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Cecilia Rikap, David Flacher

► **To cite this version:**

Cecilia Rikap, David Flacher. Who collects intellectual rents from knowledge and innovation hubs? questioning the sustainability of the singapore model. *Structural Change and Economic Dynamics*, 2020, 55, pp.59 - 73. 10.1016/j.strueco.2020.06.004 . hal-03492498

HAL Id: hal-03492498

<https://hal.science/hal-03492498v1>

Submitted on 8 Sep 2022

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Title page

Title: Who collects intellectual rents from knowledge and innovation hubs? Questioning the sustainability of the Singapore model

Authors and affiliations:

Cecilia Rikap (Institut Francilien Recherche Innovation Société, Centre Population et Développement (CEPED), IRD/Université de Paris, France. Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Universidad de Buenos Aires, Argentina)

David Flacher (Laboratoire COSTECH, Université de Technologie de Compiègne, France).

Corresponding author: Cecilia Rikap (ceciliarikap@gmail.com). Present address: IICE, Universidad de Buenos Aires, CONICET. Puán 480 4° Piso, Of. 440 (1406), Buenos Aires, Argentina.

Declarations of interest: none

Funding: This research was supported by an Institut Francilien Recherche Innovation Société (IFRIS)/ Laboratoire d'Excellence SITES exploratory project grant.

Who collects intellectual rents from knowledge and innovation hubs? Questioning the sustainability of the Singapore model

Abstract

While knowledge and innovation are produced in networks involving diverse actors, associated rents are greatly appropriated by global leaders, mostly coming from core countries, that become intellectual monopolies. This raises the question on emerging or peripheral countries companies' capacity to catch-up, innovate and compete for intellectual rents. The article considers the Singapore who has pursued a knowledge hub strategy aimed at: 1) creating world class universities inserted in global knowledge networks of defined fields; and 2) capturing intellectual rents through those institutions' research and contributing to local firms' catching up. We show that research universities caught-up. However, we find that foreign companies, particularly multinationals, capture most of Singapore's intellectual rents at the expense of local companies and research institutions. Overall, our findings point to the limitations of Singapore's knowledge hub as a catching-up strategy. The article ends discussing the relevancy of these findings for emerging countries in general.

Keywords: knowledge networks; knowledge and innovation hubs; intellectual rents; catching-up; Singapore.

1. Introduction

Catching-up as a strategy for emerging or peripheral countries face new challenges because of the growing importance of intangible over tangible assets (Haskel & Westlake, 2018) that has led to the emergence of intellectual monopolies (Pagano, 2014). In core countries, companies leading this transformation enjoy higher profits without a parallel increase in investment (Auvray et al., 2018; Orhangazi, 2018; Schwartz, 2016). Intellectual monopolies systematically capture intellectual, knowledge or technoscientific rents (Birch, 2019; Durand & Milberg, 2018; Foley, 2013; Pagano, 2014; Schwartz, 2016; Teixeira & Rotta, 2012). Moreover, there is an incipient but growing literature that differentiates between who produces intellectual assets -including academic research institutions and different types of firms such as start-ups and multinationals- and who captures their associated rents. These authors find that intellectual monopolies profit from intellectual rents from their own innovation activity, but also garner rents from the innovation networks they organize (Foley, 2013; Rikap, 2019; Yeung & Coe, 2015).

Not only this distinction between producing an intellectual asset and capturing rents from it is still under-researched, but there is also little empirical evidence on how the emergence of global intellectual monopolies -that garner rents from their innovation networks and concentrate intangible assets- could affect indigenous catching-up opportunities of emerging and peripheral countries. Taking into account that most intellectual monopolies are originated in core economies, their capacity to garner intellectual rents could result in a redistribution of those rents from the periphery to the core.

In this article, we study Singapore' catching-up model and its limitations by using a mixed-method case study methodology. Based on the elements provided by exploratory interviews conducted at the beginning of our investigation, we build on descriptive statistics and network

analyses of scientific publications and patent data in order to assess outcomes of research and innovation production and its associated rents.

Since the 2000s, Singapore's science, technology and innovation policy explicitly aimed to develop a knowledge (cum innovation) hub, understood as a condition that could contribute to local firms' catching-up (while the country had historically relied on foreign multinationals). The different policies introduced to create such a hub assigned a key role to Singapore's two research universities –the National University of Singapore (NUS) and the Nanyang Technological University (NTU). These institutions were supposed to become central players of the global knowledge networks of strategically defined fields, and capture intellectual rents from their research, which was expected to contribute to local firms' catching up.

We show that while Singapore's research universities effectively caught-up and are greatly integrated to global knowledge and innovation networks. However, those universities (as well as the public sector as a whole) fail to capture their associated intellectual rents whereas foreign corporations garner most of the rents of this hub.

Overall, our findings for the case of Singapore point to the limitations of emerging or peripheral countries' knowledge hubs as a catching-up strategy as far as foreign multinationals can freely appropriate rents from knowledge produced in the hub by local actors. Moreover, these results also raise the question on the sustainability of the Singaporean model especially considering the existence of other geographically close global innovation hubs like Shenzhen in China (Chen & Ogan, 2017). Alternative hubs may eventually become more attractive for multinationals currently doing R&D in Singapore with potential negative consequences on Singapore' capacities to innovate.

The rest of this article is organized as follows. Section 2 elaborates on our theoretical framework about the role of intangibles and the emergence of persistent intellectual rents.

Section 3 introduces our approach and methodology, followed by a findings and discussions in Sections 4 and 5, respectively. Section 6 concludes.

2. Intellectual monopolies, rent-seeking and catching-up

The spread of the linear model of innovation, between the 1920s and 1960s in the United States (US) linked science with innovation (Godin, 2006). Since then, this link was strengthened up to the point where, for some authors, science was subsumed under innovation production processes becoming what Slaughter and Leslie (1997) called technoscience, which is at once science and product.

In this process, according to Münch (2014), the sharp functional differentiation between science and economy ceased. The economic performance of a country became deeply intertwined with the technological capabilities of its firms. For peripheral and emerging countries, technological catching-up was identified as a strategy that could reduce their gap with the core (Abramovitz, 1986; K. Lee & Lim, 2001; K. Lee & Malerba, 2017). In simple terms, when latecomers catch-up they ‘follow the path of technological development of the advanced countries’ (K. Lee & Lim, 2001, p. 460), which may include skipping steps or even taking a detour (K. Lee, 2019). From a Schumpeterian perspective, Burlamaqui and Kattel (2016) claimed that leapfrogging and divergence were more appropriate than catching-up and convergence which suppose a linear path towards development. According to these authors, there is a constantly dynamic environment where leapfrogging -through innovation and finance- enables different companies to become leaders at different points in time.

In the process of catching up, it was observed that not only industrialization but also a good management by domestic institutions was necessary (Botta, 2009) and, more recently, that catching-up needed to be linked up with globalization through international production

networks (Landesmann & Stöllinger, 2019). Within the Global Value Chain and Global Production Network frameworks, this has been analysed with the concepts of upgrading and clusters' strategic coupling, which should lead to a higher bargaining power and an increased share of the created and captured value (Barrientos et al., 2011; Coe & Yeung, 2015, 2015; Dedrick & Kraemer, 2015; Gereffi, 2014; Humphrey & Schmitz, 2002; J. Lee & Gereffi, 2015).

Global Value Chain and related literature emphasize on upgrading because it is recognized that the company leading the chain will capture more value from it, typically exercising power on the other participating firms (Gereffi et al., 2005; J. Lee & Gereffi, 2015; Mahutga, 2014). Moreover, it was recently argued that the increased importance of intangible over tangible assets is reinforcing inequalities within Global Value Chains (Durand & Milberg, 2018; Gereffi, 2014; Haskel & Westlake, 2018; Orhangazi, 2018). Intangible assets (such as patents, copyright, trademarks and brand names) were early defined by Veblen (1908, p. 105) as 'immaterial items of wealth, immaterial facts owned, valued, and capitalized on an appraisalment of the gain to be derived from their possession'.

In terms of empirical evidence concerning the rise of intangible assets, Clarivate Analytics (2019) uses its centralized patents' database -Derwent Innovation- to define top 100 innovators by considering their total number of granted patents together with indicators of success, globalization and influence.¹ Since 2011, when the ranking was created, only 204 organizations made it at least once to the top 100 innovators, 35 of which appeared every year. This strong core of organizations profiting from intellectual rents is dominated by multinationals (97 of the 100 organizations in 2018-19 ranking) mostly originally from the

¹ Success is defined as the ratio of patent applications to granted patents in the last five years. Global patents are defined as quadrilateral patents meaning that the same invention is patented in the four major patent offices: the Chinese Patent Office, the European Patent Office, the Japanese Patent Office, and the United States Patent & Trademark Office. Finally, the influence of a patent portfolio results from counting citations by other companies' in the last five years.

US and Japan (72 organizations in total in 2018-19 ranking). Moreover, for 2018-2019, this data shows that top 100 innovators' patent portfolios are becoming more successful, global and influential compared to the rest of the patenting organizations, which showed little growth or even degrowth in these indicators. To some extent, it may be said that this data reflects intellectual rents' concentration because the used indicators proxy the quality of patent portfolios, and thus the concentration of quality patents around top innovators may imply a concentration of rents.

There has also been a concentration of Business Expenditure in Research and Development (R&D) at the global level. By 2018, the 10 companies with highest investment in R&D accumulated 13.5% of the world's Business Expenditure in R&D (and 48% was accumulated by the top 100 companies) (Scoreboard, 2018).

Furthermore, recent empirical evidence for the US proves a greater concentration of intangible assets in firms with greater profits. It was observed that R&D is used to further monopolization, with R&D efforts positively and significantly correlated with corporate net profits and with performance in the Standard and Poor's Stock Market Index (Lambert, 2019). Similarly, Orhangazi (2018) revealed that intangible-intensive industries' rate of profit grew faster than their total assets. This was also shown by Schwartz (2016) who, based on the distribution of cash holdings by US corporations, suggests that profit differentials are explained by an uneven distribution of intellectual property rights. Firms owning more intangible assets enjoy greater cash holdings, which accounts for greater profits. Greater profits are explained by the emergence of technoscientific, knowledge or intellectual rents defined as rents triggered by the artificial scarcity generated by the private appropriation of intangible goods (Birch, 2019; Durand & Milberg, 2018; Foley, 2013; Pagano, 2014; Teixeira & Rotta, 2012).

Overall, rents emerge from the monopolization of a (eventually artificially) scarce resource that limits competition and that induces a redistribution of value. Intellectual monopolies enjoy intellectual rents when they monopolize knowledge. Durand and Milberg (2019) distinguished four types of intellectual rents that, they state, can be combined for a single company: vertical natural monopoly, intangibles-differential rents, legal monopoly and data-driven innovation rents. Intangibles-differential rents were defined by these authors as the difference in endless economies of scale for intangible assets (whose marginal costs are zero or negligible) versus the at most temporary economies of scale of tangible assets. Every global value chain leader has the exclusive knowledge of who can do what within the chain. This form of knowledge, defined by Johnson and Lundvall (1994) as know-who, is an advantage that enables to set the chain in motion, hence to organize and integrate the chain. The capacity to be the only one knowing the whole chain is an intangible asset that, following Durand and Milberg (2019), triggers vertical natural monopoly rents from network externalities. Legal monopoly innovation rents result from intellectual property rights and data-driven innovation rents result from the fact that centralizing original data enhances innovation capabilities. Amazon, for instance, enjoys all these four forms of intellectual rents.

While these different forms of monopolization appear to be successful mostly in core countries, recent literature studies China's catching-up as a unique case of a country with recent catching-up in certain industries, in particular looking at Huawei and other high-tech intellectual monopolies (Godinho & Ferreira, 2012; Guo et al., 2019; Hawes & Chew, 2011; Humphrey et al., 2018; D. Li et al., 2019; R. Li & Cheong, 2017; Wen, 2017; Wu & Gereffi, 2018). From many respects, China appears as a unique case of catching-up in a context of rising intangible asset's concentration. Among others, its place in the New International Division of Labour as a huge market and as cheap and under-regulated world's labour factory triggered a skyrocketing economic growth (Milberg & Winkler, 2013). China's government

used foreign firm's desire to access to the domestic market as the basis for negotiating access to their knowledge. Often this took the form of joint ventures where the foreign firms were required to partner with Chinese firms. This enhanced the technological capabilities of domestic (state-owned and private) corporations (Durand & Milberg, 2019). A special chapter refers to China's protectionist measures that particularly limited the penetration of US high-tech intellectual monopolies. China's 'Great Fire Wall' limits access for foreign companies to internet-based business (including cloud services), favouring local companies in particular Baidu, Alibaba and Tencent (Mueller, 2011; Wu & Gereffi, 2018). The result has been the emergence of what could be conceived as Chinese intellectual monopolies.

With regards to intellectual monopolies, either in China or in other countries, they do not innovate alone. They organize innovation processes involving organizations from different countries, that combined could be conceived as the intellectual monopoly's corporate innovation system (Granstrand, 2000). In fact, concerning innovation dynamics in a globalized capitalism, recent literature has moved away from country-based studies and focuses on transnational technological asymmetries across institutions. Global Innovation Networks and innovation circuits' concepts refer to innovations' slicing or modularizing process. Innovation steps are spread in multiple locations and involve diverse actors including academic institutions (Ernst, 2008, 2009; Levín, 1977; Liu et al., 2013; Rikap, 2018).

However, while innovation is produced collectively by multiple organizations within an innovation circuit, the capacity to turn the result into an artificially scarce resource, and thus to extract (intellectual) rents, lays mostly in the hands of intellectual monopolies. Eventually, they may share the rents with innovating companies that played a paramount role in achieving the result but, overall, there is an unequal distribution of the profits extracted from an innovation (Rikap, 2019).

From a different perspective, but also looking at the interplays between firms, the business ecosystem's literature has focused also on the interdependencies between different types of actors within a network, with special focus on the positive role of 'keystone' firms. In this framework, these are companies (like Walmart, Microsoft or Apple) whose successful business depends of the long-term sustainability of their respective ecosystems (Iansiti & Euchner, 2018; Iansiti & Levien, 2004a, 2004b). This literature emphasizes mutual benefits and the interdependency between the lead or keystone firm and the rest of the participants of an innovation (eco)system. In this paper, we will show that this kind of interdependency does not necessarily lead to equal distribution of the profits within the system, nor to a distribution of such profits according to the contribution of each participant.

As stated by Yeung and Coe (2015), what is at stake is who captures the value created from R&D. From a Marxian tradition, Foley (2013, p. 259) conceptualizes this distinction as the difference between 'value creation, surplus value generation, and surplus value appropriation', arguing that the specificity of the so called information economy does not lay on how value is created but on the introduction of new modes of surplus value appropriation.

On the grounds of the aforementioned literature, an underlying hypothesis (that in this paper we will consider but only applied to a single case study), is that this unequal distribution of intellectual rents further reinforces centre/periphery dynamics. This article thus contributes to expand the dependency theory on the unequal exchange of value between the centre and the periphery (Emmanuel, 1972), to include the unequal appropriation of intellectual rents that results from innovations achieved in the periphery. Indeed, the increased importance of intangibles and innovation, in particular for global leaders, may appear as a greater challenge for catching-up processes. As Lee and Lim (2001) concluded, in industries with greater innovation rhythm, catching-up opportunities are limited. Hence, the emergence of intellectual monopolies narrows down windows of opportunity for catching-up. It was argued

by Lee and Malerba (2017, p. 346) that the higher costs of new technologies tend to prevent the forerunner commanding the highest productivity from their adoption. Nevertheless, it is possible to argue that outsourcing (both of manufacturing and innovation steps) favors global leaders, further limiting latecomers' catching-up, because those extra costs (and uncertainty in the case of developing a new technology) can be diverted to other links of the network or chain, such as the state as observed by Mazzucato (2015).

Presumably attempting to counterbalance these trends, and recognizing the economic value of science and technology, policies are being put in place in multiple emerging countries (as well as in some cities in advanced countries) to create knowledge and innovation hubs, aiming that local actors could create and capture intellectual rents partly relying on public R&D (Belderbos et al., 2014; Knight, 2014). It is expected that the concentration of knowledge and innovation will improve success rates and trigger greater rents. The idea of hubs as spaces where the synergies between firms, public research institutions and the state in a geographically limited space reinforce innovation certainly builds on the innovation systems' framework, mostly focused on national innovation systems (Freeman, 1982; Lundvall, 1985), but also on sectoral and regional innovation systems (Philip Cooke, 1992; Malerba, 2002). Hub strategies led by States can be thus reconceived as strategies to develop a regional innovation system (Philip Cooke, 1992) at the location of choice.

Still, there is an open question on who will capture the intellectual rents from the hub's successful results. Empirical assessments on these matters –especially when emerging countries are pursuing such hub strategy- are scarce, with only few exceptions like Mazzucato and Penna (2016). There is also a lack of evidence on whether local firms caught-up after such initiatives. In the aforementioned context, hubs may end up favouring intellectual monopolies' rent-seeking activity, further subordinating public to private science (Coriat & Weinstein, 2011; Pestre, 2003; Rikap & Harari-Kermadec, 2019; Slaughter & Leslie, 1997).

Summing up, there are two simultaneous processes to be considered when analysing emerging and peripheral countries' technological catching-up opportunities. On the one hand, different cities –from London and New York, to Qatar and Singapore- try to become innovation hubs (Belderbos et al., 2014; Knight, 2014). On the other hand, the emergence of global intellectual monopolies has changed the overall distribution of intellectual rents within innovation networks. These monopolies may outsource and offshore innovation modules in those hubs, garnering from them intellectual rents, therefore potentially profiting from those hubs as enclaves of science and technology. Since these hubs are developed as a strategy to catch-up in emerging and peripheral countries, foreign multinationals' appropriation of associated rents may endanger such objective rendering the hub initiative unsuccessful (and costly) in the long-term. In the rest of this paper we assess this possibility by studying Singapore's knowledge (cum innovation) hub.

3. Approach and methodology

3.1. Case Selection and related assumptions

Singapore is an example of a country that historically depended on foreign multinationals' activity and technology (Wong & Goh, 2013). Since the 2000s, the State has put in place policies to transform the country into a knowledge and innovation hub aimed at developing local capabilities. These policies were synthesized in 'Science and Technology' (S&T) Plans, renamed 'Research, Innovation, Enterprise' Plans since the plan initiated in 2011. Colossal public investments in R&D have supported those policies (Mok, 2015; Sidhu et al., 2014).

A critical piece of this hub strategy was the development of two 'world class universities' (Salmi, 2009), namely the National University of Singapore (NUS) and the Nanyang Technological University (NTU). This was promoted by: (i) public investment in R&D

incentivizing higher education and research institutions (as well as corporations) to focus on strategic fields (Sidhu et al., 2014), (ii) importing talent, and (iii) attracting foreign direct investment in higher education and research. This meant attracting foreign world class universities both to settle branch campuses and to partner with the NUS and the NTU.

On the grounds of our general framework (Section 2), our research on Singapore's case is guided by the following hypotheses: 1) Singapore's government succeeded in transforming the NUS and the NTU into key global players in selected strategic fields' knowledge networks, 2) but failed in its attempt to locally garner most of its knowledge hub intellectual rents. These assumptions are coherent with what we derived from the literature review: global leaders becoming intellectual monopolies not only capture rents from their in-house innovations, but also appropriate intellectual rents from the innovation networks they organize and plan.

3.2. Data collection

In order to study Singapore's knowledge hub, we conducted a mixed-methods case study relying on two types of data: qualitative data derived from in-depth interviews and quantitative data. We complemented this collection with grey literature from the NUS, the NTU and the Singaporean government (including reports where the hub strategy was presented).

Regarding qualitative data, we interviewed 15 stakeholders in November 2016: (i) managers of the NUS and the NTU; (ii) managers of overseas Higher Education institutions settled in Singapore; (iii) researchers from the NUS and NTU; and (iv) a responsible for the scientific cooperation from a core country embassy in Singapore. Interviews lasted between 60 and 90 minutes. For confidentiality issues we do not provide the identity of the interviewees.

We conducted interviews at the beginning of our investigation because we wanted to understand Singapore's higher education and research system, the state policy, the strategies of its main institutions and researchers' perceptions, logics and practices. In particular, in relation to Hypotheses 1 and 2, we wanted to verify to what extent the NUS and the NTU are aligning to the government priorities with real impacts in terms of their publishing strategies, before looking at their places in global knowledge networks. We also wanted to gather information on other forms of economic valorisation besides patents. For instance, universities may also be benefiting from creating spin-off companies as well as providing technical assistances. NUS and NTU staff were also interviewed about the enterprises conducting research with them or sponsoring their research, and about the signed agreements with these companies in terms of property rights of achieved results.

Our quantitative data relies on the analysis of R&D outcomes in terms of (i) scientific publications retrieved from Web of Science, (ii) patents retrieved from Derwent Innovation database and (iii) innovation or intellectual rents gathered from Singapore's National Survey of Research and Development. The survey also provided information on the distribution of patent ownership per sector (private, government, higher education institutions). We also used OECD data on R&D expenditure at country and sector level to complement our analysis on the place of the private sector as R&D investor in Singapore.

Scientific publications' corpuses were defined after looking at the research priorities of the 'Research, Innovation, Enterprise 2020' plan which reoriented research towards more applied topics and economic valorisation (Ministry of Trade and Industry, 2016). The four research priorities defined by the Singaporean government in that plan were: 'Advanced Manufacturing and Engineering', 'Health and Biomedical Sciences', 'Services and Digital Economy' and 'Urban Solutions and Sustainability'. In order to select the journals by research priority, we searched those having in their names any of the keywords associated to

the descriptions of each of those strategic areas as defined in that plan (see list in Appendix 1). The number of articles and journals for each research priority is provided in Table 1.

Table 1 should be placed here

Top publications in the prioritized research areas were identified using Web of Science's journal impact factor. We selected the journals with the highest impact factor on the topics aligned to Singapore's four strategic research priorities. We retrieved all these journals' papers between 2003 and 2017 from Web of Science (the reason for selecting this time period is presented in the next subsection).

Then, we used Derwent Innovation database to extract the NUS and the NTU granted and applied patents between 2000 and 2017, a period that corresponds to Singapore's government decision to create a knowledge hub. Derwent Innovation provides all the information from the following patent offices: USPTO, WIPO, European, Japan, Australian, British, Canadian, French, German, Russian and Korean patent offices. We found 2 006 granted or applied patents for the NUS and 1 269 for the NTU. We retrieved both granted and applied patents in order to analyse whether these universities' research partnerships -as they were either disclosed in our interviews or publicized in university reports- led to successful results that were jointly patented.

Finally, we retrieved Singapore's distribution of intellectual rents from innovation from its National Survey of Research and Development. This survey provides two indicators that considered together are a proxy of intellectual rents from innovation activities conducted in Singapore: licensing revenues and sales revenues from products resulting from R&D activities.

3.3. Data analysis

The interviews contributed to further develop intuitions that were later confirmed in our quantitative analysis. They provided evidence on the strong influence of the Singaporean government on the NUS and NTU research and development orientations, as well as on Singapore's overall higher education and research system. All our interviewees agreed that the government priorities became their institutions' priorities, and that researchers look at the national plans for guidance and orientation on topics to work on, especially when applying for funds. The NUS and the NTU redesigned laboratories, such as the NUS Environment Research Institute, an interdisciplinary research centre aligned with the government's predefined research priorities on environmental research, in particular concerning water. Interviewees also pointed out that the NUS and the NTU were barely garnering intellectual rents from their R&D activities and that both institutions faced difficulties when negotiating with enterprises the distribution of intellectual property of research results that were at least partially funded by the enterprises. Concerning the types of private partners, most of the examples provided corresponded to foreign multinationals.

Quantitative data was then analysed in different ways. We combined descriptive and network analyses of scientific publications' data together with descriptive analysis of the NUS and the NTU co-patenting activity and monetary returns from R&D.

In order to assess if the Singaporean government succeeded in transforming the NUS and the NTU into key global players in knowledge networks of selected strategic fields, we represented global knowledge networks for each strategic field by looking at high-impact factor publications' authoring institutions.

Within innovation system's literature it was claimed more than 20 years ago that social network analysis using co-patenting and co-publication data allows to map relations between actors within such systems (Wasserman and Faust, 1994). Moreover, as explained by Beigel (2014), there is a mainstream circuit or network for each discipline, defined by publications in

high-impact factor journals. Drawing on Beigel (2014), we may consider each mainstream circuit's participants as the most relevant actors within each research field. In the same vein, Cooke (2006) analysed top impact factor journals from health and biomedical sciences to proxy its global knowledge network. While his interest was the geographical distribution of that network, ours is the institutions that are leading the network and their connections. In particular, we are interested in studying whether the NUS and NTU are among the most important actors of each global knowledge network defined as those institutions most frequently connected within the network. Therefore, we focus on top 50 institutions in terms of their frequency of co-occurrence in each network.

With respect to the period of analysis for knowledge networks corresponding to Singapore's strategic fields, the year 2011 is a turning point in Singapore's policy: it is the year of publication of the first five-year 'Research, Innovation, Enterprise' plan. Compared to the previously named 'Science and Technology' plans, the 'Research, Innovation, Enterprise' plans represent an explicit turn towards economic valorisation of science and technology results. Therefore, our two complementary hypotheses justify to look at global knowledge networks before and after this change (2003-2010 and 2011-2017).

To build each network we processed retrieved scientific publications' data, field by field, using CorText platform.² CorText allowed us to build co-occurrence maps. These maps were constructed by using specific algorithms that associate terms (in our case research institutions' names) according to the frequency of their co-occurrence within a chosen corpus of texts (Barbier et al., 2012), in our case each set of articles from the identified top journals from the four priority research areas. The procedure used to draw these maps, including our corpuses cleaning, follows Tancoigne et al (2014)'s methodology. Nodes represent research

² CorText is an open platform for performing bibliometric and semantic analysis that uses the spatial algorithms that draw on classic graph visualisation methods for depicting the network maps (Fruchterman–Reingold). It can be accessed online at: <https://www.cortext.net/>

institutions (universities, research bodies, firms, etc.). The frequency of authorship is represented by the nodes' sizes. Additionally, since we wanted to focus on the most influential research institutions (defined as most connected and frequent), we prioritized the top 50 nodes. Co-authorships are depicted as direct but also as indirect links. The latter is the case of co-authorship between two research institutions that share publications but always associated to a third institution that also enjoys separate links with the former two. Hence, in the network the latter appears connecting these institutions.

Once we provided evidence on the success in transforming the NUS and the NTU into key global players in three out of the four selected strategic fields' global knowledge networks, we proceeded to analyse data on patents and their associated rents. We analysed these universities most frequent patent co-owners, paying special attention to the proportion of patents shared with local and foreign corporations.

We specially looked whether global leaders performing research with the NUS and/or the NTU, as mentioned by our interviewees (and afterwards checked at the NUS and NTU official web sites and documents), are also patenting innovative results with these universities.

Finally, we contrasted these intermediary goals (scientific publications and patenting activity), with the final goal of Singapore's knowledge (cum innovation) hub strategy, capturing rents from R&D that can contribute to local firms' catching up. To look at intellectual rents we retrieved information from Singapore's National Survey of Research and Development. We analysed the actual share of business expenditure in R&D in relation with the government's targets as stated in Science & Technology plans. Moreover, we compared patent ownership and innovation rents among different types of actors: higher education institutions, public research organizations as a whole including the former, private sector and within it types of firms distinguishing between local and foreign corporations. Based on the theoretical

assumption we derived from the literature review, we anticipate that results will show that even if the NUS and the NTU, and more broadly public research organizations, are patenting results of their R&D activity, they are almost completely unable to garner intellectual rents. In addition, by distinguishing according to the type of company (foreign vs. local), we also find that foreign companies appropriate most of the intellectual rents of the Singaporean hub.

3.4. Considerations on the reliability of the data and of the analytical process

Concerning data reliability limitations, the interviews can only be considered as a first indication that needs to be confirmed and detailed. However, it must also be mentioned that the variety, number and relevance of stakeholders interviewed is a good indicator of the quality of the preliminary approach. Interviews allowed us to confirm a strong power exercised by the state in defining the research fields, the nature of the relations with the private firms, and consequently helped us framing the core analysis developed in this article.

Regarding quantitative data, we only focused on publications and patents. Looking at other research outcomes could complement our analysis on alternative ways to valorise research. Interviews to some extent overcome this limitation since they provided additional information on alternative forms of research commercialization, in particular on start-ups and the difficulties to assure venture capital and compete with global leaders but this needs to be further assessed.

Information on intellectual rents comes from a survey responded by each organization (private companies, government organizations, higher education institutions, etc.). Such data may be of course, to some extent, inaccurate. It should also be stated that information on intellectual rents only refers to companies' activities in Singapore: it does not allow us to provide an overall assessment of multinational companies' intellectual rents but only of those that they associate to their R&D activity in Singapore. Anyway, since our aim is to explain how intellectual rents are distributed in Singapore, the fact that companies may also derive

intellectual rents from their activities in other parts of the world is not an issue. Finally, concerning survey data, we also regret not being able to neither distinguish results by fields, nor by firm.

In terms of our analytical process some considerations should also be made. We assume that a central place in the global knowledge network provides evidence on the contribution of the NUS and NTU not only to knowledge in general but also specifically to innovation. The latter is justified in a twofold way: 1. We conceive knowledge results published in top journals (therefore at the knowledge frontier) that correspond to the topics chosen by the Singaporean government as potentially needed modules or steps of larger innovation processes and results that could be integrated to innovation networks, 2. Interviews at the NUS and NTU allowed us to evidence the strong focus on research valorisation in particular since the ‘Research, Innovation, Enterprise’ plans were put in place. This means that researchers are incited to transform research results into innovations. These universities consciously align their research to more applied topics pursuing the aim of achieving or contributing to achieve innovations. All things considered, we assume that a central place in global knowledge networks is an evidence of the NUS and NTU’s capacities to contribute to innovation networks recognizing that not every published result may play such a role.

4. Empirical findings

At a first glance, industrial policy for higher education and research aimed at transforming the NUS and the NTU in world class universities was successful, as highlighted by governmental reports but also by various scholars (Olds, 2007; Sidhu et al., 2011, 2014). The NUS scaled from the 30th to the 11th position in the QS World University Ranking between 2009 and 2019, while the NTU went from the 73rd to the 12th position in the same period. Moreover,

since the 2000s, the NUS and the NTU show a sharp increase in their total publications (see Figure 1).

Figure 1 should be placed here

In terms of joint research collaborations, while according to the Leiden Ranking 67.2% of the NUS and 62.1% of the NTU's publications between 2006 and 2009 were co-authored with at least another organization, between 2013 and 2016 those percentages had risen to 80.3% and 75.1%, respectively. The change is even stronger in terms of international collaborations. Between 2006 and 2009, 46.6% of the NUS and 44.5% of the NTU's publications had at least one international co-author. These percentages increased to 62.9% and 62.8% between 2013 and 2016. This strategy can be considered as a channel for local players to catch-up in research, while they learn how to publish in international peer-reviewed journals.

Overall, these are impressive results. However, Singapore government's aim was not only to make the NUS and the NTU climb in world rankings, but also to make them key innovative actors capable of profiting, together with local firms, of resulting intellectual rents. In particular, they were expected to excel as innovating institutions in the areas targeted by public policy as privileged for technological catching-up. Hence, we observe next the NUS and NTU's specific results in terms of each strategic field defined by the Singaporean government. This assessment is afterwards complemented with an analysis of who collected intellectual rents from Singapore's knowledge (cum innovation) hub.

4.1. NUS and NTU publications within global knowledge networks

We look at the place of the NUS and the NTU in the global knowledge networks of their government's strategic fields in chosen sub-periods (2003-2010 and 2011-2017). We analyse the 50 most frequently connected actors publishing academic papers in selected journals for

each of those areas. Therefore, if the NUS and the NTU are (or became) leader research institutions integrated to global knowledge networks of those fields, they should appear in the maps, in particular in the second sub-period, and should occupy a key connecting position in the network.

We will show that this was the case in the fields of ‘Urban Solutions and Sustainability’, ‘Services and Digital Economy’ and -to a certain extent- ‘Advanced Manufacturing and Engineering’. However, the situation is not as fruitful when we look at the ‘Health and Biomedical Sciences’ field, which paradoxically was the most privileged sector in terms of financial support. It received S\$1,030.3 million (33% of the total public R&D funding) in 2013, and S\$1,156.1 million (35%) in 2014 (Ministry of Trade and Industry, 2009). Additionally, the ‘Research, Innovation, Enterprise 2015’ plan launched the Biomedical Sciences open collaborative fund (S\$590 million) (Ministry of Trade and Industry, 2009).

Concerning ‘Urban Solutions and Sustainability’ global knowledge network (Figure 2), especially the NTU but also the NUS are depicted in core positions (ranking 2 and 6 in terms of their number of published papers in the selected journals between 2003 and 2017). The place of these universities grows between the two periods. In the second period, the NTU became the leader of the biggest and most connected cluster, which is also integrated by the NUS. Both universities enjoy multiple connections with institutions from all the other clusters. In fact, even if in terms of authorship’s frequency, the Chinese Academy of Science ranks first (1 073 different papers), it occupies a peripheral place in the network. Hence, we may say that, unlike the NUS and the NTU, the Chinese Academy of Science is not at the heart of the ‘Urban Solutions and Sustainability’ global knowledge network, regardless of its importance in number of publications because these are co-authored with fewer frequent partners, as particularly shown in the right side of Figure 2.

Figures 2 should be placed around here

To a lesser extent, the positions of the NUS and the NTU are also important in the ‘Services and Digital Economy’ network. For both periods, both universities ranked among the top 50 research institutions and they became more central to the global knowledge network throughout time (Figure 3). In the latter period, both universities have become highly connected, linking different clusters (which is particularly true for the NUS). The NUS is directly connected to seven institutions in the top 50, linking its cluster with two academic clusters (led by South Wales University and British Columbia University, respectively) and a business cluster (integrated by Microsoft and Google). The strong link between NUS’s cluster and that of Microsoft and Google also suggests the capacity of Singapore to be highly involved in global innovation networks led by intellectual monopolies. The NTU appears also highly connected: its direct links involve eight institutions, all but one within its cluster. The remaining one belongs to a cluster led by the University of Sydney. Through this link it is also connected to the cluster led by South Wales University.

Figures 3 should be placed around here

Regarding the ‘Advanced Manufacturing and Engineering’ area, even though the situation of the NUS and the NTU improves throughout time, the core position of Singapore appears less clear (Figure 4). Between 2003 and 2010 both universities were among top 50 authors in a cluster led by the Chinese Academy of Science, somewhat disconnected from the other world academic players. This cluster was mostly composed of Asian research institutions. In the second period, the interconnectedness with other clusters increases, by developing the links with two North American clusters (led by Harvard and the MIT, and by Northwestern and Illinois Universities) and with a cluster with European and Japanese institutions (led by Cambridge University and the École Polytechnique Fédérale de Lausanne). Hence, it may be said that as ‘Advanced Manufacturing and Engineering’ research becomes more global, the NUS and the NTU followed that trend.

Figures 4 should be placed around here

Finally, the success is more dubious when looking at the ‘Health and Biomedical Sciences’ area (Figure 5). The NTU is not among top 50 research institutions and the NUS, which is among the top 50 between 2003 and 2010 (although in a relatively weak position), disappears from the world leading institutions in the subsequent period. This is not an entirely surprising result for the NTU, which created its medical school very recently (2010), but the NUS was born as a medical school more than a century ago. In the 2003-2010 period, the NUS connects institutions from different clusters, thus occupying a somehow central position in the conformation of the global knowledge network. In the 2011-2017 period, the absence of both universities could be explained by the fact ‘Health and Biomedical Sciences’ is a highly competitive research area, with the highest investments in R&D worldwide. Therefore, it could be expected that, despite major investments in R&D, the NUS was not able to keep its previous position while the NTU’s efforts were not enough to be included.

Figures 5 should be placed around here

At this point, considering that research priorities are meant to be the seed for innovation rents (Ministry of Trade and Industry, 2016), we complement the relative success in terms of these universities’ centrality in global knowledge networks with an analysis of their patent portfolios as well as with the distribution of innovation rents in Singapore.

4.2. NUS and NTU institutional collaborations from a patents co-ownership perspective

We analyse the NUS and the NTU patent portfolios focusing on their corporate co-owners for the 2000-2017 period. Patents will provide an incomplete yet compelling depiction of these universities’ innovation performance. Furthermore, their contribution to the local companies’ catching-up can be partially inferred from the relative importance of their patent co-

ownership. If, as expected by Singapore's Research, Innovation, Enterprise plans, universities are privileging local corporations and these partnerships are successful, there should be more co-owned patents with them than with foreign enterprises. However, anticipating our results, the opposite prevails.

The NUS co-owns applied or granted patents with 43 corporations, 26 of which are foreign companies including global leaders like Huawei, BASF and General Electric. However, most of them are not among its top 100 patent co-owners where there are only nine corporations, four of which are local companies (see Table 2 in Appendix 2). Considering all the NUS patents between 2000 and 2017, local corporations share 40 applied or granted patents (2% of total NUS patents in that period), while those shared with foreign corporations are 80 (4%). Even if these percentages seem low, it should be considered that BASF is the NUS's 6th most frequent patent co-owner (with 24 co-owned granted or applied patents). Globalfoundries, a Singaporean large corporation, is the next corporation in importance sharing 14 patents.

The NTU co-owns patents with 26 corporations, 14 of which are foreign including Huawei, BMW and Siemens (see Table 3 in Appendix 2). During the 2000-2017 period, the NTU shared 43 applied or granted patents with local corporations (3.4% of total NTU patents in this period) and 55 with foreign ones (4.3%).

The institutional setting developed in Singapore in relation to the NUS and the NTU has led to many collaborations that, as we could verify in our interviews, exceed partnerships that led to joint patents. Hence, they may raise the question of the real benefits these collaborations provide to the NUS and the NTU and, more broadly, to the Singaporean government in the terms analysed by Mazzucato (2015) and considering their effects on public research agendas (Slaughter & Leslie, 1997).

For instance, according to our interviews, the Campus for Research Excellence And Technological Enterprise at the NUS, which also involves the NTU, has led to research

collaborations with big global pharmaceuticals like Roche, Merck, AstraZeneca, Novartis and GlaxoSmithKline as well as with other powerful multinational corporations such as Fujitsu, IBM, Danone, Boeing, Shell, Toyota, Exxon Mobil, Alstom, Vestas, BMW and Siemens. From all these companies, only IBM shares (2) granted and/or applied patents with the NUS until 2017 included. In the case of the NTU, only BMW and Siemens are its patent co-owners.

Furthermore, the NUS currently hosts three corporate laboratories: Keppel-NUS, Sembcorp-NUS and the NUS-Singtel Cyber Security Research and Development Laboratory.³ In 2016, the NUS also opened the Institute of Data Science with Microsoft. In turn, the NTU hosts four corporate laboratories: Rolls-Royce@NTU, ST Engineering-NTU, SMRT-NTU Smart Urban Rail Corporate Laboratory and Delta-NTU Corporate Laboratory for Cyber-Physical Systems. Rolls-Royce@NTU was established in July 2013 with a total funding of S\$75 million for manpower with a target of 30 patents and 260 publications over a 5-year period. Nevertheless, until 2017 included, neither the NTU nor the NUS co-owns any granted or applied patent in international patent offices with any of the corporations sharing corporate laboratories with.

Summing up, in terms of patent results, foreign corporations are more frequent co-owners than local corporations, and still most of Singapore's biggest initiatives in terms of university-industry collaborations have not led to NUS or NTU patents. Hence, if research taking place at the NUS and NTU is at the knowledge frontier (sub-section 4.1) and the partnerships with private companies are strong -in particular with foreign companies-, why is this not reflected in the NUS and NTU's patent portfolios? The study of Singapore's innovation rents' distribution contributes to answer this question by providing evidence on who profits from Singapore's knowledge hub.

4.3. Distribution of innovation rents in Singapore

³ Retrieved from: <https://www.nrf.gov.sg/programmes/corporate-laboratory@university-scheme> last access May 2, 2019.

The predominant place of foreign capital, especially transnational corporations, stands in the initial Science & Technology Plans while the government tried to leverage R&D in local companies:

Going forward, the aim is to anchor more flagship R&D projects and attract multinational companies (MNCs) to locate more corporate R&D activities in Singapore. Greater efforts will be also put in to help Singapore local companies to upgrade and develop depth through R&D capabilities, in order to stay competitive... (Ministry of Trade and Industry, 2006, p. 41).

But foreign companies were supposed to contribute to local corporations' catching-up. The literature is still inconclusive in this respect with some authors stating that it can negatively affect local firms' productivity (see for instance: Fu & Gong, 2011; Hu & Jefferson, 2002). On the contrary, other studies concluded that local firms in certain industries could and have benefited from foreign technology introduced by multinationals but only when it is complemented by indigenous innovation efforts (Fu et al., 2011; K. Lee & Lim, 2001).

In abstract terms, Singapore's economic benefit from its inception as a knowledge (cum) innovation hub could result from (i) private R&D investment, including foreign corporations, particularly global leaders (from which Singapore could expect externalities for local actors' R&D), and (ii) innovation rents captured by Singaporean stakeholders.

Concerning private investment in R&D (i), we find that the private sector has not responded in line with the government expectations, leading to a higher share of public investment in total R&D than expected. The 'Science & Technology 2005' Plan defined among its key performance indicators that the Business Expenditure on R&D (BERD) should have reached a 67% share of total country expenditure in R&D. This figure was reaffirmed in the 'Science & Technology 2010' plan. Yet, the goal was never met and, since those plans, no further

BERD target was defined. The share of the local plus foreign BERD decreased between 1994 (62%) and 2016 (60%). In absolute terms, BERD increased during the period but not as much as the government expected, and not as much as to reach -in share- benchmark countries like Korea (78% in 2016) or Germany (68% in 2016) (OECD data). As explained by Cheah et al. (2016), the overall growth in firms' investment in innovation still has significant room for improvement if we compare BERD as a percentage of GDP in Singapore (1.3% in 2016) with the OECD average (2.5% in 2013).

It should also be noted that these figures exaggerate BERD since part of the public investment is 'hidden' as tax benefits for innovative firms. For instance, the 'Productivity and innovation credit grants' offers '400% tax deductions/allowances [subject to a cap of 800,000 Singapore dollars (S\$)] and/or 60% cash pay-out for investments made'.⁴

Inside the business sector, we can distinguish between types of enterprises in order to analyse if Singapore's R&D is driven by local or foreign corporations. Table 4 shows that foreign companies are still the main responsible of the R&D performed in Singapore.

Table 4 should be placed here

We may thus expect foreign companies to hold greater innovation rents since they invest the most in R&D. Still, regardless of their own research activity, they may be also profiting from the research capacity of the main public actors of the Singaporean hub. Concerning the latter, our main finding is that, even though universities and public research institutions own around 13% of total patents owned by stakeholders operating in Singapore, almost 100% of the innovation rents are appropriated by private enterprises (see Table 5). The public sector, including universities, is not capturing rents from its research results (less than 1% as a whole, and less than 0.1% if we only look at the higher education sector). In terms of dollars that

⁴ Retrieved from <https://www.iras.gov.sg/irashome/Schemes/> last access March 15, 2019

each actor extracts per owned patent, universities receive 758 times less dollars per patent than the private sector. It is of course possible to claim that patents owned by higher education and research institutions focus more on basic research and that these patents are more difficult to valorise. In line with Singh et al. (2015), we may also argue that patent quality is lower in universities than in non-university sectors which, according to them, is a sign of weak technology commercialization impacts. But, despite all the latter, the overwhelming results point to a private appropriation of public (including higher education and research institutions) innovation rents.

Table 5 should be placed here.

This result is consistent with the outcomes of our interviews. NUS and NTU authorities evidenced the difficulties of research commercialization, not only concerning patents but also in terms of creating university spin-offs. Among the relatively few successful cases that were mentioned in these interviews, it was observed that researchers main aim tend to be to sell the company to an already settled -in many cases multinational- corporation. In the case of patents, those shared with enterprises are not appealing for other private companies because the firm co-owning the patent enjoys it for free, without the obligation of sharing the profits neither paying royalties to the university co-owning the patent. Thus, even when formally patents are co-owned between universities and corporations, almost only the latter enjoys rents. Innovation rents are created but not enjoyed by public research institutions.

In fact, the gap between innovation rents created and captured at the NUS and NTU is even greater since we are only considering patents owned by these institutions. We are not taking into account that professors' privilege as well as the lack of resources to patent every single invention at the university level lead to patents invented at these institutions but not owned by them, as discussed in Schoen and Buenstorf (2013) for German universities.

Moreover, the distribution of innovation rents within private corporations appears to be very favourable to foreign firms. As shown in Table 6, foreign companies hold 83.3% of private companies' innovation rents. Two indicators are used to measure these rents: licensing revenues and sales revenues from products resulting from R&D activities. What we observe is that foreign companies usually do not license their patents, they rather use patented innovations to increase revenues by commercializing resulting products. On the contrary, Singaporean enterprises mostly license their patents, instead of increasing their created value from commodities produced embedding patent results. All in all, even considering that patents owned by the public sector may have weaker technological impacts, innovation rents measured by associated revenues show that only enterprises (and mostly foreign companies) are profiting from all the R&D done in Singapore (see Tables 5 and 6). And this is true regardless of total public investment in R&D (35% of total R&D funding sources in 2016). Results have not been those expected by governmental instruments which aimed at contributing to local firms' catching up, and to create and capture rents from universities and local firms' R&D (particularly since the 'Research, Innovation, Enterprise 2015' plan).

Table 6 should be placed here

However, it must also be noted that the share of R&D invested in the higher education sector by private companies increased in this period, from 2.9% in 1994 to 13.1% in 2016. This highlights the attractiveness of the sector for corporations. It is not only lower costs what may drive companies (in particular multinationals, as was pointed out by interviewees) to partner with universities. Both universities' research capabilities and the availability of public funds - which represented 78% of R&D funds enjoyed by Singapore's higher education sector in 2016- attract companies to work with universities.

Summing up, the growing number of NUS and NTU's publications and patents was not enough to reduce Singapore's dependence on foreign companies which appear to be the main

collectors of innovation rents triggered by Singapore's successful R&D. Meanwhile, the public sector (in particular the NUS and the NTU) and local firms participate in Global Innovation Networks in a subordinated position judging by their lack of intellectual rents regardless of their R&D capabilities.

5. Discussion

By integrating all our findings we may point out that while the NUS and the NTU are actively contributing to knowledge and innovation, they barely collect intellectual rents from that activity. Both our interviews and analysed data provided evidence on multinational companies' appropriation of most of the innovation rents of the Singaporean hub, while local companies remain laggards. These results are in line with the intellectual monopoly capitalism theory (Durand & Milberg, 2019; Pagano, 2014; Rikap, 2018). They also point to a specific form of unequal exchange (Emmanuel, 1972) and call to rethink catching-up policies.

In these respects, our results are in line with Cooke's (2006) concluding remark on global networks of bioscientific knowledge. According to the author, the formation of knowledge clusters in certain regions (among which he mentions Singapore, although not as one of the most important in bioscience, unlike Cambridge–Boston led by Harvard Medical School) “have begun to exert spatial knowledge monopoly effects that are already bringing ‘increasing returns’ as multinationals establish R&D facilities to capture ‘knowledge spillover’ advantages from cluster conventions of both ‘open science’ and ‘open innovation.’” (Phil Cooke, 2006, p. 457). In our case the same can be said for Singapore's knowledge hub as a whole. Moreover, we provided further evidence on how multinationals profit from knowledge hubs by looking at the distribution of innovation rents in Singapore, while Cooke's (2006) paper is only based on the analysis of co-publication's networks.

In the specific case of Singapore's hub, our findings nuance other assessments that stressed Singapore's hub success (Cheah et al., 2016; Mok, 2015; Sidhu et al., 2014). Unlike these studies, we did not only look at Singapore's hub results in terms of science and technology indicators, but also included an analysis of resulting innovation rents' distribution. This is what allowed us to distinguish between Singapore's success in terms of science and technology achievements, and its relative failure when it comes to garner rents and develop indigenous technological capabilities in local enterprises.

Our findings also contradict Landesmann and Stöllinger's (2019, p. 21) conclusions in the sense that it should at least be put into question that "being successful receptors of internationally generated knowledge (...) and attracting the main 'agents' of diffusion of such knowledge", as Singapore has done, leads to spillovers unto local firms. Singapore attracted multinationals' R&D laboratories as well as world class universities that established branches or collaborations with the NUS and the NTU. It also conducted industrial policies within and beyond its 'Research, Innovation, Enterprise' plans to stimulate local firms' catching-up. Nevertheless, so far, the latter was not achieved, at least in terms of garnering intellectual rents. Hence, our findings also put into question those analyses such as that of Fu et al (2011) who state that local universities and research institutions' R&D contributes to enhance local actors' absorptive capacities, since foreign instead of local companies are profiting the most from the greater R&D performance of the NUS and the NTU.

We have also provided other more specific findings that open questions for further research, in particular on the role of two global intellectual monopolies, Google and Microsoft, in the 'Services and Digital Economy' global knowledge network. The fact that these companies occupy such a central position in the global knowledge network of the field means that they could be influencing the global research agenda on these topics, thus orienting academic research in line with their priorities.

Overall, our findings broaden the scope of the intellectual monopoly framework, so far focused on theorizing on these monopolies' effects on Global Value Chains (Durand & Milberg, 2019) and evidencing their emergence and effects in terms of intangible assets and profits' concentration in core countries, in particular the United States (Pagano, 2014; Rikap, 2018, 2019; Schwartz, 2016). We did so by showing that foreign (especially multinational) corporations appropriate most of the innovation rents of the Singaporean knowledge hub, thus the science and technology efforts of the NUS and the NTU end up mostly benefiting foreign (typically multinational) rather than local companies. In this scenario, we have put into question local firms' chances to catch-up and, eventually, become technologically autonomous. All in all, our findings alert on how multinational corporations profit from public policies not only in their home countries, as shown by Mazzucato (2015), but also from the research capacity and public funds of emerging economies thus deepening global asymmetries.

6. Concluding remarks

In this paper we elaborated on the distinction between who produces knowledge (in particular innovation) and who captures associated innovation rents by looking at Singapore's case. Singapore's industrial policy, since the 2000s, has relied on a knowledge *cum* innovation hub strategy. The main contribution of this article was to evidence the need to rethink hub initiatives aimed at catching-up since they may fail and end up reinforcing global leaderships. While these policies in Singapore contributed to the development of local science and technology capabilities, profits keep being enjoyed by foreign multinationals from core countries.

Our results show that, on the one side, the NUS and the NTU became world class universities recognized by the quality of their research and characterized by a clear success in at least

three out of the four strategic areas identified by government's 'Research, Innovation, Enterprise' plans. Moreover, by creating connections with various research hubs (in Asia, Europe and the USA), and by developing multiple research agreements with intellectual monopolies, they were apparently able to create a strong insertion in global innovation networks. Hence, we may conclude that they effectively caught-up.

On the other side, we provided empirical evidence on how private companies hold almost 100% of intellectual rents, while holding 86% of total patents owned by stakeholders operating in Singapore. Among companies, foreign ones loom large, appropriating 83.3% of total private companies' innovation rents. Therefore, there is slim evidence on local firms' catching-up and, even if they did so to some extent and/or in some industries, most of the intellectual rents of Singapore's knowledge hub are captured by foreign companies.

Summing up, the Singaporean case illustrates that even if it is possible to transform universities into world class universities inserted in global knowledge networks and develop a knowledge and innovation hub, these achievements -together with tax credit incentives for innovative firms and a wide variety of measures to promote entrepreneurial activity in Singapore (Cheah et al., 2016)-, were not enough for industrial catching-up.

It thus appears that Singapore's knowledge hub policy cannot be considered effective from many respects and that its sustainability can be put into question. This is all the more true that competitors in the region, in particular China, are threatening Singapore's hub. As we pointed out in Section 2, China has a set of specific conditions that, coupled with a protectionist policy towards foreign multinationals, contributes to explain catching-up in high-tech industries. In a country like Singapore without a big internal market, the State has less leverage to negotiate with multinational companies. Hence, a knowledge hub strategy should be complemented with policies that limit multinationals' appropriation of intellectual rents deriving from local R&D, in particular from public institutions.

Another dimension to consider when rethinking knowledge hub policies concerns the identification of strategic fields. At least two of Singapore's strategic fields – 'Services and Digital Economy' and 'Health and Biomedical Sciences'- are dominated by intellectual monopolies (Durand & Milberg, 2019; Orhangazi, 2018; Rikap, 2018, 2019). In broader terms, in a context where innovation networks are transnational, picking fields where some countries or specific companies are indisputable leaders should be considered cautiously if the aim is to develop indigenous technological capabilities in emerging or peripheral regions. It may instead be a better strategy to choose fields where there is no such a clear global dominance, or more broadly fund public R&D as a long shot (from which new industries may spring from), instead of focusing in short-term applications.

Finally, our conclusions provide empirical evidence supporting a turn towards intellectual monopoly and rent-seeking that narrows catching-up windows of opportunity (K. Lee & Malerba, 2017). These companies play a great role in the definition of which areas of the planet will be the major producers of R&D, and which will be the factories of the world. As long as the Singaporean government assures these companies a higher rate of profit than other countries (with similar institutional, political and economic stability) in the region, it is likely to observe that Singapore remains as a knowledge and innovation hub. Yet, since innovation rents produced in Singapore are not mainly captured by local actors, this form of hub strategy widely open to foreign companies seems not to assure catching-up in contemporary capitalism.

To conclude, more research needs to be done in order to identify the extent to which these conclusions are compatible with the experiences of other wannabe or recent world class universities, and more in general with other knowledge and innovation hubs. Among other questions to be consider in future research it is of utmost importance to further elaborate on whether (or to what extent) limiting multinationals' businesses could be a successful strategy

if the aim is to develop indigenous technological capabilities? Comparing Singapore's hub with China's Shenzhen hub could be a good starting point in this respect. Moreover, an actor that was absent in the Singaporean case is military research. In this respect, we may inquire about the role of military research in other knowledge and innovation hubs, such as Israel.

7. References

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Funding: This work was supported by the Institut Francilien Recherche Innovation Société under their Postdoctoral Fellowship program.

Appendix 1. List of journals associated to each strategic field.

‘Services and Digital Economy’: ACM TRANSACTIONS ON GRAPHICS; BMJ QUALITY SAFETY; COMMUNICATIONS OF THE ACM; HEALTH AFFAIRS; HUMAN COMPUTER INTERACTION; IEEE COMMUNICATIONS SURVEYS AND TUTORIALS; IEEE TRANSACTIONS ON CYBERNETICS; IEEE TRANSACTIONS ON

EVOLUTIONARY COMPUTATION; IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS; IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE; IEEE WIRELESS COMMUNICATIONS; JMIR MHEALTH AND UHEALTH; JOURNAL OF MANAGED CARE PHARMACY; JOURNAL OF MEDICAL INTERNET RESEARCH; JOURNAL OF STATISTICAL SOFTWARE.

‘Urban Solutions and Sustainability’: ANNUAL REVIEW OF ECOLOGY EVOLUTION AND SYSTEMATICS; ANNUAL REVIEW OF MARINE SCIENCE; BEHAVIORAL AND BRAIN SCIENCES; CITIES; COMPUTER AIDED CIVIL AND INFRASTRUCTURE ENGINEERING; DESALINATION; ENERGY ENVIRONMENTAL SCIENCE; GREEN CHEMISTRY; LANDSCAPE AND URBAN PLANNING; OCEANOGRAPHY AND MARINE BIOLOGY; PROGRESS IN ENERGY AND COMBUSTION SCIENCE; RENEWABLE SUSTAINABLE ENERGY REVIEWS; TRANSPORT REVIEWS; TRANSPORTATION RESEARCH PART B METHODOLOGICAL; TRENDS IN COGNITIVE SCIENCES; TRENDS IN ECOLOGY EVOLUTION; VEHICULAR COMMUNICATIONS; WATER RESEARCH.

‘Advanced Manufacturing and Engineering’: ACTA BIOMATERIALIA; ADVANCED SYNTHESIS CATALYSIS; ADVANCES IN ORGANOMETALLIC CHEMISTRY; ALDRICHIMICA ACTA; BIOMATERIALS; BIOSENSORS BIOELECTRONICS; BIOSENSORS BIOELECTRONICS; CHEMICAL REVIEWS; CHEMICAL SOCIETY REVIEWS; COORDINATION CHEMISTRY REVIEWS; ENERGY ENVIRONMENTAL SCIENCE; IEEE INDUSTRIAL ELECTRONICS MAGAZINE; IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS; IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS; INTERNATIONAL JOURNAL OF ROBOTICS RESEARCH; JOURNAL OF ASTRONOMICAL TELESCOPES INSTRUMENTS AND SYSTEMS; JOURNAL OF PHYSICAL CHEMISTRY LETTERS; JOURNAL OF POWER SOURCES; MARINE

STRUCTURES; NATURAL PRODUCT REPORTS; NATURE MATERIALS OR NATURE NANOTECHNOLOGY; NATURE METHODS; NATURE PROTOCOLS; NPJ QUANTUM INFORMATION; OCEAN ENGINEERING; PROGRESS IN AEROSPACE SCIENCES; PROGRESS IN CRYSTAL GROWTH AND CHARACTERIZATION OF MATERIALS OR NANOSCALE AND MICROSACLE THERMOPHYSICAL ENGINEERING; PROGRESS IN ENERGY AND COMBUSTION SCIENCE; PROGRESS IN QUANTUM ELECTRONICS; SEPARATION AND PURIFICATION REVIEWS; SOFT ROBOTICS; TRAC TRENDS IN ANALYTICAL CHEMISTRY.

Health and Biomedical Sciences: ANNUAL REVIEW OF BIOMEDICAL ENGINEERING; ANNUAL REVIEW OF FOOD SCIENCE AND TECHNOLOGY; ANNUAL REVIEW OF NUTRITION; BIOLOGICAL REVIEWS; BIOMATERIALS; CA A CANCER JOURNAL FOR CLINICIANS; CELL; CIRCULATION; CIRCULATION RESEARCH; CLINICAL MICROBIOLOGY REVIEWS; CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION; EUROPEAN HEART JOURNAL; JOURNAL OF THE AMERICAN COLLEGE OF CARDIOLOGY; LANCET DIABETES ENDOCRINOLOGY; LANCET HIV ; LANCET INFECTIOUS DISEASES ; LANCET NEUROLOGY; NATURE BIOTECHNOLOGY; NATURE MEDICINE; NATURE NEUROSCIENCE; NATURE REVIEWS CANCER; NATURE REVIEWS DRUG DISCOVERY; NATURE REVIEWS DRUG DISCOVERY; NATURE REVIEWS ENDOCRINOLOGY; NATURE REVIEWS MICROBIOLOGY; NATURE REVIEWS MOLECULAR CELL BIOLOGY; NATURE REVIEWS NEUROLOGY; NATURE REVIEWS NEUROSCIENCE; PHARMACOLOGICAL REVIEWS; PHYSICS OF LIFE REVIEWS; PROGRESS IN LIPID RESEARCH.

Appendix 2. Tables and figures.

Table 2. NUS patents' corporate co-owners (2000-2017).

Corporation	Type	Ranking	Frequency	Number of distinct documents
CHARTERED SEMICONDUCTOR MFG CO	local corporation	5	28	28
BASF SE	foreign corporation	7	25	24
STMICROELECTRONICS ASIA	foreign corporation	19	8	8
GLOBALFOUNDRIES SG PTE LTD	local corporation	20	7	7
HADASIT MED RES SERVICE	foreign corporation	21	6	6
TEMASEK LIFE SCIENCES LAB LTD	local corporation	21	6	6
IMEC corp	foreign corporation	22	5	5
ISIS PHARMACEUTICALS INC	foreign corporation	22	5	5
KINERGY PTE LTD	local corporation	22	5	5
HUAWEI	foreign corporation	23	4	4
MULTICLONAL THERAPEUTICS INC	foreign corporation	23	4	4
OSTEOPORE KOREA CO LTD	foreign corporation	25	4	3
TEXAS INSTRUMENTS INC	foreign corporation	24	3	3
AUCKLAND UNISERVICES LTD	foreign corporation	24	3	3
IRIDEX CORP	foreign corporation	24	3	3
Apple	foreign corporation	24	3	3
HONEYWELL PTE LTD	local corporation	24	3	3
OKI TECHNO CT PTE LTD	foreign corporation	25	2	2
60 DEGREES PHARMACEUTICALS LLC	foreign corporation	25	2	2
OSTEOPORE INTERNAT PTE LTD	foreign corporation	25	2	2
ILLUMINA INC	foreign corporation	25	2	2
IBM	foreign corporation	25	2	2
MPORT PTE LTD	foreign corporation	25	2	2
TOSHIBA CORP	foreign corporation	25	2	2
HOPE TECHNIK PTE LTD	local corporation	25	2	2

JURONG CONSULTANTS PTE LTD	local corporation	25	2	2
CET TECHNOLOGIES PTE LTD	local corporation	25	2	2
ABB LUMMUS GLOBAL INC	foreign corporation	26	1	1
GEN ELECTRIC	foreign corporation	26	1	1
PGS GEOPHYSICAL AS	foreign corporation	26	1	1
SEAGATE TECHNOLOGY LLC	foreign corporation	26	1	1
ALLIUM MEDICAL LTD	foreign corporation	26	1	1
AMERICAN PRESIDENT LINES CO PTE LTD	foreign corporation	26	1	1
KRATON POLYMERS US LLC	foreign corporation	26	1	1
DAVOS LIFE SCIENCE PTE LTD	local corporation	26	1	1
MUSTARD TECHNOLOGY PTE LTD	local corporation	26	1	1
TEO WAY YONG & SONS PTE LTD	local corporation	26	1	1
MUVEE TECHNOLOGIES PTE LTD	local corporation	26	1	1
WONG FONG ENGINEERING WORKS 1988	local corporation	26	1	1
ST ELECTRONICS INFO SOFTWARE S	local corporation	26	1	1
CELLONICS INC PTE LTD	local corporation	26	1	1
OFFSHORE TECHNOLOGY DEV PTE LTD	local corporation	26	1	1
YONGNAM HOLDINGS LTD	local corporation	26	1	1

Source: Compiled from Derwent Innovation.

Table 3. NTU patents' corporate co-owners (2000-2017).

Corporation	Type	Ranking	Frequency	Number of distinct documents
SINGAPORE TECH DYNAM PTE LTD	local corporation	11	10	10
INSIGHTRA MEDICAL INC	foreign corporation	11	10	10
YISSUM RES DEV CO	foreign corporation	12	9	8
GLOBALFOUNDRIES SG PTE LTD	local corporation	13	8	8
MENICON CO LTD	foreign corporation	13	8	8
LOCKHEED CORP	foreign corporation	15	6	6
ROBERT BOSCH SEA PTE LTD	local corporation	16	5	5
HUAWEI	foreign corporation	16	5	5
THALES SOLUTIONS ASIA PTE LTD	local corporation	17	4	4
SUT SERAYA PTE LTD	local corporation	17	4	4
BMW	foreign corporation	17	4	4
SIEMENS PTE LTD	foreign corporation	17	4	4
ACOUSTICAL TECH SG PTE LTD	local corporation	18	3	3
LIGHTLAB SWEDEN AB	foreign corporation	18	3	3
PURECHEM ONYX PTE LTD	local corporation	19	2	2
GASHUB TECHNOLOGY PTE LTD	local corporation	19	2	2
TECHNOLITE (SINGAPORE) PTE LTD	local corporation	19	2	2
ST MICROELECTRONICS ASIA	foreign corporation	19	2	2
DAIOH SHINYO CO LTD	foreign corporation	19	2	1
PROGEN PTE LTD	local corporation	20	1	1
INTERNAT SEMICONDUCTOR PRODU	local corporation	20	1	1
ADVANCED ELECTROACOUSTIC PTE	local corporation	20	1	1
DYESOL LTD	foreign corporation	20	1	1
NINGBO SUNNY OPOTECH CO LTD	foreign corporation	20	1	1
PEC LTD	foreign corporation	20	1	1
SANTEN PHARMA CO LTD	foreign corporation	20	1	1

Source: Compiled from Derwent Innovation.

Tables

Table 1. Scientific publications per strategic field retrieved from Web of Science (2003-2017).

Strategic Field	Corpus of articles in selected high-impact factor journals	Number of journals	NTU articles	NUS articles
Advanced Manufacturing and Engineering	80 710	32	759	915
Health and Biomedical Sciences	48 010	31	117	416
Services and Digital Economy	20 756	15	236	186
Urban Solutions and Sustainability	31 264	18	314	305

Source: Compiled from Web of Science

Table 4. Sources of R&D expenditure in 2016 (S\$ billions) per sector.

Source	R&D Expenditure	Proportion inside enterprise sector	Proportion of total R&D Expenditure
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1) Local Small and Medium Enterprises	0,73	12,65%	7,62%
2) Local Large Enterprises	0,93	16,21%	9,76%
3) Foreign Companies	4,08	71,14%	42,84%
Total Private Sector (1+2+3)	5,73	-	60,22%
Government Sector	1,01	-	10,62%
Higher Education Sector	1,65	-	17,32%
Public Research Institutes	1,13	-	11,83%
Total	9,52	-	100%

Source: Compilation based on National Survey of Research and Development in Singapore.

Table 5. Research and Development Revenue Indicators in 2016 (S\$ million unless stated otherwise).

Revenue Indicators	Private Sector	Government Sector	Higher Education Sector	Public Research Institutes	Total
Licensing Revenue from Patents and New	287	0,41	2,25	8,83	298

Technologies Developed in Singapore					
Share of licensing revenues per sector	96,15%	0,14%	0,75%	2,96%	100,00%
Sales Revenue from Commercialized Products/Processes Attributed to R&D Performed in Singapore	29 257	0,05	0,65	60,69	29 318
Share of sales revenues per sector	99,79%	0,0002%	0,002%	0,21%	100%
Patents Owned (Cumulative until Dec 31, 2016)	9 922	187,00	765,00	659,00	11 533
Share of total patents	86,0%	1,6%	6,6%	5,7%	100%
Dollars per patent: (Licensing revenues + Sales revenues) / Patents Owned	2 977 619	2 459	3 790	105 493	2 568 006

Source: Compilation based on National Survey of Research and Development in Singapore

Table 6. Licensing and sales revenues per type of enterprise in 2016 (S\$ million unless stated otherwise).

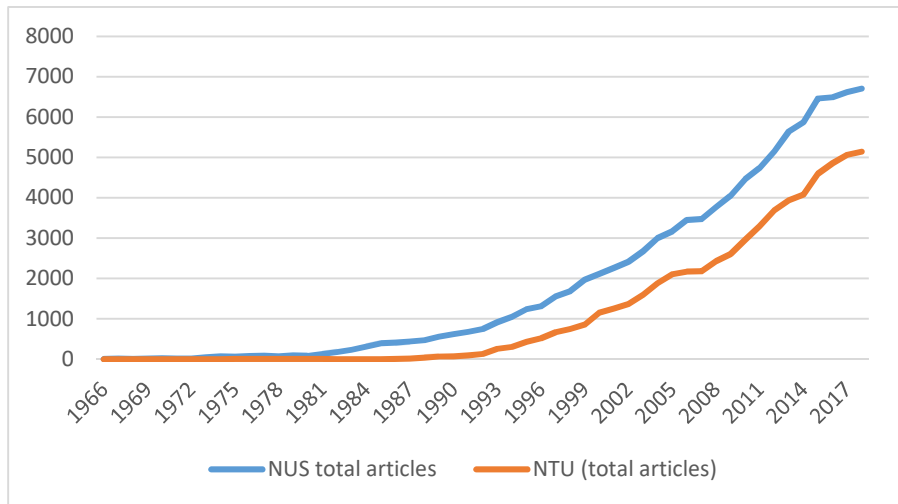
	Local Small and Medium Enterprises	Local Large Enterprises	Foreign Companies	Total
A) Licensing Revenue from Patents and New Technologies Developed in Singapore	31	221	34	287
Share of licensing revenues (A) per type of enterprise	10,8%	77,2%	12,0%	100,0%
Licensing revenues per patent (A / C * 100)	14 619	129 707	5 639	28 922
B) Sales revenue from Commercialized Products/Processes Attributed to R&D Performed in Singapore	756	3 935	24 565	29 256
Share of sales revenues (B) per type of enterprise	2,6%	13,5%	84,0%	100,0%
Sales revenue's per patent (B / C * 100)	355 305	2 304 074	4 036 398	2 948 696
C) Patents Owned (Cumulative until 31 Dec 2016)	2 128	1 708	6 086	9 922

D) Total Dollars due to Patenting activity (A+B)	787	4 156	24 599	29 543
Proportion of total income due to patenting (A / D * 100)	2,7%	14,1%	83,3%	100,0%

Source: Compilation based on National Survey of Research and Development in Singapore.

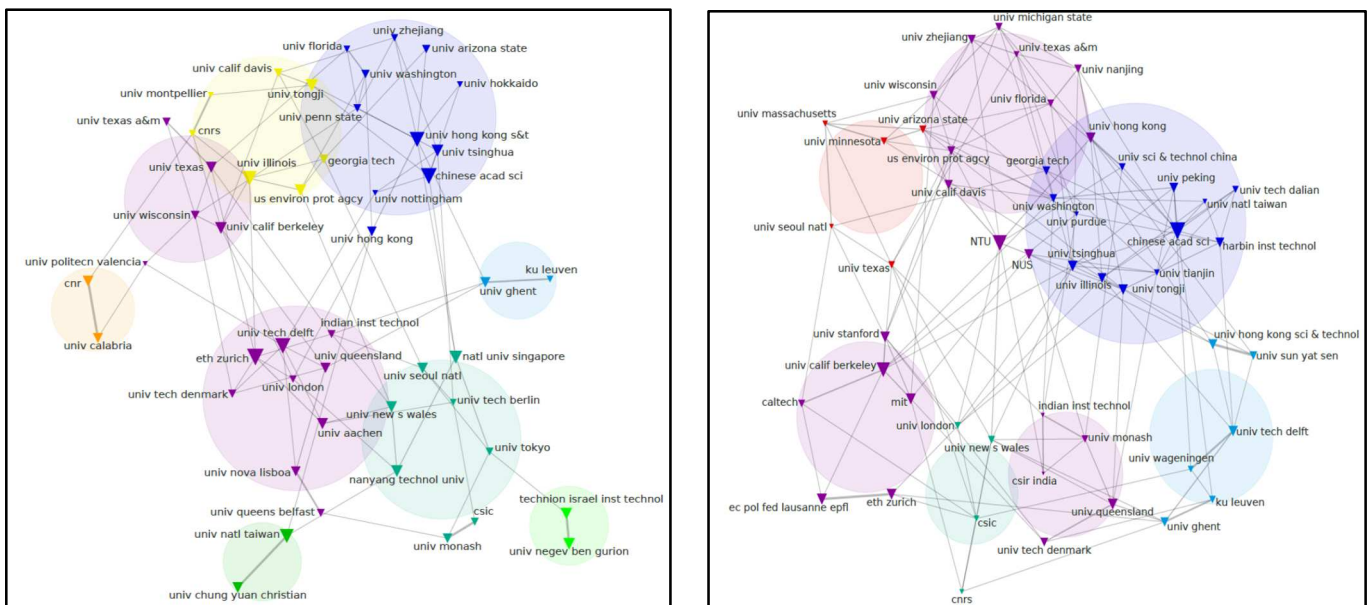
Figures

Figure 1. NUS and NTU total scientific publications



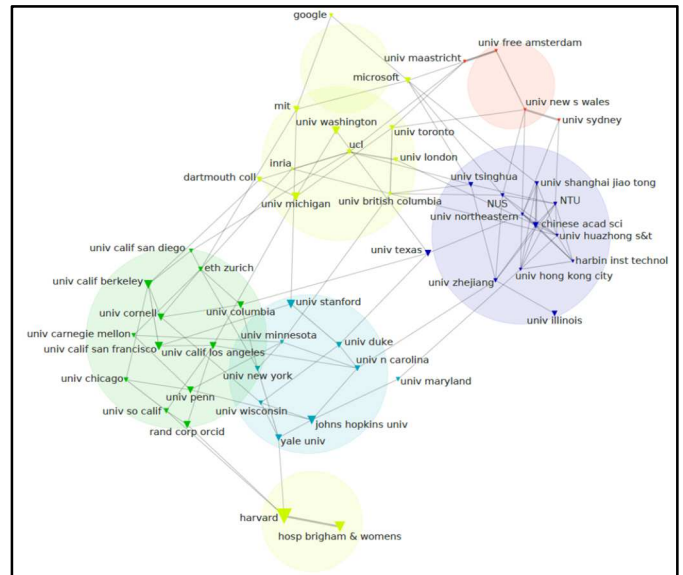
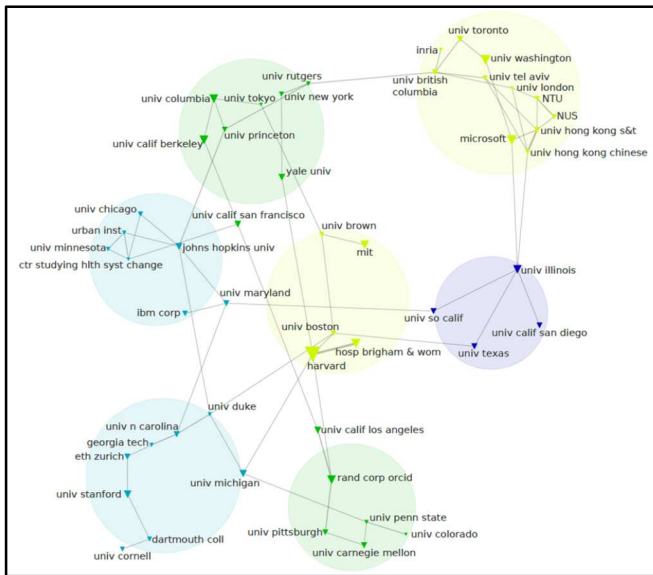
Source: Web of Science.

Figure 2. ‘Urban Solutions and Sustainability’ top 50 Research Institutions (2003-2010 on the left and 2011-2017 on the right side)



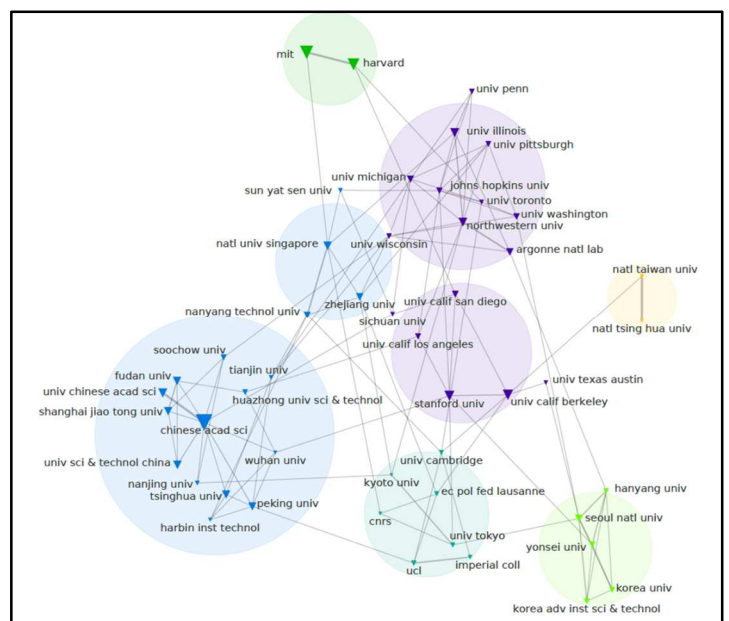
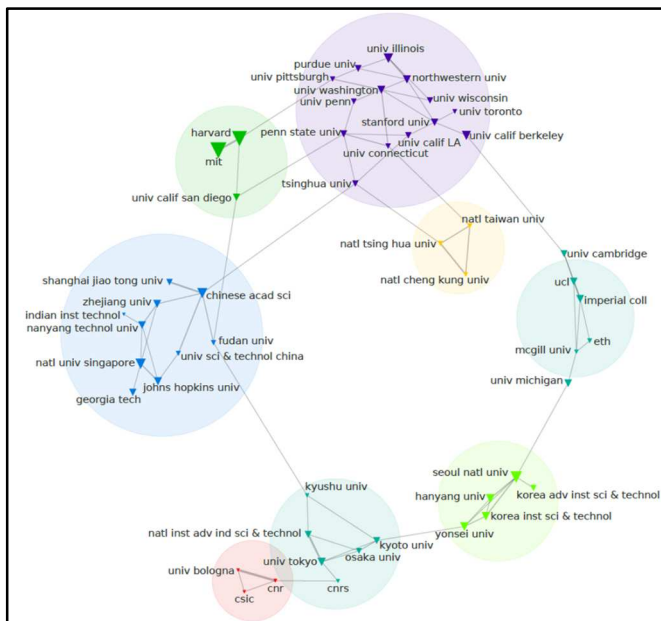
Source: Authors’ analysis based on Web of Science data extraction

Figure 3. ‘Services and Digital Economy’ top 50 Research Institutions (2003-2010 on the left and 2011-2017 on the right side)



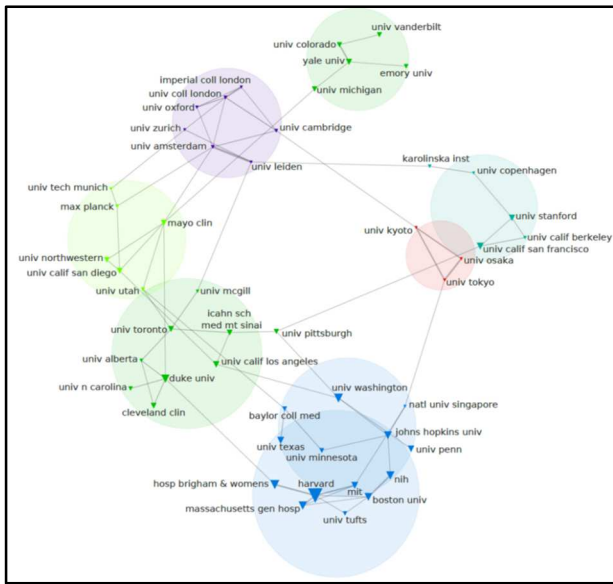
Source: Authors' analysis based on Web of Science data extraction

Figure 4. 'Advanced Manufacturing and Engineering' top 50 Research Institutions (2003-2010 on the left and 2011-2017 on the right side)



Source: Authors' analysis based on Web of Science data extraction

Figure 5. 'Health and Biomedical Sciences' top 50 Research Institutions (2003-2010 on the left and 2011-2017 on the right side)



Source: Authors' analysis based on Web of Science data extraction