of technologies developed in China thus lay firmly abroad, in particular, when considering that similar constellations within MNEs formally incorporated in China would not even show in our analysis. At the same time, high shares of Chinese-owned foreign inventions provide evidence that firms incorporated in China (even if partially MNEs) were to a large degree sourcing technological knowledge abroad.

Subsequently, both shares have been in constant decline. The share of Chinese-owned foreign inventions dropped to around 7-8% in 2013 and has been stable since while the share of foreign-owned Chinese inventions, still at 12% in 2013, declined even further. It has stabilised at around 6-7% since 2016. This picture stands in contrast to parallel developments in Europe and the United States, which saw a steady, if gradual increase in internationalisation until the 2008 economic crisis, a fairly steep drop after 2011 and stabilised thereafter without further dynamics. In both cases, China's shares have been notably below that of Western countries since 2018, quite in contrast to the situation in the early 2000s. With a view to Chinese-owned foreign inventions, this has already been the case since around 2005, with a view to foreign-owned Chinese inventions, Chinese and Western developments had fallen more or less in sync between 2006 and 2014, before they dropped remarkably further. With regard to the former, we observe that international firms are replaced by domestic inventions in Chinese firms, indicating that Chinese patent owners (i.e. domestic firms) have by and large remained less integrated into the global technological scene throughout their country's international rise than their US or European counterparts at the same time. With a view to the latter, in contrast, China's level of international integration, i.e. the (presumed) share of foreign investors in Chinese patent applications, had converged towards international standards for a prolonged period, until it dropped markedly after 2014.

B) Functional Integration between Domestic Knowledge Systems

Status Quo Ante: Learning from Foreign Sources

To document the former prevalence of international over domestic learning, as often anecdotally suggested, we juxtapose the development of Total Factor Productivity in China with the development of technological collaboration and the degree of international cross-ownership of intellectual property rights.

In both cases, the coincidence, and likely mutual dependency, is striking. Quite obviously, China's decision to open up and actively seek technology-oriented foreign direct investment led to a major infusion of applicable knowledge and an increase of TFP growth. This took a further 3-4 years to come to full fruition and peak around 2008 when all relevant measures of international integration were already decreasing. Since then, the growth of total factor productivity has slowed down markedly, with one notable, but probably not sustainable, exception in 2017. Interestingly, moreover, TFP growth development displays marked post-crisis effects subsequent to 2008.This did not occur in any of our other analytical perspectives directly pertinent to China – yet in those relating to an overall global disengagement of European and American enterprises.

In summary, the juxtaposition of measures of integration and TFP growth development more than suggest that China's engagement with the global technological scene has had notable positive influences in the course of the 2000s. Subsequent to the 2008 economic crisis, however, a certain disconnection – or parallel stabilisation – of both developments seems to be emerging which does not enable us to make direct inferences about causal relations, in the way that was possible during the 2000s.

Patenting by Universities and Research Institutions

A traditional proxy measure to gauge the socio-economic relevance of science and/or the transfer capabilities of research organisations are patent applications from the non commercial domain. In China, this share is traditionally high as it has been politically encouraged since at least the mid-2000s. However, this used to apply mostly to domestic applications whose quality and substance might not necessarily meet international standards. Since 2010, the known share of CNIPA filings by universities increased from about 12% to about 15% in 2018, complemented by a constant 3-4% from public research organisations.

For transnational applications by Chinese research organizations, this figure remains much lower at around 6% for universities and a further 1% for public research organisations. That said, a total of almost 7% still amounts to about double the value known from countries like Germany. Additionally, in the recent two years, applications from public research organisations have increased by more than half, strengthening the role of scientific institutions in technology generation. Moreover, this has happened in line with a parallel, steep increase in applications by small to medium sized firms.

This seems to be in harmony with anecdotal evidence and media reports, both of which suggest that Chinese ecosystems of technological development are seeing additional dynamics in the very recent past. Besides entrepreneurial dynamics, the public research sector continues to play a relevant role in these new constellations.

Knowledge Generation by Firms

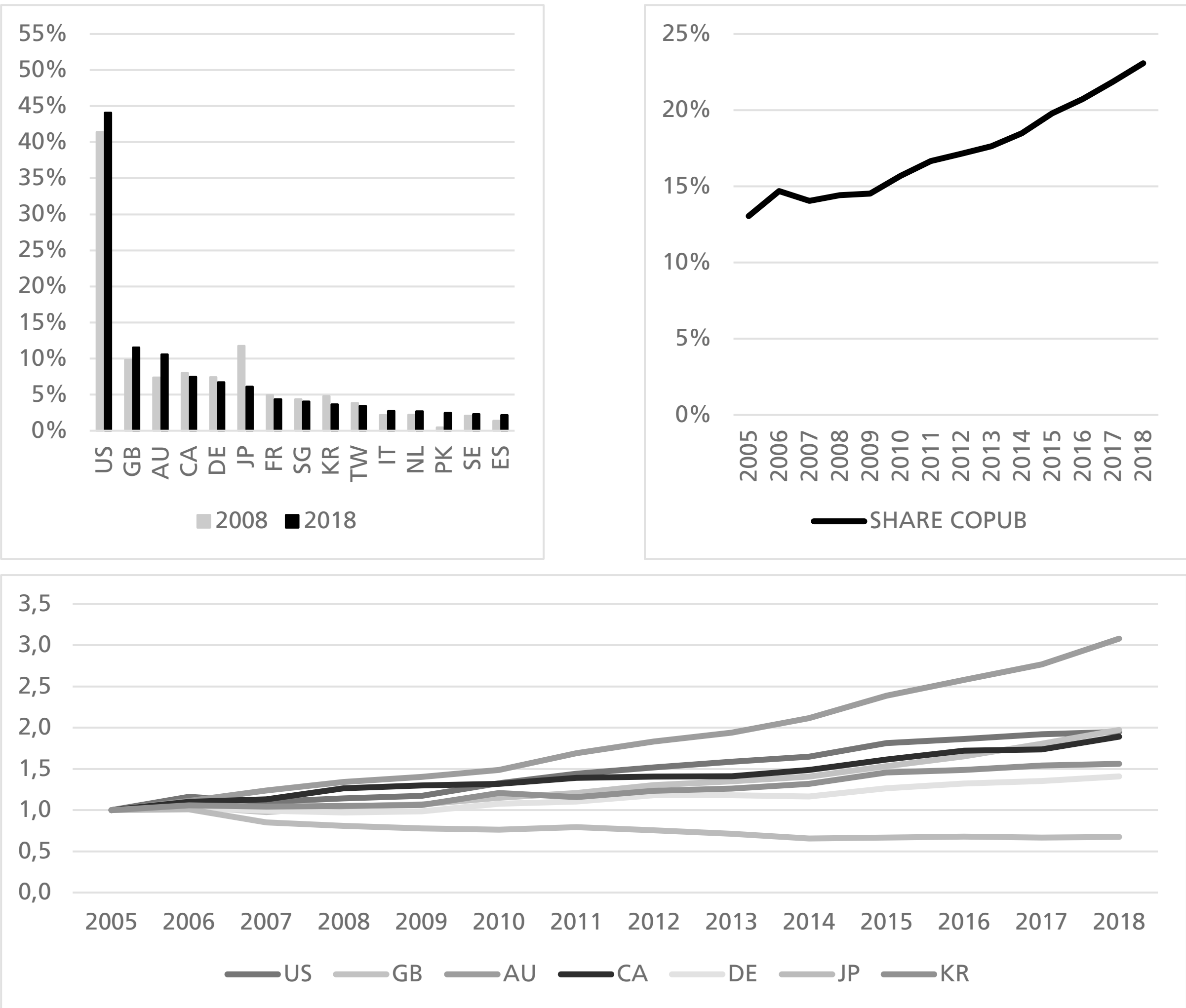
The scientific orientation of Chinese firms increased from around 4% in 2010 to above 5% in 2019. In the context of the overall surge in publications in China, this required an absolute increase from about 10,000 annual articles in 2010 to more than 30,000 in 2019. Apparently, the involvement of

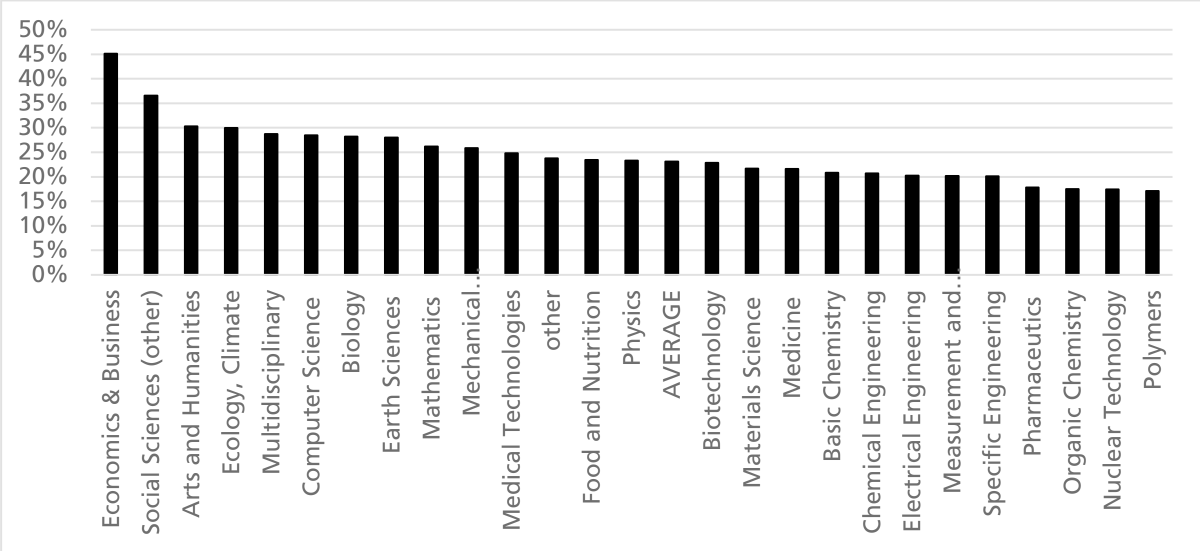
Chinese firms with high-level, conceptual development activities and/or their collaboration with public research has substantially increased across the past decade.

In an international comparison, the share of Chinese firms in overall publishing is no longer substantially lower than that of American firms which decreased from about 7% to below 6% during the same period. Even in Germany and the United Kingdom, classic examples of successful science-industry collaboration, comparable figures do not currently exceed 8%. At the same time, out data underline Chinese companies' limited international integration. While the shares of co-publications between national science and national industry is on a similar level to Germany (and many other Western countries), the shares of co-publications between national science and international industries is considerably different. In Germany, there is hardly any difference between the shares of national and international companies, while in China only 1% of total publications are in collaboration with international companies.

In sum, China has been the only major economy in which firms' publishing activities have increased notably in relative and in absolute terms throughout the past decade. Moreover, our analysis suggests a further, rather recent dynamism of developments since about 2016/2017 – in line with the above observations in the domain of non-corporate patent applications.

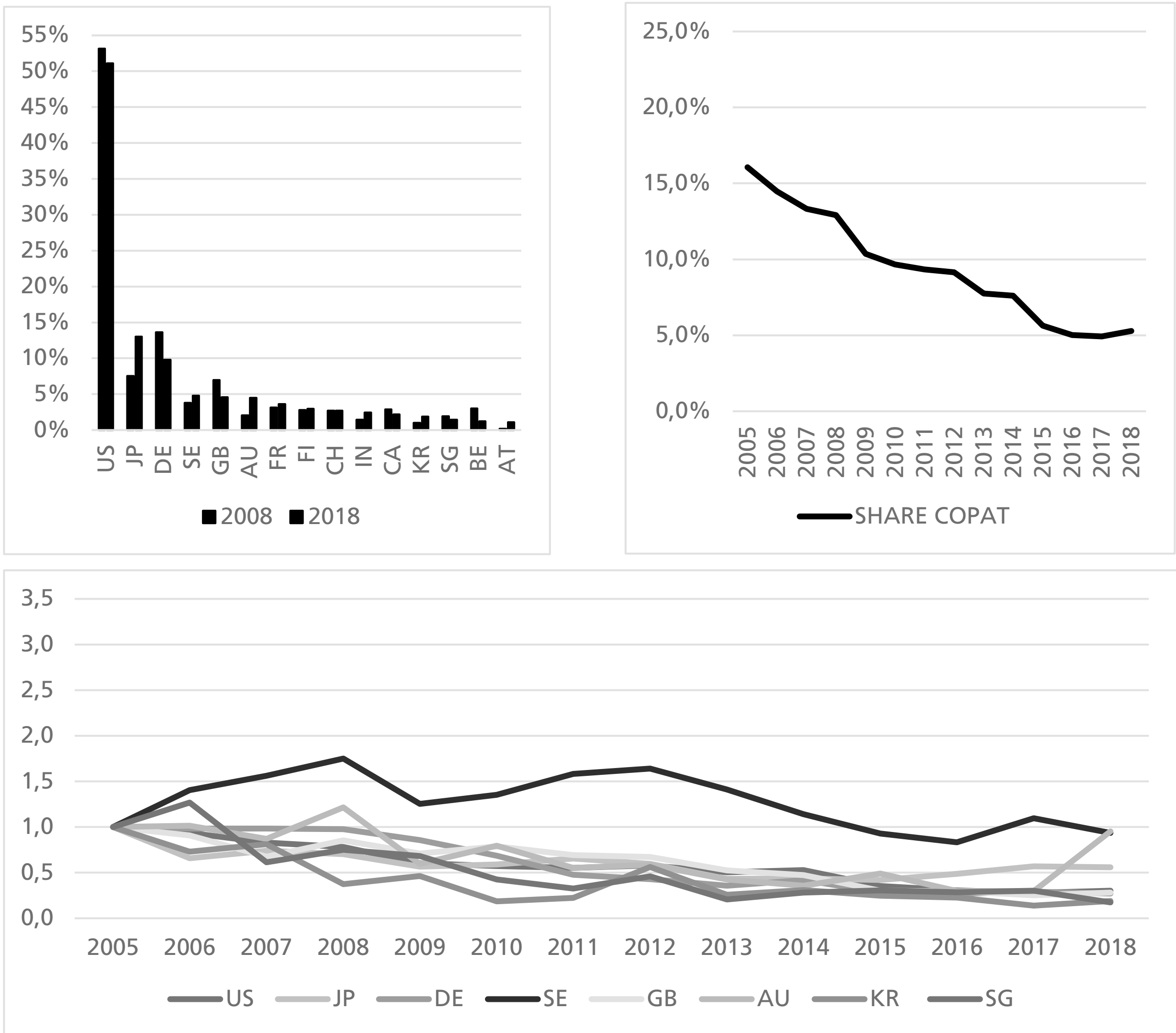
Figure 1: Co-Publications

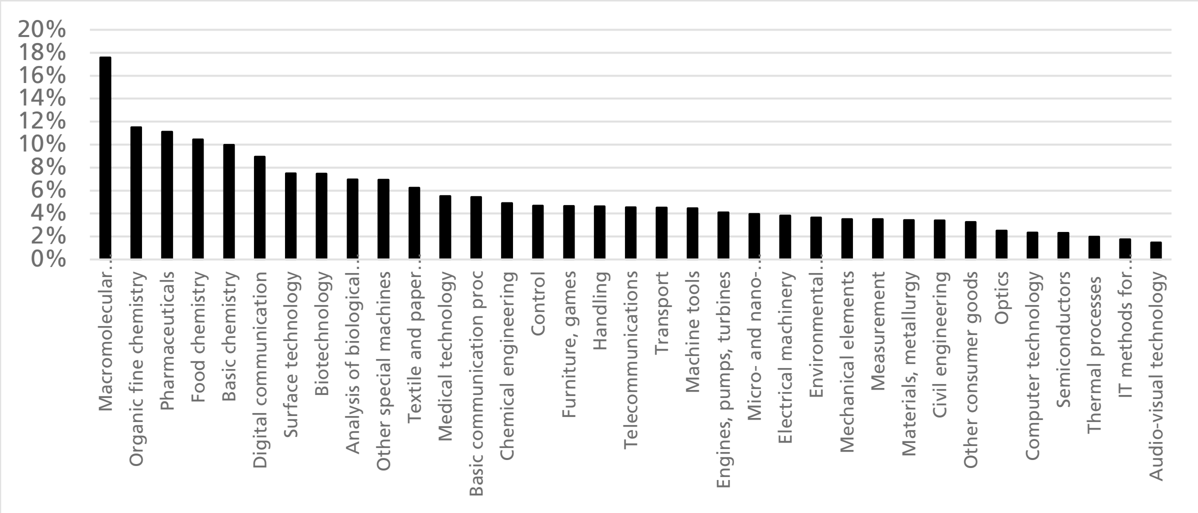




Source: authors' analysis based on Elsevier SCOPUS

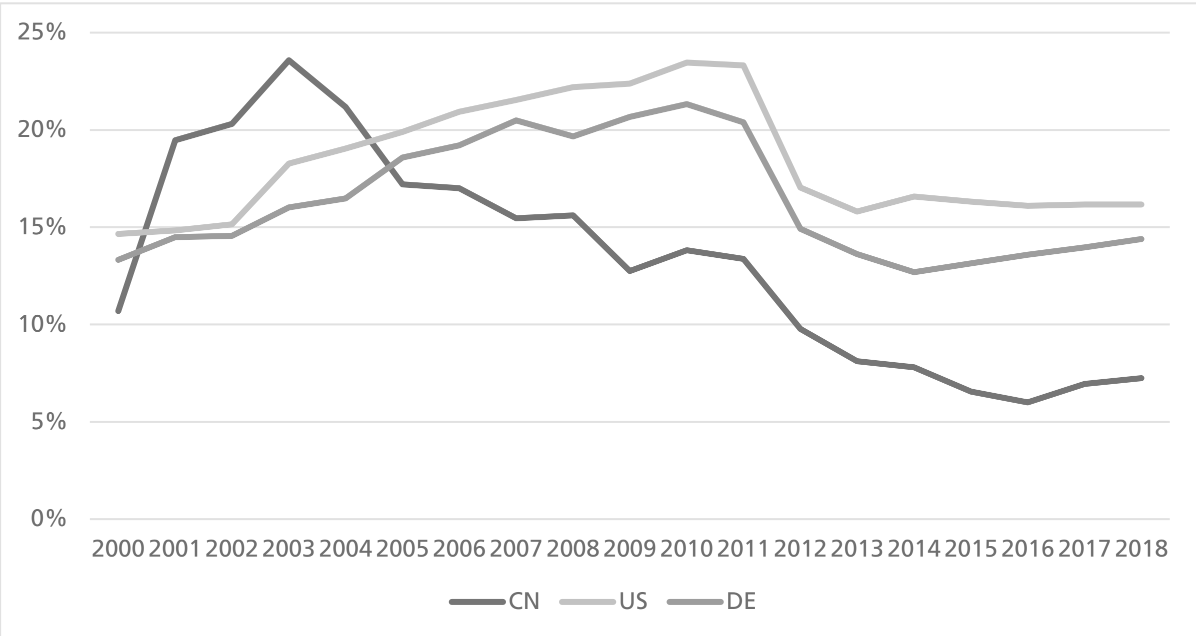
Figure 2: Co-Patents





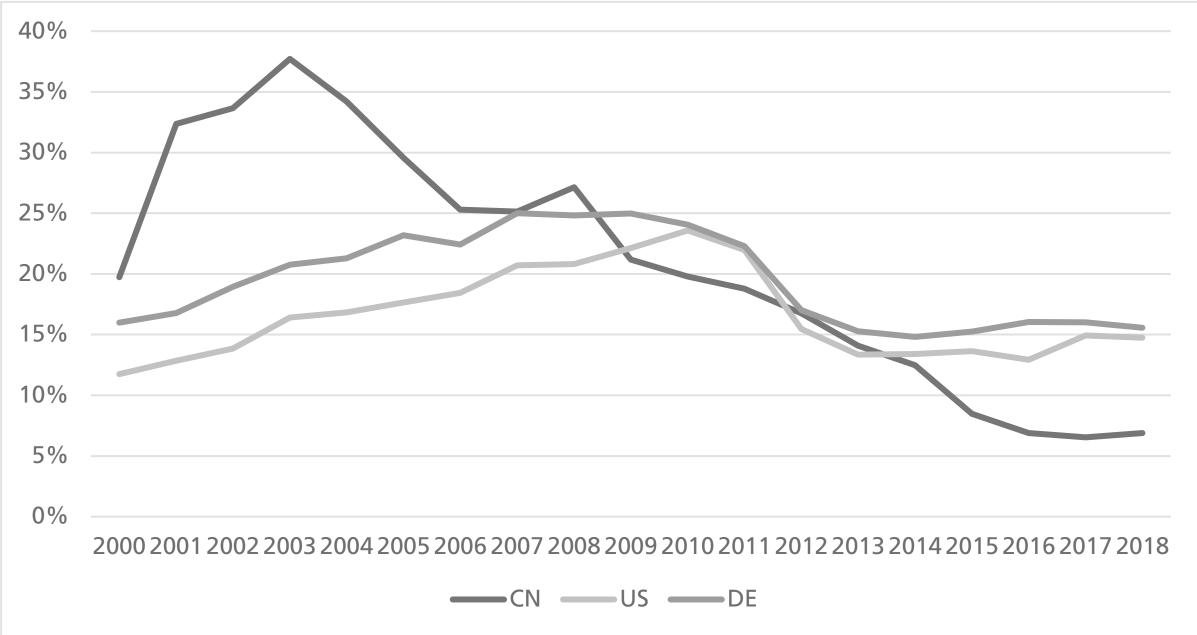
Source: authors' analysis based on EPO Worldwide Patent Statistical Database (PATSTAT)

Figure 3: Domestic Ownership of Patents Invented Abroad (SHAI)



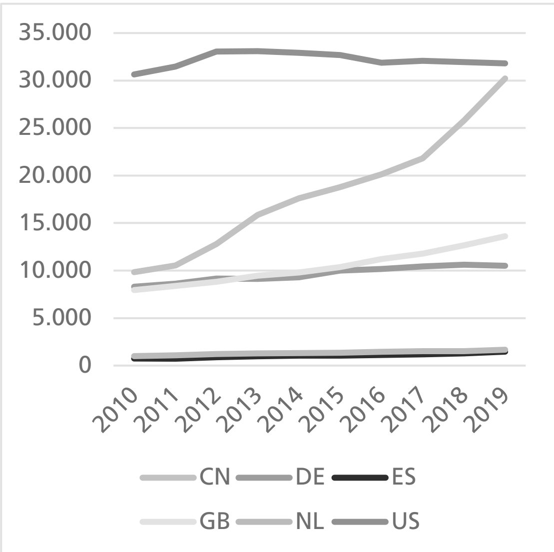
Source: authors' analysis based on EPO Worldwide Patent Statistical Database (PATSTAT)

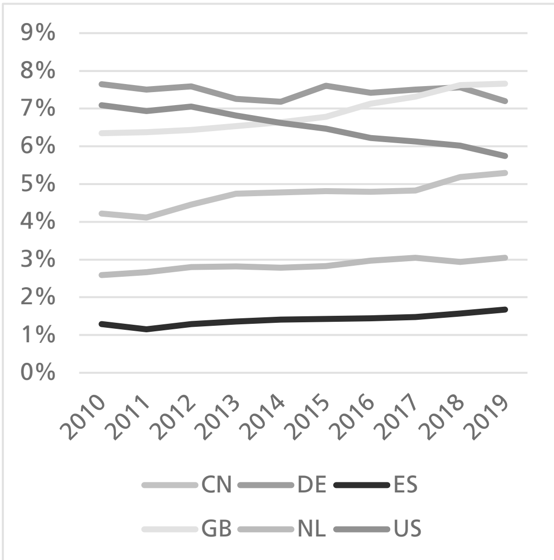
Figure 4: International Ownership of Domestically Invented Patents



Source: authors' analysis based on EPO Worldwide Patent Statistical Database (PATSTAT)

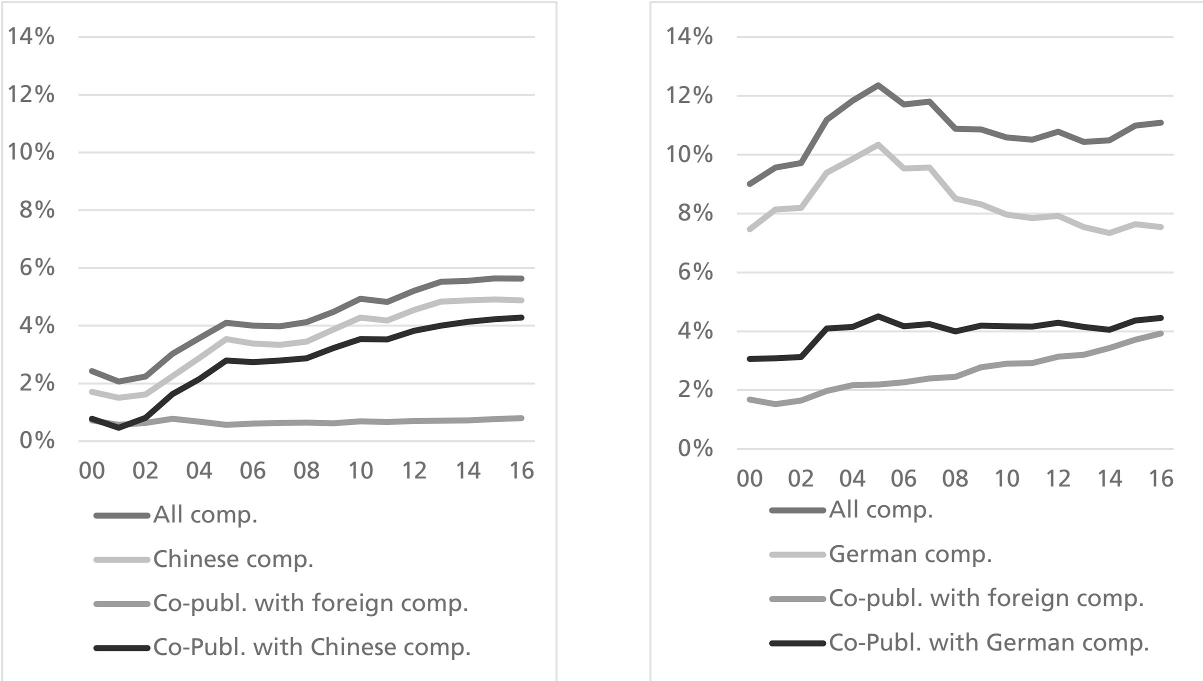
Figure 5: Publications by Enterprises





Source: authors' analysis based on Elsevier SCOPUS

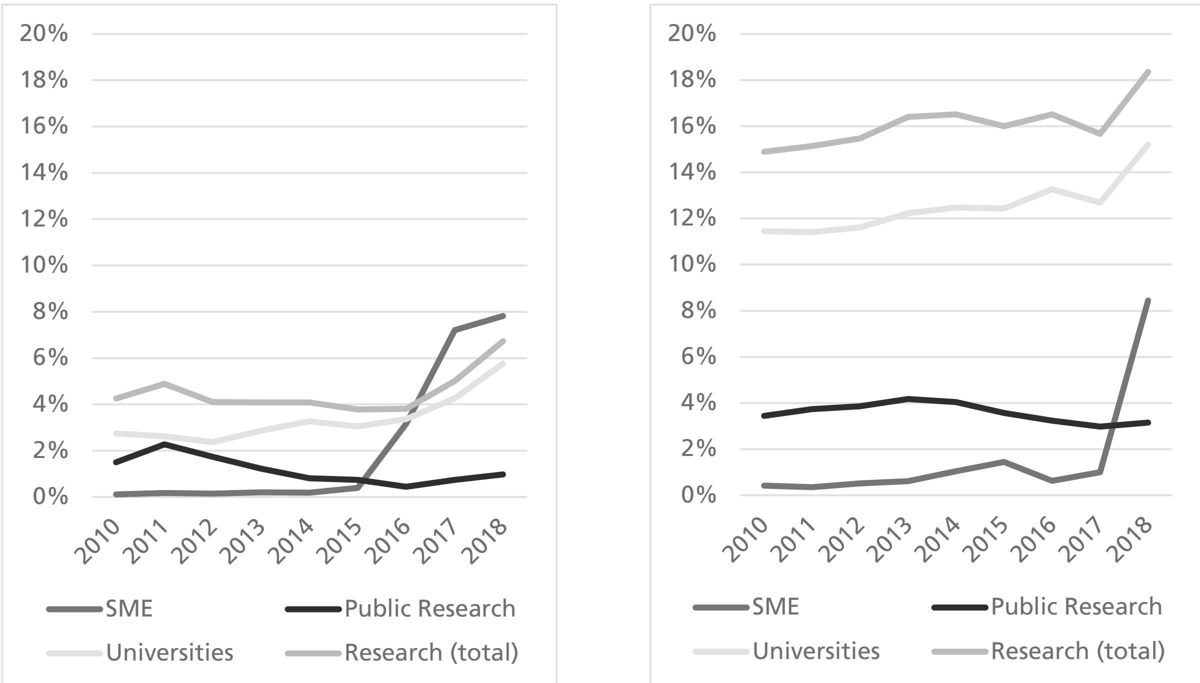
Figure 6: Publications and Co-Publications of companies with different partner types (situation in China, left, vs. situation in Germany, right)



Source: authors' analysis based on Elsevier SCOPUS

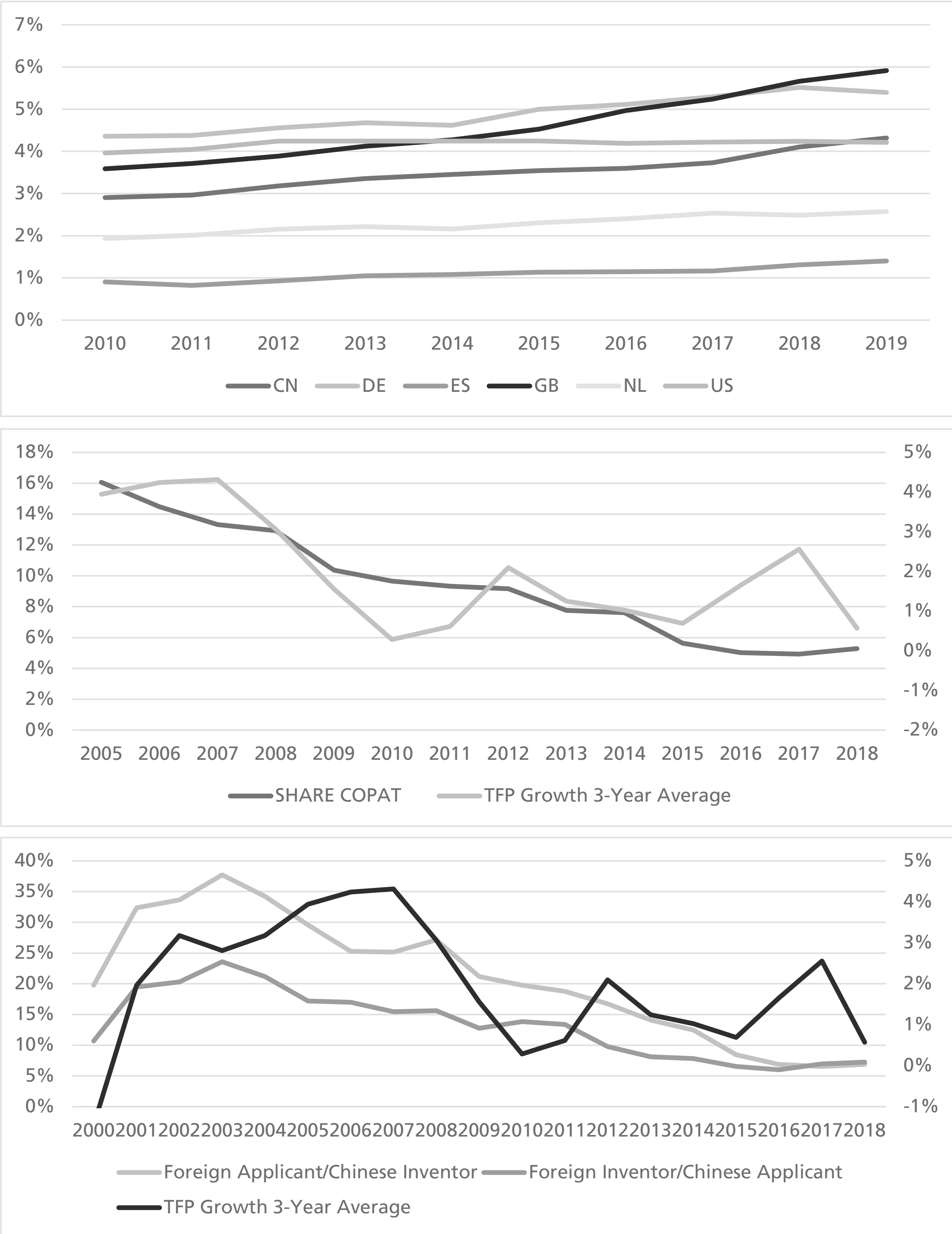
Figure 7: Structure of Patents Applicants in China

(SIPO applications, left, vs. transnational applications, right)



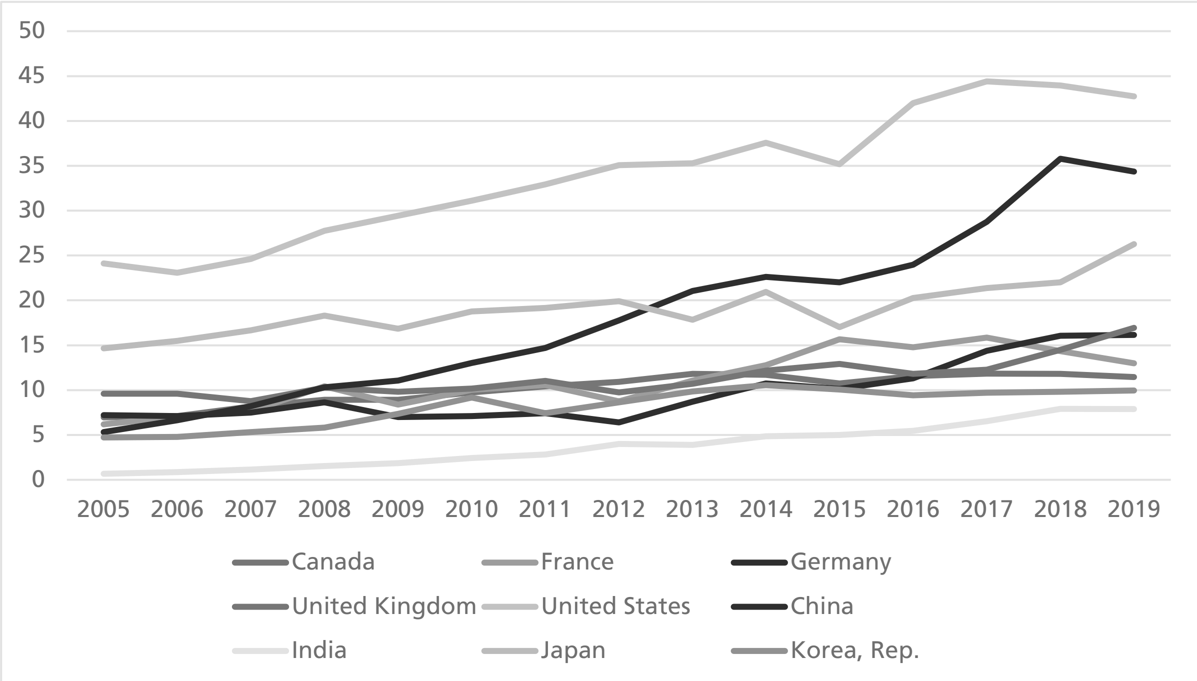
Source: authors' analysis based on EPO Worldwide Patent Statistical Database (PATSTAT)

Figure 8: Cooperation between Universities and Firms; Share of Total Publications



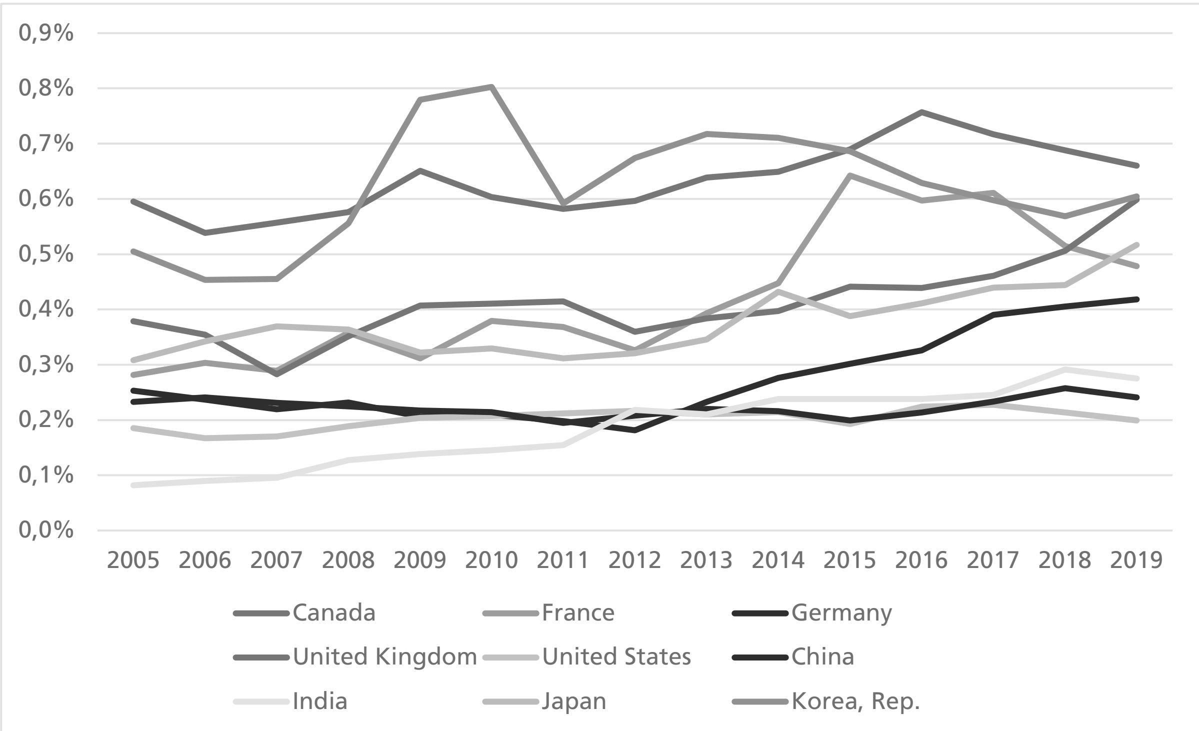
Source: authors' analysis based on EPO PATSTAT, Federal Reserve Bank of St. Louis

Figure 9: IPR Payments to Foreign Actors (bn Dollar)



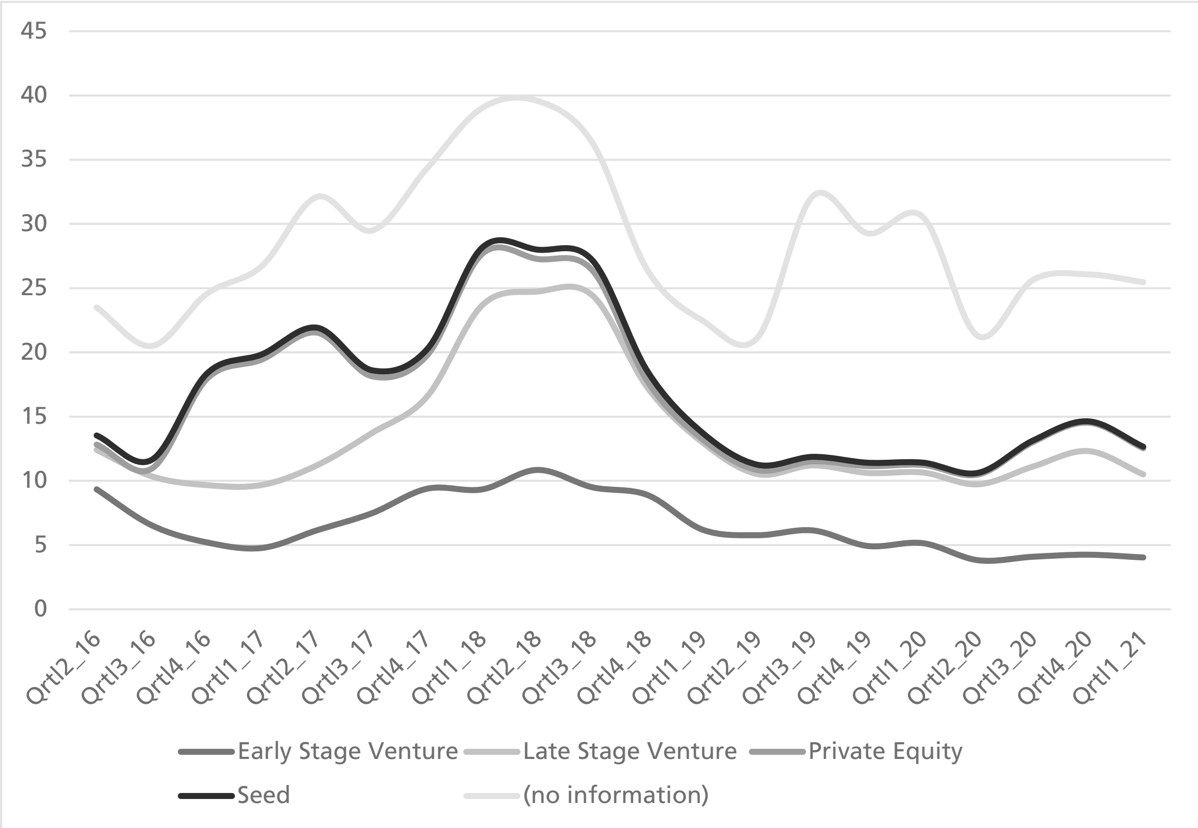
Source: authors' analysis based on Worldbank Data

Figure 10: IPR Payments to Foreign Actors (Share of GDP)



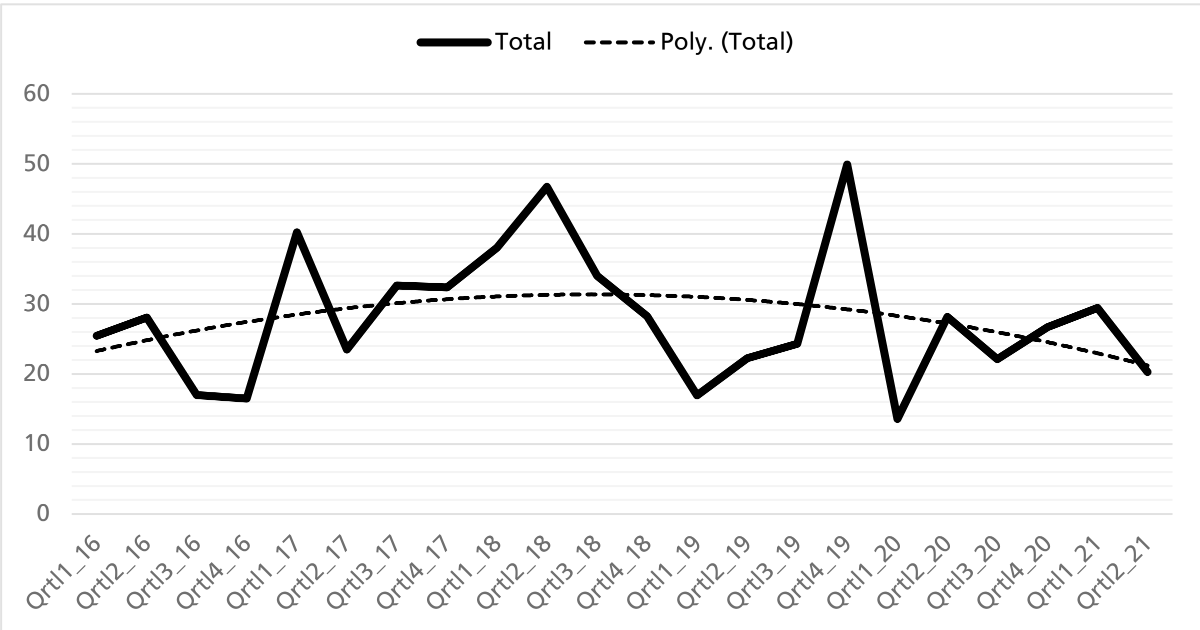
Source: authors' analysis based on Worldbank Data

Figure 11: Investment by Type (Money Raised in USD, 3Q Averages)



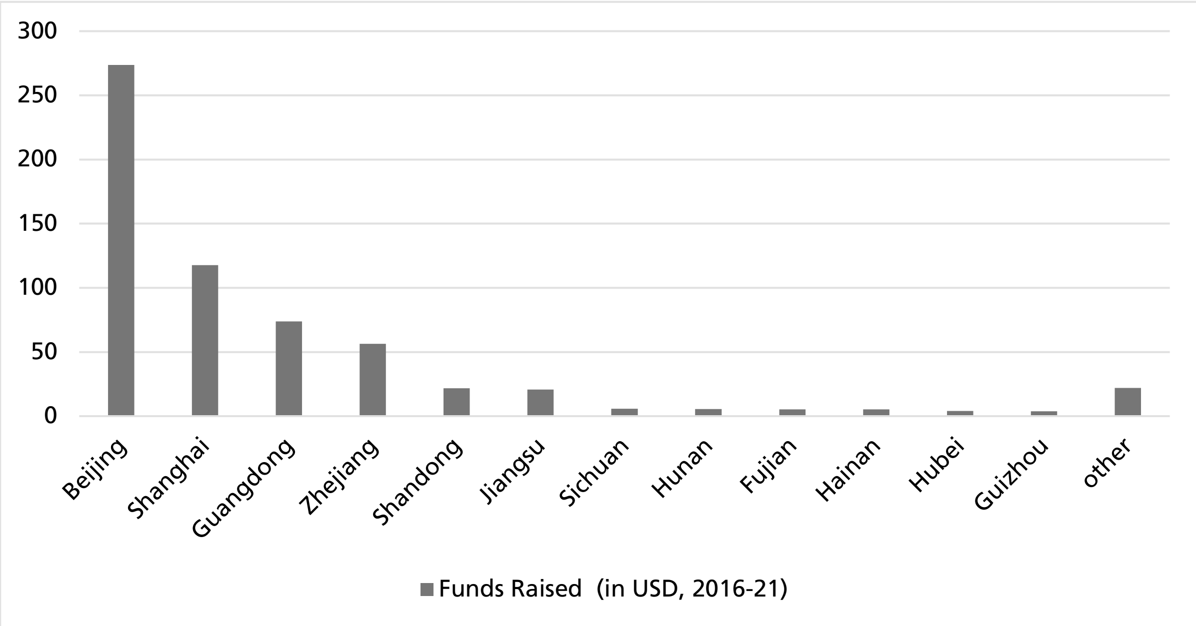
Source: authors' analysis based on CrunchBase

Figure 12: Investment (Money Raised in USD, 3Q Averages)



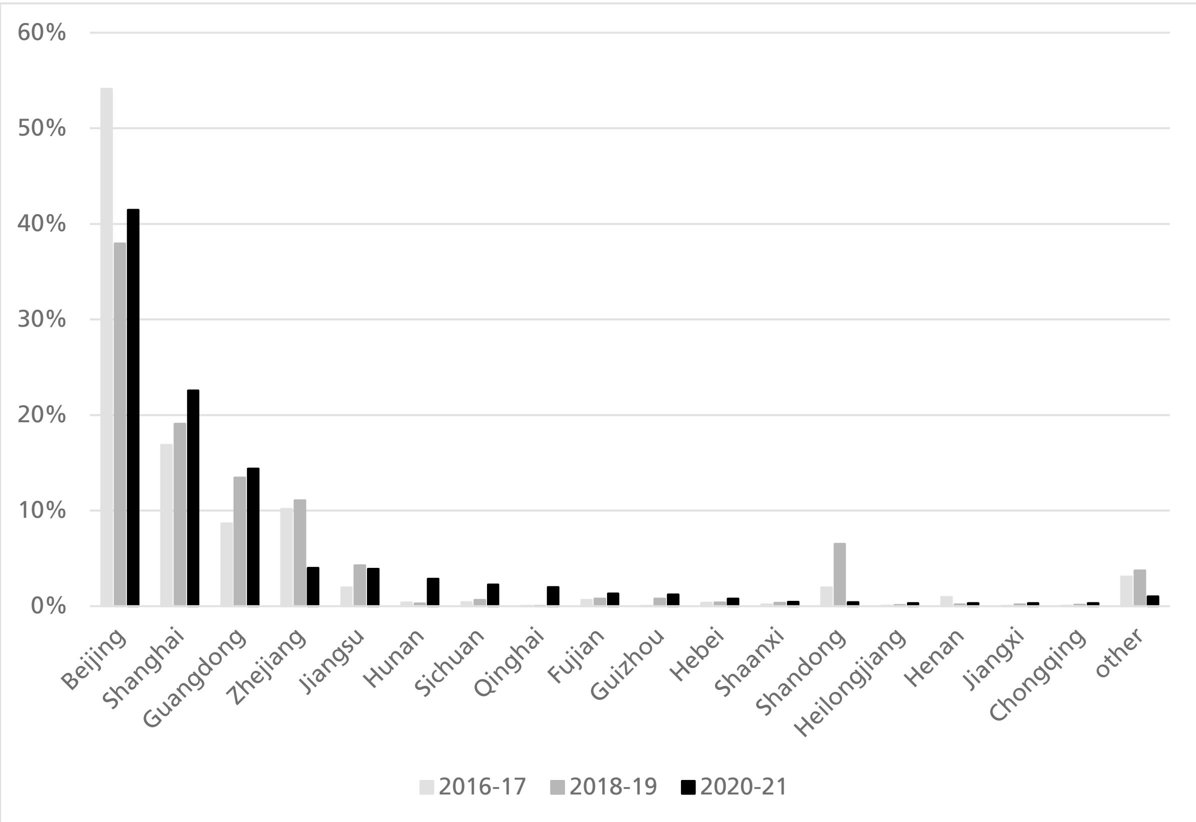
Source: authors' analysis based on CrunchBase

Figure 13: Funds Raised (in USD, 2016-21) by Province



Source: authors' analysis based on CrunchBase

Figure 14: Development of Shares of Funds Raised (in %) by Province



Source: authors' analysis based on CrunchBase

3 Discussion

Our first proposition that China has raised both the quantity and the quality of its scientific output has been confirmed – in principle. This development has increased the country's options to collaborate internationally. Despite a parallel overall surge in publications in both general and central topics concerning the future. China has increased and seems determined to further increase, its collaboration in the academic domain. Remarkably, such collaboration is in relative terms sought most in domains that could be considered politically charged and thus potentially problematic, i.e. the social sciences, economics and the humanities. As to be expected other focal areas of collaboration discuss overall global challenges (climate, ecology, geosciences), as well as national areas of industrial strength. Here China is still seeking to improve and update its knowledge base (informatics, biotechnology). Overall, it is thus obvious that China seems both capable and determined to integrate itself even better into the global academic system. This is used not least, as a device to further improve its academic capacities in areas of key national interest.

Concerning the second proposition, we indeed observe a parallel disintegration from technological collaboration, be it based on co-patenting as such or on proxy indicators for foreign direct investment. In the synopsis of all perspectives, we observe a decreasing role of foreign firms and international technology transfer. This is in line with an increasing rise of domestic firms that are on aggregate, they are therefore notably less inclined to internationally collaborate than their European or American peers. In particular, that seems to concern China's key industries and newly built fields of national strengths. In the computer technology and broader IT field, the share of collaborative patent applications is minimal with below 2.5%. In contrast, it is relatively high in more traditional areas such as chemistry in which China is known to actively seek international learning (materials, biotechnology, digital communication). Overall, two things are noteworthy with regard to the entirety of findings considered in this domain. First, it is obvious that China has moved past its first dynamic phase of technology imports, foreign investment and external learning since at least the aftermath of the 2008 economic crisis. While a lot of technology may still be imported (APRA), the degree of structural integration at a global level is unambiguously on the decline. Furthermore, Chinese firms have a lower inclination to technologically internationalise than their international counterparts. Notably, this is not a market size effect, as the respective figures differ markedly from those of the United States as well.

With a view to the third proposition, we have to concede that it is difficult to report on systemic issues of science industry collaboration with comparatively simple indicators. What we observe, however, points very clearly into a single direction. Since the most recent transformation of the world's technological system, i.e. the fully-fledged onset of digitalisation since around 2015, some shifts can be observed in the composition of patent applicants from China. One element of this is the role of SMEs, another an increasing role of public research which, taken together, may suggest the emergence of new, dynamically interconnected clusters. In parallel, publication data corroborates that Chinese firms have reached a level of expertise in pre-competitive technological development and have founded their innovation activities on scientific grounds. The substantial gap and obstacle that used to prevent most productive science-industry collaborations in China until the early 2010s do not seem to exist anymore. The share of national companies collaborating with national research organisations resembles that in most industrialised countries (Schubert and Frietsch 2018). The share of international enterprises collaborating with Chinese research organisations, however, is still rather low.

The fourth proposition addressed the antagonisms that emerge from international science and innovation up to system competition. Here we find remarkably limited evidence that the geopolitical paradigm from collaboration to contestation between e.g. the United States and China has left a notable imprint on collaboration patterns beyond what the abovementioned trends would have, by themselves, suggested in an otherwise stable institutional environment. One clear perspective is the obvious break in the trend of foreign ownership of Chinese inventions that occurred right after the leadership change in 2013. Obviously, some sort of techno-economic disintegration has thus occurred, at least in parallel to a recent geopolitical shift, particularly in terms of ownership and control. That said, most other figures show trends that are more continuous. They reflect either substantial differences between the externally-dependent 2000s and the increasingly self-reliant 2010s or very recent developments in line with the digital revolution. Hardly ever does 2013/14 appear as a decisive date, i.e. the most recent change in China's political leadership – to which many of China's recent moves towards inward-orientation have been attributed – may in itself been less uniquely responsible than sometimes suggested. Instead, first evidence of an emerging trend towards a less pronounced outward-orientation have been obvious before, as it is (also) a natural result of China's technological rise.

4 Conclusion

While this analysis may not have the scope to fully address all fundamental issues raised in the introduction, it has served to clarify some fundamental points that have so far remained insufficiently clear in the ongoing debate.

First, that China has moved beyond the stage of a traditional catching-up nation within the old technological world order since at least the early 2010s. Before that date, all indicators suggest substantive international dependency. Quite obviously, therefore, China has been in a follower position and in a skilful manner deployed different available means to emerge from it – which seems a first in modern history. After 2010, a new set up of collaboration emerges in which China acts at eye-level with most industrialised nations. Using the flying geese analogy, a second head of the flock has emerged, but it has so far not broken free from the formation. It still stays behind the leaders, but very closely – and still actively seeks some integration. At the same time, we see tentative evidence of new, domestic dynamics that coincide with the most recent technological transformation. Very likely, China is about to develop fully functional science-industry collaboration ecosystems at different levels. It does further limit the need for international sourcing.

Second, we find China's general openness in the technological domain has possibly always been fairly limited more so than obvious at first sight. While Western nations and firms have lived by the current concept of international integration since at least the 1950s, China has no such experience to build on, or possibly no inclination to reproduce a system of Western rules and regulation that would leave limited agency to China. In the past two decades, this fundamental given has been hidden by the intense dynamics of foreign direct investment during the 2000s and, more recently, the targeted investment activities of some Chinese firms abroad. Both, however, were and are sought for a purpose, which is confirmed by the current disciplines for collaboration – which continue to lie on primarily those areas where China continues to need external inputs. The overt majority of firms, in contrast, remains rather inward oriented. As opposed to Western countries, their environment may have never wholeheartedly subscribed to global integration as a principle. Now, as the immediate need has passed, this may not change. What should be noted, however, is that the absolute number of cross-ownerships in the technological domain remains on the increase. So the significance of Chinese foreign direct investment to target countries remains.

That said, we find a country that always has had a tendency and an inclination to develop independent economic and political agency based on its own strengths and maintain as many of the required capacities as possible within its national borders. While China is very willing to cooperate on knowledge development, it never appreciated the situation in the 1990s and 2000s when the country was exposed to and reliant upon other countries investing and giving technological input. Hence, its return to a position of technological self-sufficiency or at least sovereignty appears completely natural and expected. With a view to our data, much seems to suggest that this position is neither externally inflicted nor a result of the latest changes in its leadership. It is in line with China's known ambition to challenge the existing technological world order and to – rather than remaining a follower – assume the position of an independent, sovereign leader.

Certainly, these are consequential conclusions and further, more comprehensive, research will be required to corroborate and differentiate them further. This paper contributes to the debate, which allows us to position ourselves as respectful observers who acknowledge the achievements of the recent years.

5 References

Ahlgren, P.; Persson, O.; Tijssen, R. (2013): Geographical distance in bibliometric relations within epistemic communities. Scientometrics 95 (2), 771-784, https://doi.org/10.1007/s11192-012-0819-1.

Akamatsu, K. (1962): "A historical pattern of economic growth in developing countries". Journal of Developing Economies 1 (1), 3-25. https://doi.org/10.1111/j.1746-1049.1962.tb01020.x.

AsiaTechDaily (2020): Chinese Startup Ecosystem – Exclusive Year End Analysis – 2020 – All You Need To Know! https://www.asiatechdaily.com/chinese-startup-ecosystem-exclusive-year-end-analysis-2020-all-you-need-to-know/.

BBC News (2019): How China plans to lead the computer chip industry. By Danny Vincent. https://www.bbc.com/news/business-50287485.

Berger, J. (1996): Was behauptet die Modernisierungstheorie wirklich – und was wird ihr bloß unterstellt? Leviathan 24 (1), 45-62.

Berger, J. (2000): Modernization Theory and Economic Growth. In: Waltraud Schelkle, Wolf-Hagen Krauth, Martin Kohli und Georg Elwert (Hg.): Paradigms of Social Change: Modernisation, Development, Transformation, Evolution. Frankfurt/Main: Campus Verlag GmbH, 31-47.

Boeing, P. (2016): The allocation and effectiveness of China’s R&D subsidies – Evidence from listed firms. Research Policy, 45 (9), 1774-1789. https://doi.org/10.1016/j.respol.2016.05.007.

Boeing, P.; Mueller, E.; Sandner, P. (2016): China's R&D explosion – Analyzing productivity effects across ownership types and over time: Research Policy 45 (1), 159-176.

Brezis, E. S.; Krugman, P. R.; Tsiddon, D. (1993): Leapfrogging in International Competition: A Theory of Cycles in National Technological Leadership. The American Economic Review, 83 (5), 1211-1219.

Cao, C. (2004): Challenges for Technological Development in China’s Industry. Foreign investors are the main providers of technology. https://doi.org/10.4000/chinaperspectives.924.

Chen, A.; Patton, D.; Kenney, M. (2016): University technology transfer in China: a literature review and taxonomy. The Journal of Technology Transfer 41. https://doi.org/10.1007/s10961-016-9487-2.

Chen, K.; Kenney, M. (2007): Universities/Research Institutes and Regional Innovation Systems: The Cases of Beijing and Shenzhen: World Development, 35, 1056-1074.

Chen, Z. (2015): The Revival, Legitimization, and Development of Private Enterprise in China.

Cohen, W. M.; Levinthal, D. A. (1990): Absorptive capacity: A new perspective on learning and innovation. Administrative Science Quarterly, 35 (1), 128-152. https:// doi.org/10.2307/ 2393553.

Conlé, M.; Zhao, W.; ten Brink, T. (2020): Technology Transfer Models for Knowledge-Based Regional Development: New R&D Institutes in Guangdong, China. Science and Public Policy, 48 (1), 132-144, https://doi.org/10.1093/scipol/scaa063.

Crupi, A. (2020): Technology transfer and team boundary-spanning activities and their antecedents: do the classic measures apply to China? R and D Management https://doi.org/10.1111/radm.12441.

Cunha, L. (2015): China's techno-nationalism in the global era, In: Dasho Karma Ura, D.K.; Ordoñez de Pablos, P. (Eds.): Asian business and management practices: Trends and global considerations, Hershey, PA: IGI Global, 85-91. European Chamber 2017.

de Graaff, N.; ten Brink, T.; Parmar, I. (2020): China's Rise in a Liberal World Order in Transition, Introduction to the Special Forum, Review of International Political Economy, 27 (2), 191-207. https://doi.org/10.1080/09692290.2019.1709880.

Dong, M.; Flowers, S. (2016): Exploring innovation in Shanzhai: The case of mobile phones: Asian Journal of Technology Innovation 24, 234-253.

Ernst, D. (2011): China's Indigenous Policy as a Wake-up Call for America, Honolulu, HI: East-West Center.

Europäische Kommission (EASME), Heimberger, H., Karaulova, M. (2021): Advanced technologies for industry : international reports : advanced technology landscape and related policies in China, Publications Office, https://data.europa.eu/doi/10.2826/573690.

Fan, P. (2011): Innovation, globalization and catch-up of latecomers: cases of Chinese telecom firms. Environment and Planning A 43, 830-849.

Financial Times (2019): Beijing orders state offices to replace foreign PCs and software. Communist party directive aims to boost domestic tech supply chain. https://www.ft.com/content/b55fc6ee-1787-11ea-8d73-6303645ac406.

Foreign Policy (2020): China's Drive to Make Semiconductor Chips Is Failing: The stunning success of U.S. efforts to hobble Huawei shows the fragility of Beijing's highly centralized tech sector. https://foreignpolicy.com/2020/12/14/china-technology-sanctions-huawei-chips-semiconductors/.

Frietsch, R.; Neuhäusler, P.; Karpenstein, A.; Conlé, M.; Schüler-Zhou, Y.; Schüller, M.; Wieczorek, I. (2018): Monitoring des Asiatisch-Pazifischen Forschungsraums (APRA) mit Schwerpunkt China. 1. Bericht.

Frietsch, R.; Helmich, P.; Neuhäusler, P. (2017): Performance and Structures of the German Science System, Expertenkommission Forschung und Innovation (Ed.): Studien zum deutschen Innovationssystem No. 5-2017, Berlin: EFI.

Frietsch, R.; Gruber, S.; Helmich, P.; Neuhäusler, P. (2016): Analyse bibliometrischer Indikatoren im Rahmen des Pakts für Forschung und Innovation, Phasen I und II, Karlsruhe: Fraunhofer ISI.

Frietsch, R.; Rothengatter, O.; Neuhäusler, P.; Helmich, P.; Gruber, S. (2016): Bibliometrische Analyse des Asiatisch-Pazifischen Raums 2016, Hintergrundbericht für das Bundesministerium für Bildung und Forschung (BMBF) im Rahmen eines Projekts für das Deutsche Zentrum für Luft- und Raumfahrt (DLR), DLR Projektträger Amerika, Asien, Ozeanien, Karlsruhe: Fraunhofer ISI.

Frietsch, R.; Neuhäusler, P.; Jung, T.; van Looy, B. (2014): Patent indicators for macroeconomic growth – The value of patents estimated by export volume. Technovation 34 (9), 546-558.

Frietsch, R.; Schmoch, U. (2010): Transnational Patents and International Markets. Scientometrics 82 (1), 185-200.

Frietsch, R.; Schmoch, U.; van Looy, B.; Walsh, J. P.; Devroede, R.; Du Plessis, M.; Jung, T.; Meng, Y.; Neuhäusler, P.; Peeters, B.; Schubert, T. (2010): The Value and Indicator Function of Patents, Expertenkommission Forschung und Innovation (Ed.): Studien zum deutschen Innovations-system No. 15-2010, Berlin: EFI.

Frietsch, R.; Hinze, S.; Tang, L. (2008): Bibliometric data study. Assessing the current ranking of the People's Republic of China in a set of research fields. Karlsruhe: Fraunhofer ISI.

Fu, W.; Revilla Diez, J. R.; Schiller, D. (2012): Regional innovation systems within a transitional context: Evolutionary comparison of the electronics industry in Shenzhen and Dongguan since the opening of China: Journal of Economic Surveys, 26, 534-550.

Fukuyama, F. (1992): The End of History and the Last Man, New York: The Free Press.

Global Times (2019): China’s tech firms won’t give up on overseas markets https://www.globaltimes.cn/content/1135834.shtml (letzter Abruf 01.10.2021).

Grupp, H. (1998): Foundations of the Economics of Innovation. Theory, Measurement and Practice. Cheltenham: Edward Elgar.

Gu, S. (1999): China's Industrial Technology: Market Reform and Organisational Change. London: Routledge.

Guellec, D.; van Pottelsberghe de la Potterie, B. (2001): The internationalisation of technology analysed with patent data, Research Policy 30 (8), 1253-1266, https://doi.org/10.1016/S0048-7333(00)00149-9.

Hemmert, M.; Cross, A. R.; Cheng, Y.; Kim, J.-J.; Kohlbacher, F.; Kotosaka, M.; Waldenberger, F.; Zheng, L. J. (2019): The distinctiveness and diversity of entrepreneurial ecosystems in China, Japan, and South Korea: an exploratory analysis Asian Business and Management 18 (3), 211-247.

Hoekman, J.; Frenken, K.; Tijssen, R. J. W. (2010): Research collaboration at a distance: Changing spatial patterns of scientific collaboration within Europe. Research Policy 39 (5), 662-673.

Hyun, S.; Lee, H.; Oh, Y.; Cho, K. (2020): China’s Startup Ecosystem Policy and Implications, World Economy Brief. https://think-asia.org/bitstream/handle/11540/12235/WEB20-17.pdf?sequence=1.

Kaiji, X.; Crupi, A.; Di Minin, A.; Cesaroni, F. (2021): Team boundary-spanning activities and performance of technology transfer organizations: evidence from China Journal of Technology Transfer.

Kasahara, S. (2004): "The Flying Geese Paradigm: A Critical study of Its Application to East Asian Regional Development" (PDF). United Nations Conference on Trade and Development. Discussion Paper 169. CiteSeerX 10.1.1.871.3.

Koleski, K.; Salidjanova, N. (2018): China’s Technonationalism Toolbox: A Primer. U.S.-China Economic and Security Review Commission, Issue Brief, Washington D.C.

Kroll, H. (2011): Exploring the validity of patent applications as an indicator of Chinese competitiveness and market structure, World Patent Information, 33 (1), 23-33.

Kroll, H.; Liefner, I. (forthcoming): User-Driven Innovation with Frugal Characteristics. On Lasting and Technologi-cally Renewed Foundations of China's Innovation-Driven Economy. In: Brem, A.; Agarwal, N. (Hrsg.): Frugal Innovation and its Implementation. Leveraging constraints for driving innovations on a global scale. Springer.

Kroll, H.; Schüller, M.; Conlé, M.; Cuhls, K.; Knüttgen, N.; Neuhäusler, P.; Schäfer, C.; Tiwari, R. (2021): Monitoring des Asiatisch-Pazifischen Forschungsraums (APRA), 3. Bericht. Berlin, Bonn: BMBF, DLR.

Kroll, H.; Conlé, M.; Hillmann, J.; Neuhäusler, P.; Schüller, M.; Wieczorek, I. (2020): Monitoring des Asiatisch-Pazifischen Forschungsraums (APRA), 2. Bericht. Berlin, Bonn: BMBF, DLR.

Kroll, H.; Schiller, D. (2014): The role of public R&D funding in innovation systems of East Asian and ASEAN catch-up coutries. In: Irawati, D.; Rutten, R. (Ed.): Emerging Knowledge Economies in Asia. Abingdon: Routledge, 94-126.

Kroll, H.; Schiller, D. (2010): Establishing an interface between public sector applied research and the Chinese enterprise sector: Preparing for 2020. Technovation 30 (2).

Kroll, H.; Liefner, I. (2008): Spin-off enterprises as a means of technology commercialisation in a transforming economy – Evidence from three universities in China. Technovation 28 (5), 298-313.

Liefner, I. (2014): Explaining regional development and innovation in China: how much can we learn from applying established Western theories. In I. Liefner & Y.D. Wei (Eds.), Innovation and regional development in China (21-40). New York, NY [u.a.]: Routledge.

Liefner, I.; Kroll, H. (2019): Advancing the structured analysis of regional innovation in China. Integrating new perspectives in a comprehensive approach. Erdkunde 73 (3), 167-184.

Liefner, I.; Kroll, H.; Peighambari, A. (2016): Research-driven or party-promoted? Factors affecting patent applications of private SMEs in China's Pearl River Delta, Science and Policy Policy, https://doi.org/10.1093/scipol/scw002.

Liefner, I.; Wei, Y. D. (2014): Innovation and Regional Development in China. New York, London: Routledge.

Liefner, I.; Wei, Y. D.; Zeng, G. (2013): The innovativeness and heterogeneity of foreign-invested high-tech companies in Shanghai: Growth and change a journal of urban and regional policy, 44, 522-549.

Lindtner, S. (2014): Hackerspaces and the Internet of Things in China: How makers are reinventing industrial production, innovation, and the self: China Information, 28, 145-167.

Liu, H.; Jiang, Y. (2001): Technology transfer from higher education institutions to industry in China: nature and implications. Technovation 21, 175-188.

Liu, L. (2021): The Rise of Data Politics: Digital China and the World Studies in Comparative International Development 56 (1), 45-67.

Liu, X.; Gao, T.; Wang, X. (2018): Regional Innovation Index of China: 2017: How Frontier Regions Innovate. Singapore: Springer Singapore.

Liu, X.; Xie, Y.; Wu, M. (2015): How latecomers innovate through technology modularization: Evidence from China's Shanzhai industry: Innovation: organization & management IOM, 17, 266-280.

Liu, X.; White, S. (2001): Comparing innovation systems: a framework and application to China's transitional context. Research Policy 30 (7): 1091-1114.

Ma, Y.; Cai, J.; Wang, Y.; Farooq Sahibzada, U. (2021): From venture capital towards venture firm innovation performance: Evidence from SMEs of China Journal of Intelligent and Fuzzy Systems 40 (4), 8109-8115.

May, C.; Nölke, A.; ten Brink, T. (2019): Public-Private Coordination in Large Emerging Economies: The Case of Brazil, India and China, Contemporary Politics, 25 (3), 276-291.

Michels, C.; Schmoch, U. (2012): The growth of science and database coverage. Scientometrics 93 (3), 831-846.

Nakayama, S. (2012): Techno-nationalism versus Techno-globalism. East Asian Science, Technology and Society: An International Journal, 6 (1), 9-15.

Naughton, B.; Tsai, K. S. (2015): State capitalism, institutional adaptation, and the Chinese miracle. Cambridge University Press, Cambridge.

Negara, S. D.; Suryadinata, L. (2021): THE FLYING GEESE and CHINA'S BRI in INDONESIA, Singapore Economic Review 66 (1), 269-292.

Nirei, M.; Shoji, T.; Yu, F. (2021): Formation of Chinese venture capital syndication network, Japanese Economic Review 72 (1), 49-64.

Nölke, A.; ten Brink, T.; Claar, S.; May, C. (2020): State-permeated Capitalism in Large Emerging Economies. Basingstoke: Routledge (RIPE Series in Global Political Economy).

OECD (2018): Oslo manual 2018. Guidelines for collecting, reporting and using data on innovation, 4th edition, Paris: OECD Publishing.

Ozawa, T. (2006): Institutions, Industrial Upgrading, and Economic Performance in Japan: The "flying-geese" Paradigm of Catch-up Growth. Edward Elgar. ISBN 978-1-84720-197-3.

Prud'homme, D.; von Zedtwitz, M.; Thraen, J. J.; Bader, M. (2018): "Forced technology transfer" policies: Workings in China and strategic implications Technological Forecasting and Social Change, 134, 150-168.

Radosevic, S. (1998): National Systems of Innovation in Economies of Transition: Between Restructuring and Erosion. Industrial and Corporate Change 7, 1, 77-108.

Roberts, H.; Cowls, J.; Morley, J.; Taddeo, M.; Wang, V.; Floridi L. (2021): The Chinese approach to artificial intelligence: an analysis of policy, ethics, and regulation. AI & Society 36, 59-77. https://doi.org/10.1007/s00146-020-00992-2.

Rostow, W. W. (1960): The stages of economic growth. A non-communist manifesto. Reprinted. Cambridge: Univ. Press.

Schubert, T.; Frietsch, R. (2018): Strukturen der österreichischen Kooperationsbeziehungen in Wissenschaft, Forschung und Entwicklung. Wirtschaftspolitische Blätter (Nr. 4), 527-542.

Schwaag Serger, S.; Breidne, M. (2007): China's Fifteen-Year Plan for Science and Technology: An Assessment, Asia Policy, 4. https://doi.org/10.1353/asp.2007.0013.

Segal, A. (2003): Digital Dragon: High-Technology Enterprises in China. Ithaca, Cornell University Press.

Sheehan M. (2018): How China's Massive AI plan actually works. Marco Polo. https://macropolo.org/chinas-massive-ai-plan-actually-works/.

Si, Y. F.; Liefner, I.; Wang, T. (2013): Foreign direct investment with Chinese characteristics: A middle path between Ownership-Location-Internalization model and Linkage-Leverage-Learning model. Chinese Geographical Science 23 (5), 594-606.

Stahlschmidt, S.; Stephen, D.; Hinze, S. (2019): Performance and structures of the German science system, Expertenkommission Forschung und Innovation (Ed.): Studien zum deutschen Innovationssystem No. 5-2019, Berlin: EFI.

Suttmeier, R. P. (2014): Trends in U.S.-China Science and Technology Cooperation: Collaborative Knowledge Production for the Twenty-First Century. Research Report Prepared on Behalf of the U.S.-China Economic and Security Review Commission, Washington.

Suttmeier, R. P. (2005): A new technonationalism? China and the development of technical standards. Communications of the ACM, 48 (4), 35-37.

ten Brink, T. (2019): China's Capitalism. A Paradoxical Route to Economic Prosperity. Philadelphia: University of Pennsylvania Press.

ten Brink, T. (2015): Chinese Firms 'Going Global': Recent OFDI Trends, Policy Support, and International Implications, International Politics, 52:6, 666-683.

Tagscherer, U.; Frietsch, R. (2014): E-mobility in China: Chance or daydream. Discussion Papers Innovation Systems and Policy Analysis No. 40, Karlsruhe: Fraunhofer ISI.

Tang, Y.; Motohashi, K.; Hu, X.; Montoro-Sanchez, A. (2020): University-industry interaction and product innovation performance of Guangdong manufacturing firms: the roles of regional proximity and research quality of universities, Journal of Technology Transfer, 45, 578-618.

Techspot (2021): China will use aging chips while its semiconductor industry catches up – A bold plan to get around US export controls By Adrian Potoroaca. https://www.techspot.com/news/88838-china-use-aging-chips-while-semiconductor-industry-catches.html.

Walcott, S. M. (2003): Chinese Science and Technology Industrial Parks, Aldershot: Ashgate.

Wang, T.; Kroll, H.; Wang, L.; Zheng, X. (2020): How S&T connectivity supports innovation-driven development. An analysis of China's cooperation networks in high and new technology fields. Asian Journal of Technology Innovation. https://doi.org/10.1080/19761597. 2020. 1792783.

Wei, Y. D. (2014): FDI networks, R&D activities and the making of global cities in China. Innovation and Regional Development in China, 97-120, ed. Liefner, I., and Wei, Y.D., New York, London: Routledge.

Weinhardt, C.; ten Brink, T. (2019): Varieties of Contestation: China's Rise and the Liberal Trade Order. Review of International Political Economy, https://doi.org/10.1080/09692290.2019. 1699145.

Wilsdon, J. (2007): China: The next science superpower? Engineering & Technology, 2 (3), 28-31.

Xu, C. (2011): The Fundamental Institutions of China's Reform and Development, Journal of Economic Literature, 49 (4), 1076-1151.

Xu W. Q.; Qiao, N. N. (2018): 'Review and Prospect on New Type R&D Instutions in China Based on Domestic Researches form 2001 to 2016' (in Chinese), Science and Technology Management Research, 12/2018, 1-8.

Yang, C. (2015): Government policy change and evolution of regional innovation systems in China: evidence from strategic emerging industries in Shenzhen. Environment and Planning C: Politics and Space. https://doi.org/10.1068/C12162r.

Yang, C. (2014): Emerging regional innovation systems in Shenzhen, China: Technological evolution of foreign-invested and indigenous firms, Innovation and regional development in China: New York, NY [u.a.], Routledge, 191-215.

Zhang, X.-W.; Du, Y.-F.; Zeng, M. (2021): Analysis of the promotion effect of China's financial venture capital development on innovative capital Journal of Testing and Evaluation 49 (4).