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Research Cooperation Between Universities and Local Firms: Comparing University Ecosystems in China and the USA

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Abstract

The academic research systems of China and the USA are characterised by different policies and practices with regards to *university-business research cooperation* (UBRC). To examine those differences, from the perspective of research-intensive universities, this study's analytical framework focuses on university research outputs that involve collaboration with local business sector partners. More specifically, university-business co-authored publications with authors from a business enterprise located within a 50 km range of the university's city of location (*UBRC_50km publications*). The study comprises 193 research-intensive universities in China and 179 in the United States. Regression modelling of each country's UBRC_50km publication output levels comprise two models: (1) 'internal' research profiles of universities; (2) extended model with two 'external' variables related to characteristics of the local geographical area. The findings of model 1 show that the two university research systems seem fairly similar in terms of UBRC_50km output patterns. When external explanatory factors are included, some significant differences emerge: in the USA, UBRC_50km output is significantly affected by the total patent output of the local area (i.e. patents of universities and local firms) representing the local R&D system; in China, it's the number of other large research-intensive universities located in the same city or metropolitan area, thus reflecting the positive effects of urban agglomeration and the local science system.

Keywords United States · China · University research performance · University-business cooperation · Bibliometrics · Local science systems

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Introduction

University Research Cooperation with Local Firms

The regional dimension of university's propensity for research-based entrepreneurship, commercialization and R&D cooperation with business sector partners has been studied extensively in the academic literature (e.g., Berman, 1990; Drucker & Goldstein, 2007). But joint research with the business sector in their hometown or local metropolitan area is still an under-studied topic (e.g., Steinmo & Lauvås, 2021), especially in terms of performance measurement and developing comparative international statistics (Mark et al., 2014). Narrowing the analysis to a university's research collaboration activities with the business sector partners in the university's local territory, this study focusses on *university-business research cooperation* (UBRC) framed against the backdrop of geographic enabling factors and regional economic development policies (Ankrah and Omar, 2015; Olphin et al., 2024).[1]

It is fair to assume that a university's UBRC profile will depend on a mix of internal, organizational preconditions as well as external factors. The country in which a university is located, and where it concentrates a most of its operations, is likely to be an important external factor to UBRC activities, outputs and impacts. Close-proximity research-based collaboration will inevitably be affected by macro-level economic framework conditions, institutional frameworks, market forces, government policies. UBRC profiles of universities may also differ considerably because of local geographical territory (cities, metropolitan areas) in which they are located, mostly with regards to enabling factors such inter-organizational networks and R&D funding opportunities.

The spatial distance between a university and its business sector R&D partners can play a significant role in shaping local science systems, where one or more research-intensive universities act as an attractor for developing and transferring ideas or technologies through university spin-off firms in science parks or R&D partnerships with high-tech companies nearby. Over the years, many empirical studies of the co-authorship linkages found that research collaboration between different main organizations is more effective or intense as geographical proximity increases (Frenken et al., 2009). It is fair to assume that the scale and intensity of research cooperation with business enterprises will decrease when business enterprises are further away from the university's physical location. This effect is partially explained by the role of person-embodied 'tacit knowledge' that is difficult to transfer across large distances, or social or cultural boundaries, without personal contacts with business sector partners (Muscio, 2013). Very few large-scale empirical studies exist on the role of individual 'cross-sectoral' researchers who function as intermediates between universities and local firms, by initiating or supporting institutional interfaces and contributing to inter-organizational interactions. Recent

[1] In this paper, the term 'local' refers to a close-proximity geographic area surrounding the home city or metropolitan area of the university's main research-active campus. The term 'university' will refer to any kind of doctoral degree awarding higher education institution (HEI) with an official research mandate, and/or inclusion of scientific research in its strategic objectives and plans, that have one or more institutionally recognized research units, and—least one regular PhD program.

work by Yegros-Yegros and colleagues shows that the presence of such 'boundary-spanning' researchers within a university is related to the physical distance between university and its partnering firms (Yegros-Yegros et al., 2021).

Objective of Study

Some features of a university's UBRC outputs will be relatively easy to detect and monitor, such as joint research publications, patent licenses to local firms and university spin-off companies. Other outputs and impacts are less visible and be difficult to identify. Adopting a quantitative comparative approach based on empirical data, this study focusses on only one specific aspect of a UBRC profile: a university's organizational capability to successfully engage in research cooperation with partners—business enterprises. The level of cooperation is measured by way of research publication output.

The analytical focus of this paper is on publications that were co-authored by academic researchers and their local business sector partners, i.e., the R&D staff employed by companies that located in the university's immediate territorial surroundings. Applying a distance metric to assess the level of spatial proximity enables comparisons of UBRC output across universities in any territory or country worldwide.[2] Counting these university-business research co-authored publications may comprise a range of analytical units—from micro-level individual researchers to comparative studies of university systems in the USA and China (e.g. Li et al., 2020).

This paper's case study of the USA and mainland China is an extension of an earlier empirical, quantitative study that applied the same approach to assess UBRC output patterns in both countries (Zhou et al., 2016). Following the distance measure adopted in that study, the 'local distance zone' of university is defined by a 50 km (km) radius. The output of university-business co-authored publications with author affiliate addresses referring to a business enterprise located within a 50 km range of the university's city of location or where its (main) campus is located. These will be denoted as *UBRC_50km* publications. Local companies are thus defined as those business enterprises where the corporate author on the research publication mentions a physical address within 50 km from the university's city centre.[3] The 50 km range to demarcate the university's local zone has also been used subsequent studies (Tijssen et al., 2020; Van Raan, 2022).[4]

Expanding on Zhou et al. (2016), this paper compiles the *UBRC_50km* publication count data across the hundreds of universities in both countries to compare the national university research systems. The two key questions underpinning the system-level analysis are: (1) to what degree are UBRC_50km outputs determined by university related 'internal' factors or local area related 'external' factors; (2) is there a significant difference between both countries as to the significance of those factors?

[2] The geographic distance between a co-authoring university and the company is measured as the spatial distance (in kilometers) using the latitude and longitude of city mentioned in author addresses of the university and the company.

[3] Where local branches of multinationals are considered a 'local firm' in this computerised algorithm, the city of the university's main campus is used as the sole geolocation of the university.

[4] A closely related study applied a 100 km range to define local UBRCs (Li et al., 2020).

The remainder of the paper is structured as follows: the next section elaborates on the research literature on internal and external explanatory factors of a university's UBRC profile, and also introduces the study's research hypotheses that drive the statistical analysis; the following section further introduces the case study by describing similarities and differences between Chinese and US university systems with regards to UBRC-relevant factors; the fourth section presents the analytic model, the data variables and information sources used; the main results of the statistical analyses are presented in the fifth section; The final section discusses some general observations and implications from these findings.

Literature Study and Research Hypotheses

Internal Factors: R&D Capacity and Performance of Universities

Recent academic studies also highlight positive effects of research cooperation between universities and companies, arguing that such universities may help to build or enhance local R&D capabilities and human resources within companies (Mascarenhas et al., 2018; Nsanzumuhire & Groot, 2020; Sjöö & Hellström, 2019). Successful research collaboration with business sector partners depends on university-business R&D programs and infrastructures such as science parks. Universities with sizable research activities in STEM fields of science (science, technology, engineering, and mathematics) are more likely to develop knowledge and know-how of particular interest to business sector R&D (OECD, 2016). Business sector-oriented research agendas and entrepreneurial cultures are often found—'technical' universities that specialize in engineering sciences or computer sciences. Such universities are more likely to create university spin-off companies and engage in research cooperation with business enterprises in industrial sectors such as chemicals, IT, electronics, and semiconductors. The other large category of business sector-relevant research universities is the one that specializes in medical, health and life sciences. These universities, which usually have affiliated teaching hospitals and clinics, are much more likely to engage in research cooperation with local companies in biotechnology and pharmaceuticals sector.

Large research-intensive universities offer economies of scale and scope in their research portfolio and available resources. The larger the university's research size, the more likely it is that the university is based in a densely populated and industrialized area and will be able to successfully engage in research cooperation with local companies. Universities located in densely populated and industrialized metropolitan areas will benefit from geographic agglomeration of economic activities, availability of resources, local knowledge spill0vers from other organizations, and the presence of specialist labor local markets. Such 'knowledge dense' areas, often a national capital or a major city within an industrialized region or province, are more likely to be the home base of R&D-active business enterprises that cooperate with local universities. Owing to their sheer scale, large research universities are often better positioned to mobilize the R&D resources and expertise to engage in external local partnerships, thus boosting the chances to create local innovations (e.g., Ramirez & Castro, 2019).[5] Assessing the possible effect of university's volume of research output leads to the first hypothesis to be tested separately for US universities and those in China:

> H1: the total number of research publications produced by a university, is a significant contributing factor to the scale of its UBRC_50km publication output.

Universities can stimulate university-business collaboration through the creation of dedicated organizational units and an internal interface structure such as technology transfer offices, industrial liaison offices, technology licensing offices, or innovation and technology centers (e.g., Brescia et al., 2016). Those universities that operate such units tend to measure and monitor their technological development performance in terms of their patent applications, patent licenses or revenues earned on those licenses (e.g., Acs et al., 2002). The research culture within a university, especially its academic incentive systems, may shape and influence the propensity of faculty members to pursue research commercialization and file for patents to protect intellectual property.

The size of the university's patent portfolio reflects an active support for science-based technological development but also an interest in research commercialization, technology-based innovations, and related business activities. Such 'entrepreneurial universities' are more likely to create spin-off companies and cooperate with other R&D-active companies in the local area. The volume of a university's patent output is likely to reflect an organization's orientation towards research-based technological development, entrepreneurship, and active engagement with the partners in the business sector (Tijssen, 2004), thus introducing the next hypothesis to be tested:

> H2: the number of university-owned patents is a significant contributing factor to the scale of its UBRC_50km publication output.

University–business research activities often rely on informal and formal social links between collaborating individuals (e.g., Audretsch & Stephan, 1996; Oliver & Liebeskind, 1998; Owen-Smith & Powell, 2004). Their relevance is rooted in scientific research and knowledge creation as a socially embedded process where relationships and networks universities and private sector research partners (e.g., Malmberg & Maskell, 2002). Such links create 'relational involvement' via personal face-to-face contacts and exchanges of inside information and tacit knowledge (Perkmann & Walsh, 2007; Schartinger et al., 2002). The university's resource base of researchers engaged in cooperation with the business sector can then become in institutional capacity building and a key factor in local R&D networks and research systems.

Interactions and connections between universities and local business sector partners are often driven or supported by a range of 'boundary spanners' within universities: intermediates such as technology transfer offices, collaborative research centers, innovation hubs or science parks (Benneworth & Fitjar, 2019; Nsanzumuhire

[5] Large research universities are less likely to fully align their research agendas to the needs of local or regional industry, partly because they need to take a more national and international outlook in recruiting staff and sourcing research funding.

& Groot, 2020; Perkmann et al., 2013). Although a university may comprise of many types of researchers engaged in cooperation with business sector, the subset of ‘hybrid’ researchers, those with either a history of cross-sectoral job mobility and/or those holding multiple affiliations simultaneously in academia and business sector, may prove particularly relevant for UBRC.

These university-business *boundary-spanning researchers* may have spent time as a student internship—a local company or were previously employed in the local business sector. Owing to their personal experience and expertise they may function as change agents to foster knowledge transfer or initiate collaboration between universities and business sector partners. Prior empirical studies suggest that these boundary-spanning are indeed one of the enabling factors of local university-business research cooperation (Gulbrandsen & Thune, 2017; Tijssen et al., 2020; Yegros-Yegros & Tijssen, 2014) and therefore a suitable proxy measure to gauge UBRC profiles of universities and their research staff.

The boundary-spanning researchers who hold simultaneous (‘dual’) affiliations—a university and a business enterprise are likely to signify strong and institutionalized ties between academia and R&D-active business enterprises (Yegros-Yegros and Tijssen, 2014; Yegros-Yegros et al., 2021).[6] Dual affiliate researchers are likely to be familiar with research practices in academic science as well as industrial R&D and are therefore able to understand science from a business interest perspective (Breschi & Lissoni, 2009; Mangematin et al., 2014; Tijssen, 2018).

Many of these boundary spanners can be identified by analyzing author affiliate address information in a university’s research publications, especially in co-authored research publications that were co-produced by universities and their institutional research partners from the business sector (Tijssen, 2012). Hence, cross-sectoral boundary-spanning researchers offer an interesting micro-level analytical perspective on university-business research cooperation and on how universities are connected to local business sector partners. This prompts the next hypothesis for testing:

> H3: the number of boundary-spanning researchers within a university is a significant contributing factor to the scale of its UBRC_50km publication output.

External Factors: R&D Capability and Performance of the Local Urban Area

UBRC also depends on local conditions outside the university’s direct control, such as the area’s level economic development or available R&D-active organizations. Depending on type of university involved and its geographic location, UBRC outputs can also be heavily affected by the R&D-intensity of the local innovation

[6] Boundary-spanning researchers may have temporary or tenured positions—a university, either part-time or full-time. In this paper it is assumed that there are no differences between either subgroup in terms of their institutional relationship(s) and R&D involvement with (local) industry. Dual affiliated ‘multi-institutional’ researchers include those who are employed by one organization but visiting another organization for an extended period, or external PhD students from the business sector who were temporary affiliated to a university of training.

system or the university's degree of autonomy within overarching national higher education policies, regulations, and legislation (e.g., Reichart, 2019). Universities in countries with more developed municipal or regional governance systems and decentralized political powers are more likely to see engagement with local partners as a core part of their institution's mission and will be more likely to be engaged with local business sector, if only because of funding systems and resource allocation mechanisms that are designed to support such engagement.

Local economic development and urban agglomeration are correlated with the size or R&D-density of local or regional innovation systems (e.g., Orlando et al., 2019). R&D-intensive local innovation systems can become 'innovation hotspots' with economies of scale and scope that attract R&D-active business enterprises and incentivize local universities to fully realize their innovation potential (WIPO, 2019). Local proximity effects may then arise because of research-intensive, innovative firms are agglomerating and clustering around such universities for reasons of cost-reduction and opportunities to benefit from R&D spillovers from the university or other business enterprises (Griliches, 1992; Jaffe, 1989). Increasing demand for connections into local universities from a growing population of innovative firms the concentration of high-technology industries may lead to a virtuous circle of university-business cooperation as has happened in the case of *Stanford University* and the San Francisco Bay area. Such metropolitan R&D networks and local innovation hot spots usually comprise of several large research-intensive universities.

University-dense cities or geographic areas are more likely to represent R&D-intensive areas, with a well-developed local innovation system and many (potential) research partners for universities, than lesser-developed, low-density areas which usually suffer from 'institutional thinness' in their local innovation system (Tödtling & Trippl, 2005) marked by a lack of knowledge-intensive business enterprises or suffer from an underdeveloped R&D-led business sector (Vallance et al., 2018). Research-active universities may then be forced to play a dominant role in the local innovation system to fill gaps created by a scarcity of R&D-active firms or other innovation actors (Bonaccorsi, 2017; Marques et al., 2019). University-business R&D interactions and local research collaboration are then much less likely to occur. The interdependence between universities and their local geographic environment leads to the hypothesis:

> H4: the university density of a city is a significant contributing factor to the scale of UBRC_50km publication output of universities in that city.

Case study: Comparing Universities in the United States and China.

All four hypotheses are applied to China and USA, the world's largest nations in terms of university research systems. To properly interpret the findings, it is important to account for system-level differences and similarities between both countries. Most research-intensive universities in the USA and those in mainland China share a common goal of fostering research to advancing knowledge but also to drive innovation and economic development. Both countries actively support university-business research cooperation. The Chinese policy and regulatory landscape have evolved quite rapidly in recent years (Su et al., 2015; Hou et al., 2021; Liu et al., 2024). Nonetheless, several structural differences exist between the two national research systems—shaped by their historical, cultural, and institutional contexts – that may significantly impact on internal and external factors of a university's UBRC outputs.

Research-intensive universities in the USA operate in more devolved higher education system where universities often receive funding from a variety of sources, including federal agencies, private foundations, and business sector partnerships. The universities typically enjoy a high degree of academic freedom and autonomy in decision-making. They are often governed by boards of trustees and faculty senates, allowing for a decentralized and diverse academic landscape. Many research-intensive universities have a long history of research excellence, cover a wide range of disciplines and are known for their diverse research portfolios. They also have a long tradition of international collaboration and attract researchers and students from around the world, which enables them to attract top research talent more easily and invest in innovative research facilities. Research-intensive universities widely dispersed across all states and their major cities.

Chinese research-intensive universities may have less autonomy, with the government playing a more prominent role in governance and decision-making. Many universities receive government funding and support for specific research projects. Universities have a stronger focus on government-supported research priorities, including areas such as technology, engineering, and strategic sectors. The large and leading universities are increasingly aiming to establish themselves as global research hubs and some now occupy top positions in global university rankings. These universities are also actively pursuing international collaborations, but some political and regulatory factors can influence the extent and nature of these partnerships. China's most research-intensive universities are more concentrated in the country's largest cities.

As for structural differences related to UBRC_50km publications, there are several notable differences between the USA and China owing to varying institutional, cultural, and regulatory contexts in the way university-business interactions and cooperation is structured and regulated. In the United States, there is a well-established legal and regulatory framework, notably the Bayh-Dole Act, which encourages university-business collaboration. US universities often maintain strong protections for researchers' intellectual property (IP), and they actively seek to license or commercialize innovations through technology transfer offices. The USA has a well-established and diverse private sector with a long history of collaborating with research-intensive universities. Business sector partners can range from small startups to multinational corporations. In the case of the US universities, university-business collaboration therefore spans a wide range of R&D areas and R&D-intensive industries. University-business research partnerships often rely on a mix of federal grants, business sector funding, and private investments. These collaborations can lead to significant commercialization opportunities.

In China, government policies have been shifting to encourage universities to better protect and commercialize IP. Universities may have less experience in IP management and technology transfer. The Chinese government has introduced policies to promote university-business collaboration, but there may be more government oversight and involvement in technology transfer and intellectual property rights. Government priorities can heavily influence university-business collaboration with a stronger focus on key strategic industries. Some of the university-business collaborations may involve large state-owned enterprises or government-affiliated firms, reflecting the country's business environment. Government funding, particularly—the local and provincial levels, may play a more prominent role in supporting university-business R&D projects.

Some of the above system-level differences shine through in national macro-level R&D statistics. According to the official OECD statistics, the share of R&D expenditure of Chinese higher education system funded by the business sector was 26.6% in 2018; the comparative figures for USA was only 5.4% (OECD, 2022). It is unreasonable to assume that business sector funding in China is predominantly targeted—supporting the large research universities, nor that expenditures on Chinese universities will not always be designated for academic research or university-business cooperation. Comparing the total shares of all university-business co-authored publications (irrespective of the partner firm's geographic location) in the total publication output of all selected universities in our study, Chinese universities score an average of 4.3%. This is significantly less than 6.3% for universities in the USA.

The Chinese R&D-intensive business sector seems to be catching up with the USA: according to a research study, their co-publication output with universities and other public research institutes has substantially increased across the past decade and is now probably on par with the share of American firms in the total national research publication output of the USA (Kroll & Frietsch, 2022). This upsurge is the product of a series of Chinese government policies and five-year plans in science, technology, and innovation (STI), and associated investments in university research (e.g., Horvart, 2021). Chinese government policies to develop a knowledge economy by boosting investments in STI became a national strategy about 15 years ago (Eun et al., 2006; Xue, 2006; Zhou & Peng, 2008). By taking steps towards building a high-performance national science and innovation system, major investments were made in a series of funding programmes—such as 'Project 211', 'Project 985' and 'Double First-Class'—to create world-class universities. China has also initiated several policies and programs to promote university-business dual affiliations or cross-sectoral mobility of researchers (Cheng et al., 2022). Several studies suggest that these programs face difficulties in implementation and may therefore not achieve their goals or intended effects (Lu, 2019; Hou et al., 2021).

Analytical Model and Information Sources

The effects and impacts of these national 'system level' characteristics on the UBRC profiles obviously vary from one university to another. The sheer volume of disciplinary diversity of university's research activities may determine that impact. In other cases, the size of existing collaboration level with local firms will be a contributing factor. The Chinese university with the largest share of UBCR_50km publications in its total research publication output is *China University of Petroleum* in Beijing – it is 13.2% share is 10 times the average of all selected Chinese universities (1.3%). The top ranked university in the USA – *University of Maryland*, with a 3.6% share—is still four times higher than the US average (0.9%). The higher level of shares—Chinese universities are explained by the fact that UBRCs in China are more likely to involve domestic firms (either in the same local area of somewhere else in the country), whereas the UBRCs of US universities involve a larger share of 'foreign' firms located outside the country (Li et al., 2020; Zhou et al., 2016).

Rather than comparing individual university profiles in search of explanatory factors, this study examines those profiles collectively to identify system-level 'structural' patterns in both countries. The analytical framework comprises of ten metrics-based 'count' variables. Figure 1 presents those variables, labelled according to their respective UBRC profile components.

With *UBRC_50km publication output* as the explained variable in this study, the other eight variables are explanatory:

1. *Research publications – all sciences*: total number of research publications produced by the university across all fields of science, a proxy of the university's research volume.
2. *Research publications – medical sciences*: research publication output within the research domain of medicine and related life sciences; an indicator that the university is likely to comprise a medical faculty, academic hospital or other organizational units devoted to healthcare.
3. *Research publications – engineering sciences*: research publication output within the main research domains of engineering, computer sciences and technology.
4. *Patents*: number of patents that were (co-)applied by the university to secure intellectual property rights.
5. *UBRC dual affiliate researchers*: number of university-business research publications with a university researcher who also mentions a business sector affiliation as author address.
6. *UBRC mobile researchers*: number of publications that involve a university researcher who has published with a business enterprise affiliate address in prior years. This variable is closely related to 'dual affiliate researchers' variable (some researchers may belong to both categories during a multi-year timespan).

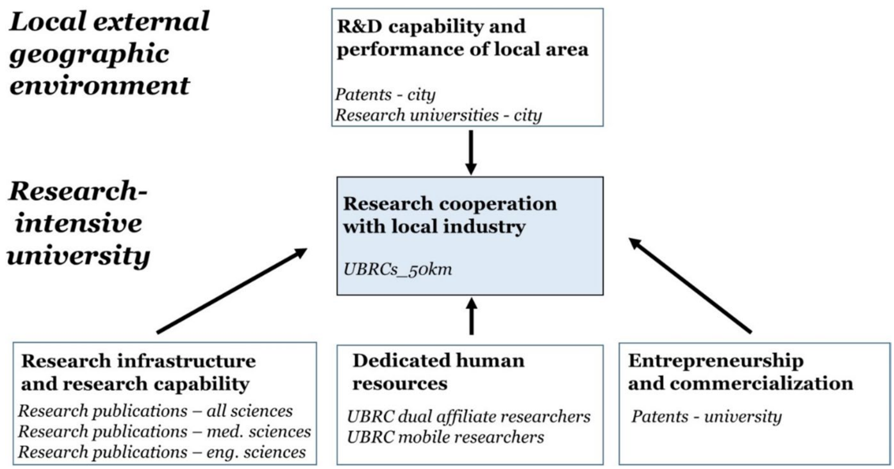

Fig. 1 Analytical model: UBRC profile components and data variables

7. *Patents – city*: number of patent applications produced by any public or private organization (universities, business enterprises or otherwise) located in the same city or metropolitan area as the targeted university. This variable reflects the technological development capacity of the entire city or metropolitan area.
8. *Research universities – city*: number of research-intensive universities selected for this study that located are in the same city or urban area as the targeted university.

These eight variables focus on the available R&D output metrics of universities and cities related to their innovation potential, more specifically their research cooperation with the business sector. Research output in other fields of science, notably the social sciences and humanities, is omitted. Owing to the analytical focus on R&D outputs, variables dealing with citation impact (of research publications and/or patents) were not taken into consideration.

Analysis of statistical relationships was based on information on two publicly available international bibliographic databases, which both allow for large-scale statistical studies across hundreds of universities worldwide:

- *Web of Science* database (some 60 million research publications worldwide; licensed version—CWTS, Leiden University);
- *PATSTAT* database (includes 90 patent issuing authorities; most of the patents registered—the USPTO, EPO or WIPO patent offices; licensed version—CWTS, Leiden University).
- Indicators 1–6 are based on Web of Science data (publication years 2016–2019); indicators 7 and 8 are PATSTAT based (patent years 2000–2018).

The data for indicator 9 are extracted from the *U-Multirank* database. The universities were selected from 2021 edition of this source.[7] Each of the selected universities should be research intensive and actively involved in research cooperation with local business enterprises. The selection criteria were set at: a total publication output of least 400 research publications in 2016–2019, including at least five UBRC_50km publications. This sampling process resulted in 193 selected Chinese universities and 179 in the USA.[8]

Main Results

General Patterns

Our empirical evidence suggests that UBRC_50km publication output is on the rise in China. In an earlier comparative study of university-business co-authored

[7] The generic term 'university' comprises any kind of university or other higher education institution (HEI) incorporated in the CWTS information system underpinning the *U-Multirank* database (www.umultirank.org). The coverage of HEIs includes multi-campus university systems, or distributed universities, with geographically distributed sites or affiliated organizations.

[8] The names of the selected universities per country are listed in Table 3 of the Appendix.

Table 1 Summary statistics of variables per country: frequency counts (mean; standard deviation between parentheses)

	China	United States
UBRCs_50km	117 (160)	109 (210)
Research publications—all sciences	8 892 (9 225)	11 808 (10 893)
Research publications—medical sciences	2 845 (3 855)	6 531 (7 542)
Research publications—engineering sciences	1 864 (2 413)	809 (857)
Patents	31 (111)	289 (598)
UBRC dual affiliate researchers	1.3 (1.9)	5.2 (7.7)
UBRC mobile researchers	10.0 (17.7)	54.7 (98.2)
Patents – city level	4 311 (7 911)	2 580 (4 057)
Research universities – city level	7.8 (6.3)	1.9 (1.7)

publications, comprising 83 Chinese universities and based on 2009–2012 data, the average share of UBRCs_50km amounted to 0.67% of their total publication output (Zhou et al., 2016). The 2016–2019 data collected is this study indicate that this share has now doubled to 1.30%. In contrast to the upward trend in China, the share of UBRCs_50km in the total research publication output of the US universities has remained relatively stable—while an earlier study examining the output of 166 US universities in 2009–2012 found a share of 1.0% (Zhou et al., 2016), the updated information for 2016–2019 shows a share of 0.9%.

Table 1 presents the descriptive statistics for the years 2016–2019 of all nine variables, categorized by UBRC profile component. The findings reveal significantly difference between both countries. With regards to total UBRC_50km output quantities, the universities in each country collectively produced a comparable average number of publications in 2016–2019. But the variation is larger among US universities as compared to their Chinese counterparts. Part of that disparity can be explained by differences in research profiles: whereas the total publication output of the selected US universities is concentrated in the medical sciences, the Chinese universities are more focused on research in the engineering sciences. These differences also reflect the composition of the selected sets of universities, with a large share of 'technical universities' or 'engineering universities' included in the set of selected Chinese universities.

The average patent output of US universities is almost ten times larger than their counterparts in China, which is partly because no national Chinese patents are included in this count. Contrary to the low level of registered university-owned international patents by Chinese universities, the Chinese cities where these universities are based do show an elevated level of international patent output. Several of those cities are innovation hotspots where local businesses, government research laboratories or other non-selected universities collectively produce large numbers of patents.

The numbers of UBRC dual affiliate research and UBRC mobile researchers are much lower in China, which could a result from a range of factors, including legislation and regulatory frameworks affecting human resource management practices—universities but also difficulties to identify these particular researchers.[9]

Owing to China's large population, and several megacities such as Beijing and Shanghai, the 193 Chinese research-intensive universities are more concentrated in university-dense areas. The Beijing metropolitan area alone includes 22 of those universities. In the USA, the spread of universities across the large cities is more geographically dispersed, where each state capital tends to have only one large research-intensive 'state university' or private university; the largest metropolitan areas in the US average only two or three selected universities.

Internal and External Explanatory Factors

Addressing the four research hypotheses, a linear regression analysis was conducted by means of a Generalized Linear Model (GLM) where negative binomial model was applied to the statistical distributions.,[10],[11]A 'main effects' analysis was applied. Two regression models are assessed: internal factors only (model 1), and internal + external factors (model 2). Results of the regression analyses are summarized in Table 2. The 'goodness of fit' diagnostics of the models are presented at the bottom of the table, where, overall, the results of all three diagnostic measures indicate that the two external variables in model 2 produce a small but significantly better fit for both countries.

With regards to model 1, both countries share two statistically significant 'internal' explanatory variables: the university's total publication output, and the number of dual affiliate researchers. The publication output in the engineering sciences is also significant in the case of the Chinese university system. The first three hypotheses are all supported in both countries. Overall, when restricting the analytical scope

[9] The lower prevalence of such boundary-spanning researchers in China may also be partially caused by the author disambiguation algorithm that was applied in this study, which is not designed to identify individual boundary spanners among researchers with similar surnames, like 'Wang' in China, and similar initials.

[10] The statistical distribution of the local UBRCs count data, the dependent variable in the GLM analysis, across the selected universities is 'over-dispersed' (the variance is much larger than the average value) but does not consist of an excessive number of zeros. The Negative Binomial (NB) model presents the most appropriate option when applying GLM to frequency count data with such a statistical distribution. The negative binomial distribution is more appropriate than the (zero-inflated) Poisson distribution for modeling and analyzing numerical data with values greater than zero or one. While the NB model is a powerful statistical tool, it does not explicitly handle (excess) zeros in the data and may not be flexible enough to handle more complex data structures, where both overdispersion and zero-inflation occurs. Given the share of zeros in the dataset (9.8% of all data points), one may assume that the NB parameter estimates are sufficiently robust and reliable for interpretation of general patterns in the dataset. The regression analysis was done by means of the GLM module (model: 'Negative Binomial with a log link') in the IBM SPSS27 statistical package.

[11] To avoid the risk of collinearity in the regression analyses, where local UBRC counts is very highly related to counts on one or more dependent variables, this list of independent variables excludes two variables: a university's total number of co-authored research publications with industry, and the total number of co-authored research publications with all partners located within 50 km).

to internal factors only, the two university research systems seem fairly similar in terms of UBRC_50km patterns. The presence of dual affiliate researchers at universities is a significant variable in both countries. The patterns change radically when the external variables are included in Model 2. As for the USA, both hypothesis 1 (the total number of research publications produced by a university, is a significant contributing factor to the scale of its UBRC_50km output) and hypothesis 3 (the number of boundary-spanning researchers within a university is a significant contributing factor to the scale of its UBRC_50km output) is, supported in the case of the USA. In the case of China, only hypothesis 4 (the university density of a city is a significant contributing factor to the scale of UBRC_50km outputs of universities in that city) is supported. Depending on the country, different external factors seem to affect the UBRC_50km counts differently: in the USA, it is the patent output of cities (i.e. patent output of universities and local firms in that area) representing the local 'technology density'. In the case of China, it is the number of other large research-intensive universities located in the same area, thus reflecting the positive effects of research concentration and 'science density'. Several large Chinese cities, such as Beijing and Shanghai, have many more universities than the largest metropolitan areas in the USA.

Discussion and Concluding Remarks

The comparative study in this paper describes some new empirical insights into country-level patterns of university-business research cooperation with local industry in mainland China and the USA. The results of the regression analysis highlight interesting similarities and differences. As for the statistical significance of university-related internal factors, the findings highlight the relevance of scale (research size of universities) both within Chinese research universities as well as in the USA, but perhaps even more importantly, that of 'dual affiliate' researchers. These cross-sectoral, boundary-spanning individuals are linking pins between universities and local research partners in the business sector.

The results suggest UBRC patterns in both countries are affected by different external local factors: in China the number of other large research-intensive universities located in the same city or metropolitan area appears to be a relevant factor, reflecting local research collaboration partnerships and networks. In the USA, where many local science systems have a long track record of university-business research collaboration activities, the external factor seems more affected by the presence of R&D-active firms in the same area that produce patents.

The possible implications for policy applications are also difficult to determine because of system dynamics and data quality. The China's science system has grown rapidly in recent years and the two systems are increasingly in competition with each other; this study's findings, based on 2016–2019 data, may no longer (fully) apply. With regards to issues of data quality, the observed findings are highly dependent on information sources, data variables, analytical parameters and selection of research-intensive

Table 2 Negative binomial regression estimates for UBRC_50km publication frequency counts (Beta coefficients and significance level of Wald Chi-Square tests)

	China				United States			
	Model 1		Model 2		Model 1		Model 2	
	Beta	Sign	Beta	Sign	Beta	Sign	Beta	Sign
Research publications – all sci	5.37E-5	0.098	5.23E-5	0.147	0.000	0.012	0.000	0.008
Research publications – med. sci	−2.00E-5	0.664	−3.43E-5	0.511	−8.57E-5	0.150	−8.005E-5	0.176
Research publications – eng. sci	0.000	0.065	0.000	0.152	0.000	0.394	0.000	0.480
Patents—university	−0.001	0.936	-0.001	0.344	-3.24E-5	0.841	1.295E-5	0.936
UBRC dual affiliate researchers	0.141	0.003	0.075	0.134	0.065	0.001	0.069	0.001
UBRC mobile researchers	0.000	0.945	0.006	0.374	0.002	0.379	−0.001	0.620
Research universities – city			0.050	0.006			0.093	0.138
Patents—city			7.47E-6	0.602			4.433E-5	0.093
Constant	3.544	< 0.001	3.178	< 0.001	3.134	< 0.001	2.779	< 0.001
Observations	193		193		179		179	
Deviance (deviance/df)*	113.6 (0.61)		90.5 (0.49)		113.5 (0.66)		101.0 (0.59)	
Pearson Chi-square	123.7 (0.67)		100.7 (0.55)		123.9 (0.72)		117.3 (0.69)	
Akaike's Information Criterion	2095.4		2076.3		1885.3		1849.8	

* Deviance measures the difference between the fitted generalized linear model and the saturated variant of the model that perfectly fits the data. The relative value of the deviance score is compared to the degrees of freedom (df) defined by the model

universities that were applied in this study. Inevitably, it offers only a partial view of general patterns in either country. Sound, evidence-informed conclusions as to the comparative performance either research system remain therefore out of reach. Determining the policy relevance of these findings requires a better understanding of national and regional policy agenda's, local research cooperation circumstances and opportunities, as well as university regulations and business R&D opportunities and university-industry cooperation practices. More information is also needed on national or regional funding initiatives specifically dedicated to promoting university-business R&D cooperation.

As for national policy frameworks, national and regional government support for university-industry R&D and innovation is likely to remain an important strategic objective in economic development policies of both countries. It is tempting to assume is that universities located in countries with greater local or regional autonomy in higher education systems and control over higher education policy, such as in the United States, will be more orientated toward local user communities or regional economic development. However, this is also not necessarily the case: these universities often face the same societal demands and competitive pressures (e.g. student recruitment or funding constraints) as those in places, such as in China, where policies are determined more centrally.

China and USA are today's superpowers in the global science system, in terms of size and impact, which limits the scope for fair country-level comparisons or meaningful benchmarking with smaller or lesser developed national university systems. The degree of generalizability of these macro-level statistical findings to other countries, with advanced science and innovation systems, is a topic for future studies. As for follow-up studies of USA and China, further studies should not only include more recent data but also a breakdown by meso-level main fields of science as well as an extended analytical scope that includes 'second tier' research universities and other types of research-active institutions. The statistical findings could provide valuable information and further insights on how both national research systems perform in different knowledge domains and institutional subsectors.

Concluding, this comparative study and its statistical outputs, building on earlier work by Zhou et al. (2016), constitutes as next step towards a more comprehensive and in-depth understanding of the research systems in China and the USA. Incorporating additional data and qualitative information, from case studies of other sources, may also help to shift the analytical perspective away from macro-level input/output models of university research cooperation profiles to more sophisticated analytical models that are based on larger variety of comparative university-level data. For example, measurements on local business sector funding for research, PhD student internships and graduate employment—local innovative business enterprises; number of university-business R&D contracts; deals through technology transfer offices; size of university funds devoted to research commercialization. Furthermore, micro-level case studies of boundary-spanning researchers could help unravel essential details of knowledge transfer and research utilization processes related to university-business R&D interactions.

Appendix

Table 3 Selected universities per country. (English-language names of universities in the CWTS information system, 2020)

China

Air Force Medical Univ. of PLA
Anhui Agricultural Univ.
Anhui Medical Univ.
Anhui Normal Univ.
Anhui Univ.
Beihang Univ.
Beijing Forestry Univ.
Beijing Institute of Technology
Beijing Jiaotong Univ.
Beijing Normal Univ.
Beijing Union Medical College
Beijing Univ.
Beijing Univ. of Chemical Technology
Beijing Univ. of Chinese Medicine
Beijing Univ. of Posts and Telecommunications
Beijing Univ. of Technology
Capital Medical Univ.
Capital Normal Univ.
Central China Normal Univ.
Central South Univ.
Chang'an Univ.
Changzhou Univ.
Chengdu Univ. of Technology
China Academy of Chinese Medical Sciences
China Agricultural Univ.
China Jiliang Univ.
China Medical Univ.
China Pharmaceutical Univ.
China Three Gorges Univ.
China Univ. of Geosciences
China Univ. of Mining and Technology
China Univ. of Petroleum, Beijing
China Univ. of Petroleum, Qingdao
Chinese Univ. of Hong Kong
Chongqing Medical Univ.
Chongqing Univ.
Chongqing Univ. of Posts and Telecommunications
City Univ. of Hong Kong
Dalian Maritime Univ.
Dalian Medical Univ.
Dalian Univ. of Technology
Donghua Univ.
East China Normal Univ.
East China Univ. of Science and Technology
Fudan Univ.
Fujian Agriculture and Forestry Univ.
Fujian Medical Univ.
Fujian Normal Univ.
Fuzhou Univ.
Guangdong Univ. of Technology
Guangxi Medical Univ.
Guangxi Normal Univ.
Guangxi Univ.
Guangzhou Medical Univ.
GuangZhou Univ.
Guangzhou Univ. of Chinese Medicine
Guizhou Univ.
Hainan Univ.
Hangzhou Dianzi Univ.
Hangzhou Normal Univ.
Harbin Engineering Univ.
Harbin Institute of Technology
Harbin Medical Univ.
Harbin Univ. of Science and Technology
Hebei Medical Univ.
Hebei Univ.
Hebei Univ. of Technology
Hefei Univ. of Technology
Heilongjiang Univ.
Henan Agricultural Univ.
Henan Normal Univ.
Henan Polytechnic Univ.
Henan Univ.
Henan Univ. of Science and Technology
Hohai Univ.
Hong Kong Baptist Univ.
Hong Kong Polytechnic Univ.
Hong Kong Univ. of Science and Technology
Huaqiao Univ.
Huazhong Agricultural Univ.
Huazhong Univ. of Science and Technology
Hubei Univ.
Hunan Normal Univ.
Hunan Univ.
Inner Mongolia Univ.
Jiangnan Univ.
Jiangsu Normal Univ.
Jiangsu Univ.
Jiangxi Normal Univ.
Jilin Univ.
Jinan Univ.
Kunming Medical Univ.
Kunming Univ. of Science & Technology
Lanzhou Univ.
Lanzhou Univ. of Technology
Nanchang Univ.

Table 3 (continued)

Nanjing Agricultural Univ.
Nanjing Forestry Univ.
Nanjing Medical Univ.
Nanjing Normal Univ.
Nanjing Univ.
Nanjing Univ. of Aeronautics and Astronautics
Nanjing Univ. of Chinese Medicine
Nanjing Univ. of Information Science and Technology
Nanjing Univ. of Posts and Telecommunications
Nanjing Univ. of Science and Technology
Nanjing Univ. of Technology
Nankai Univ.
Nantong Univ.
National Univ. of Defence Technology
Ningbo Univ.
North China Electric Power Univ.
North China Univ. of Science and Technology
North Univ. of China
Northeast Agricultural Univ.
Northeast Forestry Univ.
Northeast Normal Univ.
Northeastern Univ. China
Northwest Agriculture & Forestry Univ.
Northwest Univ.
Northwestern Polytechnical Univ.
Ocean Univ. of China
People's Liberation Army Univ. of Science and Technology
Qingdao Agricultural Univ.
Qingdao Univ.
Qingdao Univ. of Science & Technology
Qufu Normal Univ.
Renmin Universitiy of China
Second Military Medical Univ.
Shaanxi Normal Univ.
Shaanxi Univ. of Science & Technology
Shandong Agricultural Univ.
Shandong Normal Univ.
Shandong Univ.
Shandong Univ. of Science and Technology
Shandong Univ. of Technology
Shanghai Jiao Tong Univ.
Shanghai Normal Univ.
Shanghai Ocean Univ.
Shanghai Univ.
Shanghai Univ. of Trad. Chinese Medicine
Shantou Univ.
Shanxi Medical Univ.
Shanxi Univ.
Shenyang Pharmaceutical Univ.
Shenzhen Univ.
Shihezi Univ.
Sichuan Agricultural Univ.
Sichuan Univ.
Soochow Univ.
South China Agricultural Univ.
South China Normal Univ.
South China Univ. of Technology
Southeast Univ.
Southern Medical Univ.
Southern Univ. of Science and Technology
Southwest Jiaotong Univ.
Southwest Petroleum Univ.
Southwest Univ.
Southwest Univ. of Science and Technology
Sun Yat-sen Univ.
Taiyuan Univ. of Technology
Third Military Medical Univ.
Tianjin Medical Univ.
Tianjin Normal Univ.
Tianjin Polytechnic Univ.
Tianjin Univ.
Tianjin Univ. of Science and Technology
Tianjin Univ. of Technology
Tongji Univ.
Tsinghua Univ.
Univ. of Electronic Sci. and Techn. of China
Univ. of Hong Kong
Univ. of Jinan
Univ. of Macau
Univ. of Science and Technology Beijing
Univ. of Science and Technology of China
Univ. of Shanghai for Sci. and Technology
Univ. of South China
Univ. of the Chinese Academy of Sciences
Wenzhou Medical Univ.
Wenzhou Univ.
Wuhan Univ.
Wuhan Univ. of Science and Technology
Wuhan Univ. of Technology
Xiamen Univ.
Xi'an Jiaotong Univ.
Xi'an Univ. of Architecture and Technology
Xi'An Univ. of Technology
Xiangtan Univ.
Xidian Univ.
Xinjiang Medical Univ.
Xinjiang Univ.
Xinxiang Medical Univ.
Xuzhou Medical College
Yangtze Univ.
Yangzhou Univ.
Yanshan Univ.
Yunnan Univ.
Zhejiang Normal Univ.
Zhejiang Sci-Tech Univ.
Zhejiang Univ.
Zhejiang Univ. of Technology
Zhengzhou Univ.

Table 3 (continued)

United States of America	
Arizona State Univ.	New York Univ.
Auburn Univ.	North Carolina State Univ.
Baylor College of Medicine	North Dakota State Univ.
Baylor Univ.	Northeastern Univ.
Binghamton Univ., State Univ. New York	Northwestern Univ.
Boston College	Ohio State Univ.
Boston Univ.	Oklahoma State Univ. - Stillwater
Brandeis Univ.	Old Dominion Univ.
Brigham Young Univ.	Oregon Health & Science Univ.
Brown Univ.	Oregon State Univ.
California Institute of Technology	Portland State Univ.
Carnegie Mellon Univ.	Princeton Univ.
Case Western Reserve Univ.	Purdue Univ. - Lafayette
City College of New York	Rensselaer Polytechnic Institute
Clemson Univ.	Rice Univ.
Colorado School of Mines	Rush Univ.
Colorado State Univ.	Rutgers Univ. – New Brunswick
Columbia Univ.	Saint Johns Univ.
Cornell Univ.	Saint Louis Univ.
Dartmouth College	San Diego State Univ.
Drexel Univ.	South Dakota State Univ.
Duke Univ.	Stanford Univ.
East Carolina Univ.	Stony Brook Univ.
Emory Univ.	SUNY - Albany
Florida Atlantic Univ.	Temple Univ.
Florida International Univ.	Texas A&M Univ.
Florida State Univ.	Texas State Univ.
George Mason Univ.	The Graduate Center, City Univ. New York
George Washington Univ.	The Pennsylvania State Univ.
Georgetown Univ.	The Rockefeller Univ.
Georgia Institute of Technology	The State Univ. of New York - Buffalo
Georgia Regents Univ. Augusta	Thomas Jefferson Univ.
Georgia State Univ.	Tufts Univ.
Harvard Univ.	Tulane Univ.
Icahn School of Medicine - Mount Sinai	Uniformed Services Univ. Health Sciences
Illinois Institute of Technology	Univ. of Akron
Indiana Univ. - Purdue Univ.	Univ. of Alabama - Birmingham
Indiana Univ. Bloomington	Univ. of Alabama - Tuscaloosa
Iowa State Univ.	Univ. of Alaska, Fairbanks
Johns Hopkins Univ.	Univ. of Arizona
Kent State Univ.	Univ. of Arkansas
Lehigh Univ.	Univ. of California - Berkeley
Louisiana State Univ.	Univ. of California - Davis
Loyola Univ. Chicago	Univ. of California - Irvine
Massachusetts Institute of Technology	Univ. of California - Los Angeles
Medical College of Wisconsin	Univ. of California - Riverside
Medical Univ. of South Carolina	Univ. of California - San Diego
Michigan State Univ.	Univ. of California - San Francisco
Mississippi State Univ.	Univ. of California - Santa Barbara
Missouri Univ. of Science & Technology	Univ. of California - Santa Cruz
Montana State Univ.	Univ. of Central Florida
Nebraska Univ. - Lincoln	Univ. of Chicago
New Jersey Institute of Technology	Univ. of Cincinnati
	Univ. of Colorado Boulder

Table 3 (continued)

Univ. of Colorado Denver	Univ. of Pennsylvania
Univ. of Connecticut	Univ. of Pittsburgh
Univ. of Delaware	Univ. of Rhode Island
Univ. of Denver	Univ. of Rochester
Univ. of Florida	Univ. of South Carolina
Univ. of Georgia	Univ. of South Florida – Tampa
Univ. of Hawaii - Manoa	Univ. of Southern California
Univ. of Houston - Houston	Univ. of Tennessee - Knoxville
Univ. of Idaho	Univ. of Texas - Austin
Univ. of Illinois - Chicago	Univ. of Texas Health Sci. Ctr - San Antonio
Univ. of Illinois - Urbana-Champaign	Univ. of Texas Health Sci. Ctr - Houston
Univ. of Iowa	Univ. of Texas Medical Branch Galveston
Univ. of Kansas	Univ. of Texas South West Medical Center
Univ. of Kentucky	Univ. of Texas, Arlington
Univ. of Louisville	Univ. of Texas, Dallas
Univ. of Maryland - Baltimore	Univ. of Texas, San Antonio
Univ. of Maryland - Baltimore County	Univ. of Utah
Univ. of Maryland - College Park	Univ. of Vermont
Univ. of Massachusetts - Amherst	Univ. of Virginia
Univ. of Massachusetts - Boston	Univ. of Washington - Seattle
Univ. of Massachusetts Medical School	Univ. of Wisconsin - Madison
Univ. of Miami	Univ. of Wisconsin
Univ. of Michigan	Univ. of Wyoming
Univ. of Minnesota, Twin Cities	Utah State Univ.
Univ. of Mississippi	Vanderbilt Univ.
Univ. of Missouri - Columbia	Virginia Commonwealth Univ.
Univ. of Missouri - Kansas City	Virginia Polytechnic Inst. and State Univ.
Univ. of Montana	Wake Forest Univ.
Univ. of Nevada - Las Vegas	Washington State Univ.
Univ. of Nevada - Reno	Washington Univ. in St. Louis
Univ. of New Hampshire	Wayne State Univ.
Univ. of New Mexico	West Virginia Univ.
Univ. of North Carolina - Chapel Hill	Wright State Univ.
Univ. of North Carolina - Charlotte	Yale Univ.
Univ. of Notre Dame United States	Yeshiva Univ.
Univ. of Oklahoma	
Univ. of Oregon	

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