The Intellectual Evolution of the Technological Catch-up Literature: Bibliometric Analysis

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Abstract[5]

We analyse the growing literature on technological catch-up since the 1980s to identify its intellectual bases and evolution. The analysis uses co-occurrence and co-citation techniques to explore trends in keywords, journals, documents, and authors. In the 1980s, the area was characterised by two unrelated streams of work on macroeconomic growth and the building of technological capabilities at the micro-level in developing economies. During the 1990s, when the technological catch-up literature began to take off, these two streams of literature evolved further and came closer to each other. During the 2000s, firm-level studies rooted in resource-based and knowledge-based views proliferated. From 2010 they were followed by an increased number of studies of latecomer firm internationalisation. The field's qualitative evolution has been characterised by the convergence between the economic growth and technology capabilities literature, a change of focus from the macro issues of growth and convergence to firm (latecomer firm) and sectoral level issues, and a dominant concern about the relationship between globalisation and technology upgrading at the sectoral or mezzo level. There are four streams that currently underpin research on technology catch up: economic growth, systems of innovation, knowledge management, and industrial dynamics cum global value chains and latecomer firm.

Keywords: catch-up; economic growth; latecomer firm; technology capability; internationalisation; Global Value Chain; bibliometric

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1. Introduction

The world economy shows significant productivity differentials between advanced and emerging and developing economies and varying convergence and divergence trends (Dieppe, Kilic-Celik et al. 2020). The persistent gaps in income, productivity, and technology and close links among them have been a primary concern for policymakers and academics alike. They have led to substantial literature on the main long-term driver of the income gap – differences in technology capabilities (Crafts and O'Rourke 2014)[6].

Modern research on technology catch-up is a rich scholarly area that originated in the early 1980s. Forty years of history enable a depiction of the evolving patterns in the field where the research objective is relatively clearly defined but whose boundaries of inquiry are fuzzy. Technology is firm-specific but, based on its systemic features, is also a multi-level phenomenon that has resulted in explorations of the role of technology in the catching-up process at the macro, mezzo, and micro levels. Unlike conventional economics, neo-Schumpeterian economics as the core perspective on technology and growth operates at all three levels. Accordingly, the technology catch-up literature spans firms, sectors, and countries with blurred boundaries between the different levels.

The often-cited paper by Abramovitz (1986) entitled '*Catching-up, forging ahead, and falling behind*' frames national potential for catch-up as a technology gap and 'social capability' issue. This framework extends approaches to understanding growth and technology both vertically

[6] We acknowledge that there are other factors of the long-term growth, notably institutions and geography, which play also significant role in economic catchup. However, as indicated by the economic growth literature the technological change broadly defined is probably the strongest determinant of contemporary long-term economic growth.

and horizontally by embracing a variety of social and institutional factors. This broader perspective has led to a rich stream of work on catching up from a system of innovation perspective. Freeman (1987), (1988) account of Japan's innovation system was the first to use this framework to demonstrate the role of the innovation system in catching up.

At the macro level and from a growth theory perspective, Fagerberg (1987), (1988) showed early on that those countries which caught up rapidly also achieved rapid innovative activity growth. In the 1980s, a series of firm-level studies on technology catch-up in the so-called 'newly industrializing economies' such as Korea, Brazil, and Mexico emerged. Research initiated by Dahlman and Westphal (1981) and followed by Dahlman, Ross-Larson et al. (1987), Westphal (1988), Katz (1987), and Lall (1987) explores the process of technological learning and mastery of technology at the firm level. This body of work reveals the complexity of the technology acquisition process, the different taxonomies of technological activities, and their different nature compared to the advanced economies. Research showed that technology should not be equated with machinery or disembodied information but rather should be conceptualized as capability. This approach based on Penrose (1959) resource-based or capabilities theory was later 'discovered' by mainstream business economics and strategy scholars.

Understanding technology as a capability in the catch-up process is summarized in Bell and Pavitt's frequently cited papers (Bell and Pavitt 1993, 1995). The technological capability framework formed the basis of numerous firm-level empirical studies during the 1990s that investigated latecomer firms' growth and the barriers to their emergence as leaders. Hobday (1993), (1995) , Amsden (2001), Kim (1997), (1998), and Mathews (2006) investigated the success of the East Asian countries in industries such as consumer electronics, automotive, and

shipbuilding, basing their analyses on the notions of catch-up and latecomer firms. Also, in this period, research on firm-level technological catch-up focused on the successful experience of Japanese companies using conceptual lenses such as strategy (Fujimoto and Clark 1991), knowledge creation (Nonaka 1990), and 'lean manufacturing' (Womack, Jones et al. 1990).

The early 2000s were marked by the emergence of Brazil, Russia, India, China, and South Africa (BRICS), which led to an interest in the relationship between technological catch-up and globalisation (Awate, Larsen et al. 2012, Kumaraswamy, Mudambi et al. 2012). New paths of technological catch-up and modes of integration into the global economy have led to increasing research on China and India (see, for instance, Fu and Gong (2011)), and emerging economy multinational enterprises (MNEs) or 'dragon multinationals' (Mathews 2006). Others has also examined the falling further behind of sample of countries using institutional approach (e.g.Mudombi and Muchie (2014), Souzanchi Kashani (2020)

Studies of innovation focused on advanced economies emphasise project-based, complex product industries, and scholars of catch-up examined the growth of latecomer capabilities in these sectors (Kiamehr, Hobday et al. 2014, Kiamehr, Hobday et al. 2015, Safdari Ranjbar, Park et al. 2018) . Specifically, the concept of latecomer 'systems integration capabilities' was proposed to enable examination of catch-up in developing economies (Kiamehr, Hobday et al. 2014).

This summary of the evolution of the technology catch-up literature is sketchy, unsystematic, and possibly reflects the interpretative biases of the authors. The present paper uses bibliometric analysis tools to provide a thorough review by examining how the intellectual bases of the technological catch-up literature have evolved. The catch-up literature continues to grow with different scholars exploring different research threads. However, there is no

systematic analysis of the evolution of this literature so far and different streams of work it includes. The present paper aims to fill this gap. Technological catch-up emerged as a research issue during the 1980s, and a traditional literature review would identify the principal authors and papers during that period. However, by 2020, the area has expanded hugely, and its complexity has increased, making a conventional descriptive literature review insufficient. We believe that there is a need for a systemic overview of the evolution of the technological catch-up literature.

For both 'newcomers' to the field and experienced researchers, this analysis will provide a systematic review of its intellectual development, including the disciplines which have shaped catch-up research, areas of emerging research interest, and critical turning points. We hope that it will allow the reader to identify research gaps and define potential meaningful future research directions (for a similar work on innovation systems, see Souzanchi Kashani, E. and S. Roshani (2019).

We introduce the research methodology (section 2) and briefly describe the data (section 3). Sections 4.1-4.3 explore the disciplines, key co-words, and journal co-citations involved in the area. Section 4.4. explores how the network of authors and papers evolved during the four decades. Section 4.5 explores the author co-citation network underpinning the literature on technological catch-up. Section 5 concludes by highlighting eight important insights and two critical points.

2. Methodology

This paper goes beyond purely descriptive citation counts and employs CiteSpace (Chen 2006, Chen, Hu et al. 2012) to visualise the intellectual structure (Chen 1999, 2003, 2004) of the technological catch-up literature, identify turning points, and analyse how research has evolved.

Our analysis is based on three major metrics commonly used in scientific maps: co-citation, centrality, and citation burst. Co-citation analysis is used increasingly to map networks of concepts in scientific fields, based on the simple idea that if two documents are co-cited by a third paper, they may be related to each other conceptually (Kleinberg 2003). As the number of co-citations increases, this probability also increases and allows us to draw a strong link between the documents. Centrality is an index that measures the shortest distance between different nodes. A central document is positioned at the shortest distance from other nodes. The more central the document, the more likely it proposes a transformative concept that connects the other nodes. Citation burst refers to an association of a particular publication with a surge of citations. Burst measures the increase in citations to a document over time. Finally, the strength of the node's structural and temporal properties, that is, its betweenness centrality and citation burst, is defined as sigma (Chen 2006).

These methods are superior to the earlier techniques like citation counts as they provide a visualised picture of a scientific network (Chen and Paul 2001). Moreover, current methods like pathfinder are used to better show the chronological development of scientific fields. The citation counts are directionless and not able to show the conceptual transformations because more citations do not indicate that the cited document is more important, let alone resolve the problems of biased citations (MacRoberts and MacRoberts 1989)

In this paper, we use the Pathfinder Network Scaling (PNS) as this is, in our view, a superior methodology for our purpose over the widely used minimal spanning trees (MST) method. Both are used as reduction techniques to eliminate some branches to simplify the graph. Still, PNS better fits the chronological works aimed to show the evolution of a field (Chen and Morris 2003), which is the primary goal of this paper.

We use *WoS* rather than *Proquest*, *Scopus* and *Google Scholar*. The two latter are open systems (not databases) that are unsuitable for evidence-based research (Gusenbauer and Haddaway 2020). Proquest is best for the fields such as Nursing and Public Health and much less for our area (ibid).

To create the database, we need relevant keywords; otherwise, it may be difficult to delimit the scope of the research area. At first, the following keywords as the main concepts commonly used in the relevant literature are selected. These are "Indigenous capabilities", "Indigenous technological innovation", "Technological capability", "Technological capabilities", "Late industrializing", " Late Industrialising" "Late industrialization", "Late Industrialisation", "Catch up", "Catch-up", "Catching-up", "Catching up", "Latecomer firm", "Latecomer firms", "Latecomer capability", "Latecomer capabilities", "Latecomer strategies", "Latecomer strategy", "Technological development", "Technological learning", "Upgrading", and "Global Value Chain". The keywords are confined to a strict interpretation of technological catch-up which means our search will identify only those publications framed explicitly as being about technological catch-up. A broader range of keywords would lead to problems related to the boundaries of the inquiry.

Our initial search resulted in numerous relevant documents, plus many studies in psychology and learning which explore the concept of catch up but for different purposes. We refined our

search by applying the following WoS categories: Economics, Management, Development Studies, Business, Business Finance, Operations Research, Management Science, Environmental Studies, Geography, Public Administration. The resulting list was used to extract the references and construct the database to enable the bibliometric analyses. Section 3 describes the data.

The layout of each network, either those sliced by decades or the merged one, is produced by using Kamada and Kawai's algorithms. The size of a node is proportional to the normalized citation counts in the latest time interval. In the case of the merged periods, data are presented cumulatively. Landmark nodes are identified by their large discs. The label size of each node is proportional to citations of the article; thus, larger nodes also have larger-sized labels[7]. Visually salient nodes such as landmarks, hubs, and pivots are easily detected by visual inspection. CiteSpace currently does not include any algorithms to detect such nodes computationally. Instead, the visual effect is a natural result of slicing and merging. The more dissimilar links a node connects to others, the more likely the node has a pivotal role to play.

3. Descriptive Analysis

Table 1 summarizes the data sources and includes 5,626 documents published between 1932-2019. There are 1,729 distinct sources (including books, journals, and conference papers), 4,390 Keywords Plus[8], 9,899 author keywords, and 9,289 different authors. Table 2 lists

[7] The color of a link indicates the earliest appearance time of the link with reference to chosen thresholds. However, as we have drawn the networks cumulatively, these colors will not appear.
[8] KeyWords Plus are index terms automatically generated from the titles of cited articles. They must appear more than once in the bibliography and are ordered from multi-word phrases to single terms. KeyWords Plus augments traditional keyword or title retrieval.

document types and include 3,779 articles, 18 books, 272 book chapters, and 49 edited volumes, including handbooks[9].

Table 1. Description of the data sources

Description	Results
Documents	5626
Sources (Journals, Books, etc.)	1729
Keywords Plus	4390
Author's Keywords (DE)	9899
Period	1962 - 2019
Average citations per document	16.68
Authors	9282
Single-authored documents	1980

Source: authors' calculations based on data extracted from web of science

Table 2. Types of documents in the database

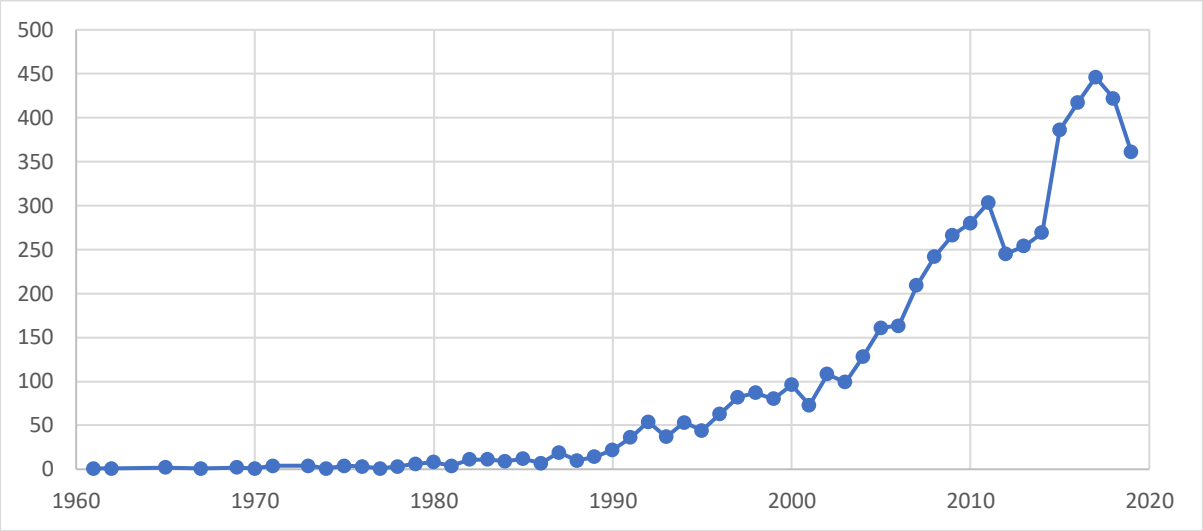
Document types	Results
Article	4779
Article; book chapter	272
Article; proceedings paper	168
Theses	147
Book	18
Book review	128
Correction	6
Discussion	1
Editorial material	49
Editorial material; book chapter	38
Letter	2
Meeting abstract	10
Note	8
Total	5626

[9] The low number of books may seem surprising especially as we identified 128 book reviews, and may suggest that our analysis is biased strongly towards journal and conference papers. However, given the much larger number of articles and assuming that the most important books are cited by the journal papers we think that this potential bias does not skew the reliability of the analysis.

Source: authors' calculations based on data extracted from web of science

Figure 1 depicts the increasing annual publications rate. Technological catch-up as the research issue was recognized in the 1960s. Still, its publications achieved critical mass only in the 1980s. They rose sharply at the beginning of the 1990s and again since 2002 and 2014. This increase reflects well the evolution of the literature. It shows that a quite narrowly defined area expanded significantly to reach a rate of more than one paper a day in the last decade.

Figure 1. Number of publications 1960-2019

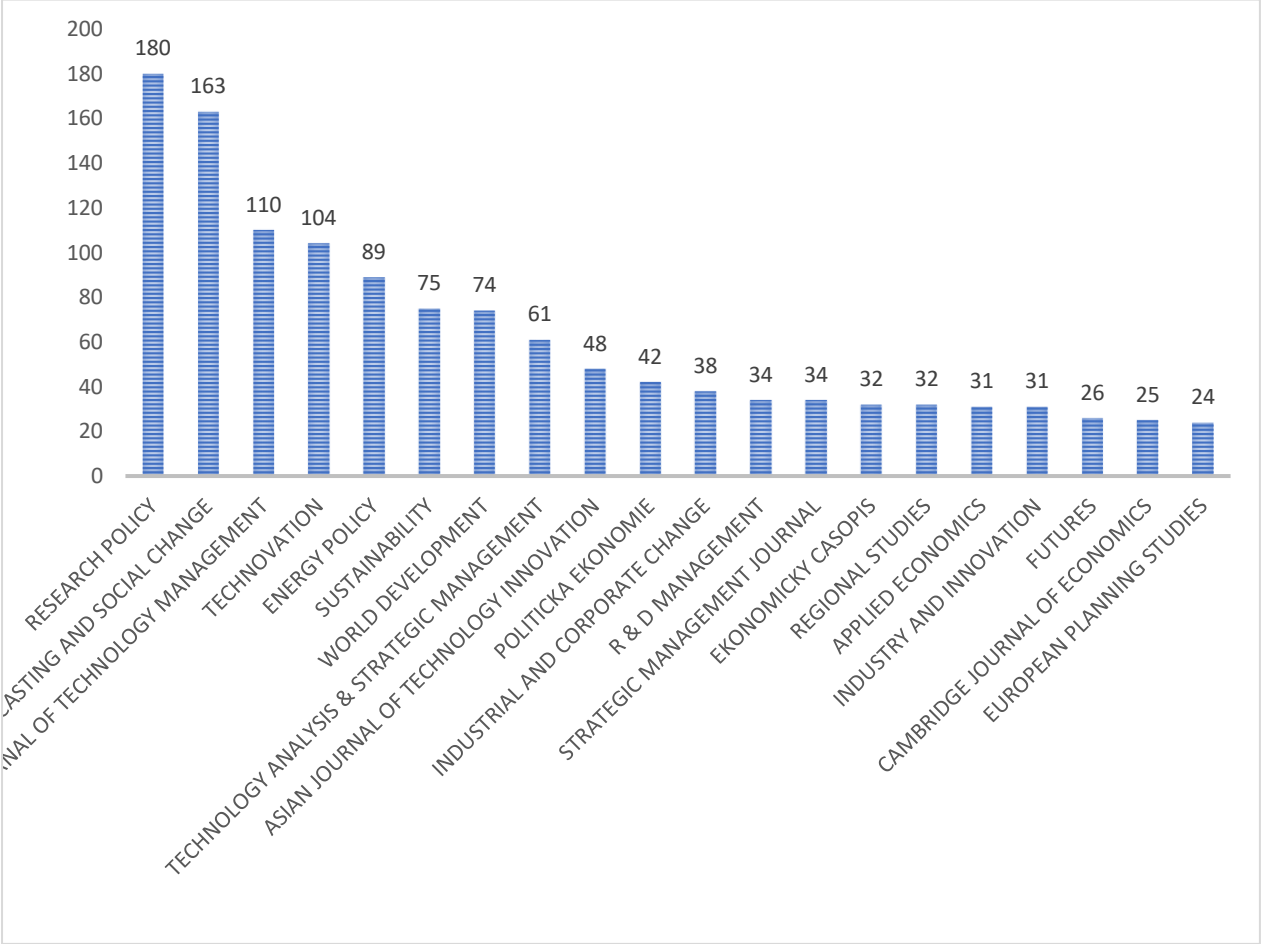


Source: authors' calculations based on data extracted from web of science

The leading journals publishing on technological catch-up are *Research Policy* (RP) with 180 publications, followed by *Technological Forecasting and Social Change* with 163 articles, *International Journal of Technology Management* and *Technovation* with over 100 publications, and *Energy Policy*, *Sustainability*, *World Development* and *Technology Analysis and Strategic Management* (figure 2). *Strategic Management Journal* is a mainstream strategy journal whose number of articles on technological catch-up is similar to those published by innovation-focused journals like *Industrial & Corporate Change* (ICC) and *R&D Management*

(RDM). Interestingly, two Czech journals (*Politická Ekonomie* and *Ekonomicky Casopis*) have published many papers on technological catch-up similar to the *ICC* and *RDM* though in different periods. This represents the legacy of the socialist period and interest in long-term growth based on 'science and technology progress' and technology forecasting ideas exemplified in Richta (1968) volume *Civilization at the Crossroads*. As expected, the list of journals shows that the issue is dominant in innovation studies journals and moderately prevalent in the other journals.

Figure 2. Top twenty journals publishing papers on technological catch-up

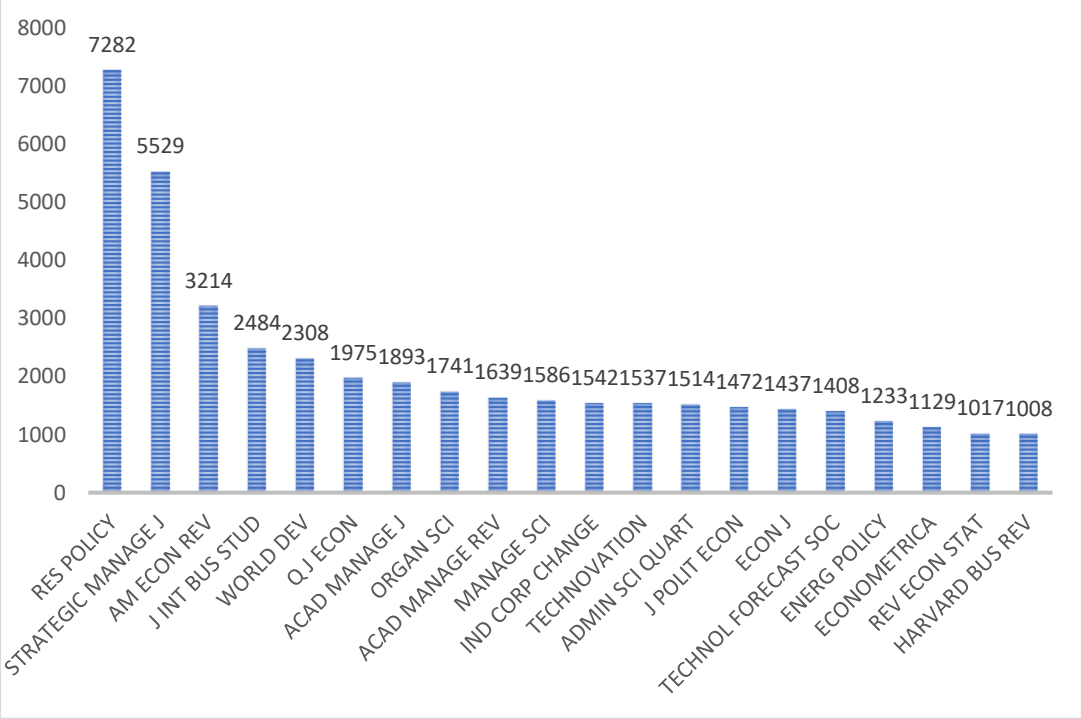


Source: authors' calculations based on data extracted from web of science

However, based on the most frequently cited journals for articles, only seven of the top 20 journals in figure 2 are included in this list. Figure 3 shows that *Research Policy* received the most citations, followed by the *Strategic Management Journal*. The following most-cited journals are *American Economic Review*, *Journal of Business Studies* and *World Developmen*t, each of over 2,000 citations. Among the top 20 most cited journals, 13 are not among the top 20 journals with the highest number of published papers. There is a significant gap between impactful literature on technological catch-up published in non-innovation studies journals and 'proper' innovation studies journals.

This gap suggests that the most effective ideas and research are not necessarily published in innovation studies journals. It also suggests a natural tendency and obligation of innovation studies journals to publish 'normal science' papers, that is, works that contribute incrementally to the knowledge in the field. Seven journals are in the top 20 for both numbers of papers and most cited papers: *Research Policy, Strategic Management Journal, World Development, Industrial and Corporate Change, Technovation, Technological Forecasting and Social Change*, and *Energy Policy*. These seven can be considered the most impactful innovation studies journals, of which only four should be regarded as 'proper' innovation studies journals. We believe this to be a healthy reflection of broader interests in technological catch up which goes beyond narrow (sub)disciplinary boundaries and probably reflects the pre-paradigmatic nature of the technological catching up literature.

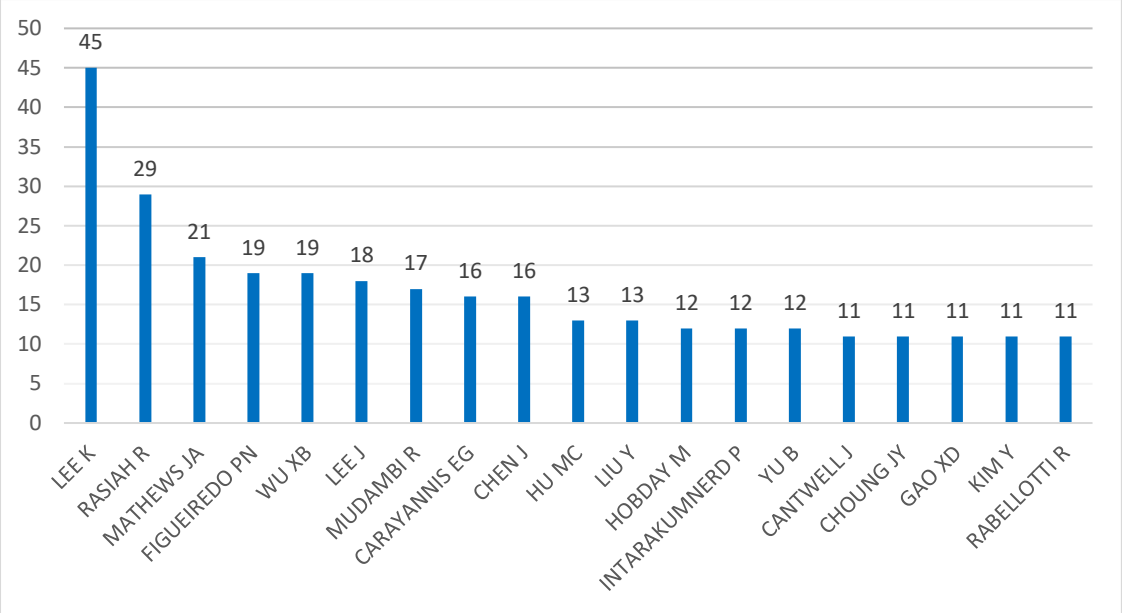
Figure 3. Most frequently cited journals for articles on technological catch-up



Source: authors' calculations based on data extracted from web of science

Keun Lee, with 45 publications, is the most prolific author in the technological catch-up area (Figure 4), followed by Rajah Rasiah, John Mathews, Paolo Figueiredo, Xiaobo Wu, Lee Jong-Wha, Ram Mudambi, Elias Carayannis, and Chen Jin. The majority of authors listed in figure 4 are from Asia, which suggests that this continent is a very fertile environment for research on technological catch-up. This may not be surprising given many catching up economies in this continent.

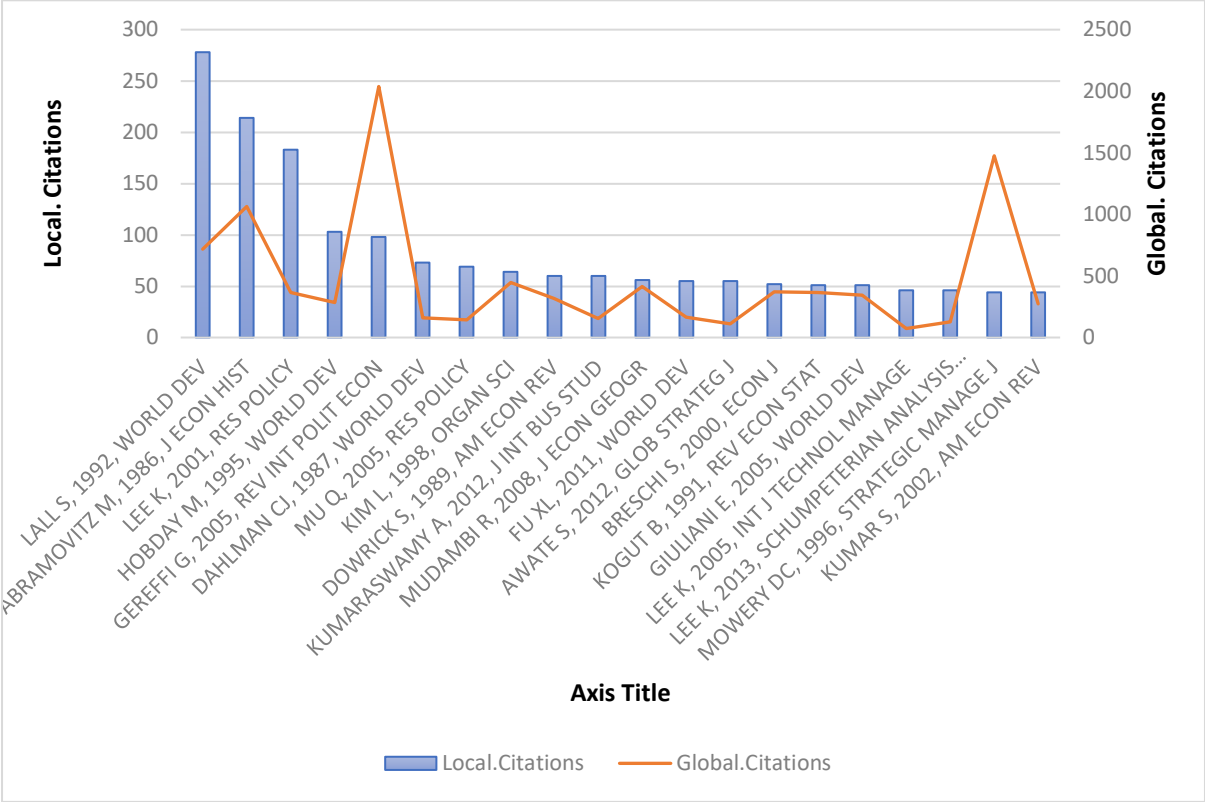
Figure 4. Authors ranked by number of technological catch-up papers



Source: authors' calculations based on data extracted from web of science

'Local' citations refer to the citations to each document among the 5,626 documents in our dataset. They are a measure of excellence or recognition within the community of technological catch-up scholars. Figure 5 shows that the most 'locally' cited article is Lall (1992) paper on technological capability published in *World Development*, followed by Abramovitz (1986) paper which introduced the concept of catch-up as an alternative to the mainstream convergence-divergence dichotomy. Third-ranked is the paper by Lee and Lim (2001), which received close to 200 'local' citations, i.e. in technological catch-up journals and explores catch-up and leapfrogging in the case of Korea. Fourth-ranked is Hobday (1995) paper on the concept of latecomer innovation and the strategic importance of the dual mechanisms of market and technology access used by East Asian consumer electronics firms. Next ranked is Gereffi, Humphrey et al. (2005) paper which introduced governance in global value chains (GVCs) and became the basis for numerous other papers on the subject. Among the most cited documents in our database is Lee (2013) book *Schumpeterian Analysis of Economic Catch-Up: Knowledge, Path-Creation, and the Middle-Income Trap*, which extends the analysis of technological catch up to 'leapfrogging,' i.e. reaching technology frontier.

Figure 5. Most locally and globally cited documents on technological catch-up*



Note: Locally cited documents are those cited by the documents included in our dataset; globally cited documents are those cited in all documents. In the case of multi-authored publications, the cited author is only the first listed.

Source: authors' calculations based on data extracted from web of science

Gereffi, Humphrey et al. (2005) paper on the governance of GVCs, and (Mowery, Oxley et al. 1996) paper on strategic alliances and interfirm knowledge transfer are two papers that received the most citations globally, that is from authors writing on other topics than technological catch-up. These two papers address issues of technology transfer which are relevant to all economies, especially in the context of globalization.

The most cited papers on technological catch-up are scattered across various journals. *Research Policy* which is ranked first for the number of published and most frequently cited papers on

technological catch-up, has only two of the top 20 articles cited globally (figure 5). *World Development* published five of the top 20 articles cited globally. A lack of concentration of cited papers suggests that technological catch-up scholars are not a closed community of scholars. Also, we find significant differences among journals for a number of papers, number of citations, and top-cited papers, which suggests that despite a narrow definition of the area, technological catch-up literature is intellectually dispersed across several intellectual communities. This situation reflects the dynamic and pre-paradigmatic nature of the area where theories, issues, and methodologies are not 'normalized' in the Kuhnian sense (Kuhn 1996). Given the evolutionary and historical nature of technological catching-up processes, we would expect this. However, our descriptive analysis does not provide a clear picture of the underlying patterns of dynamics. We address these issues in section 4.

4. Analysis

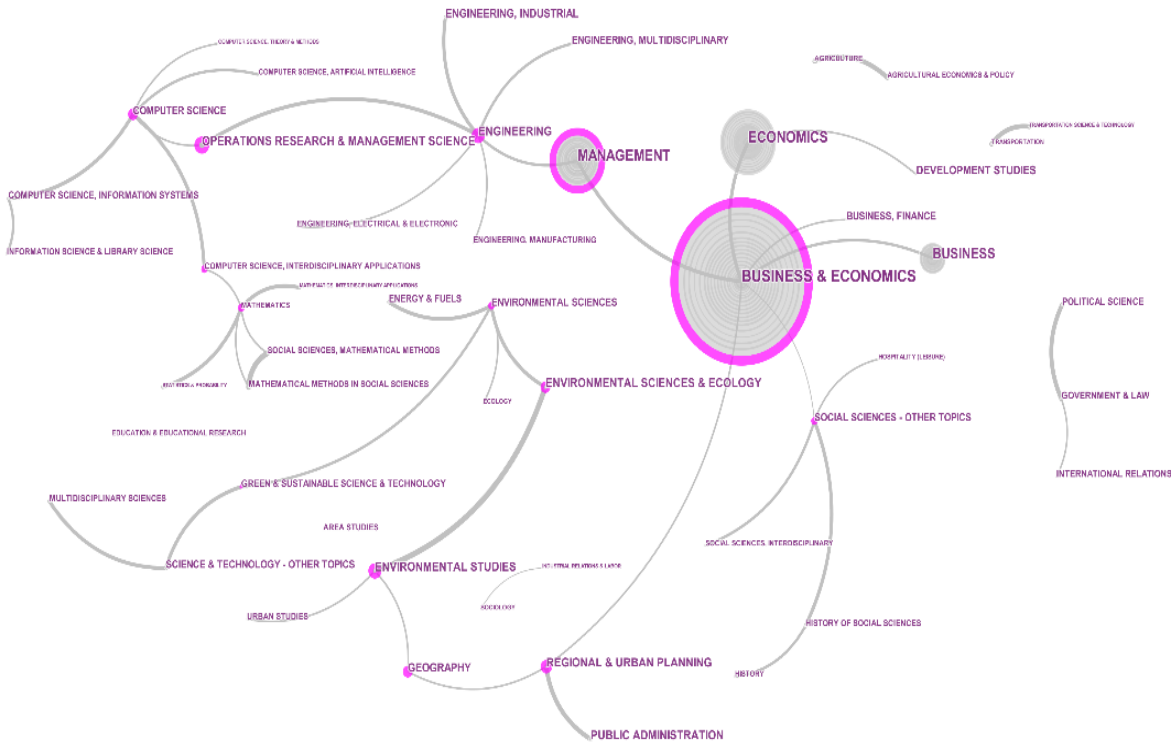
First, we present bibliometric results of three significant features of technological catch-up as an epistemic community. We explore its disciplinary features using co-occurrence measures of the disciplines publishing on technological catch-up (section 4.1). Keyword co-word analysis indicates the morphology of the topics included in technological catch-up research (section 4.2). Cross-section analysis of journal co-citations from 1980-2020 presented in section 4.3 shows the extent of fragmentation or coherence among the technological catch-up community. Section 4.4 explores the evolution of co-citation links across four decades (the 1980s, 1990s, 2000, and 2010s). Section 4.5 provides a mapping of author co-citation links and uses a range of indicators to assess their role in the technological catch-up research network.

4.1. Disciplinary distribution

Research on technological catch-up is dominated by Business & Economics as a major category in Web of Science with 4,782 co-occurrences. Among the sub-branches, the most important are Economics, Management, Business, Operational Research and Management Science, Engineering, Public Administration, Environmental Sciences and Ecology, and Environmental Studies. The dominance of these disciplines reflects the nature of technological change, which is intrinsically linked to economic, organisational, and firm-level impacts and determinants. Also, exploring different levels (especially mezzo and micro) and other dimensions of techno-economic processes (organisational, technological, financial, economic) is essential to understand the nature of technological change and how it interacts with the economy. Technological catch-up scholarship is also present in several adjacent fields such as regional studies, environmental studies, operations research, and social sciences more broadly (figure 6). Therefore, we can consider technological catch-up as a genuinely interdisciplinary area. Probably, this is an additional factor that explains its pre-paradigmatic nature.

Fig. 6 Disciplines involved in technological catch-up research[10]

[10] Newer versions of CiteSpace make it possible to reduce linkages to a subset of core nodes to improve network interpretability. In displaying these axial points, the software displays purple circles inside the key points. A high number of purple circles in our network display is high because we show also sub-nodes

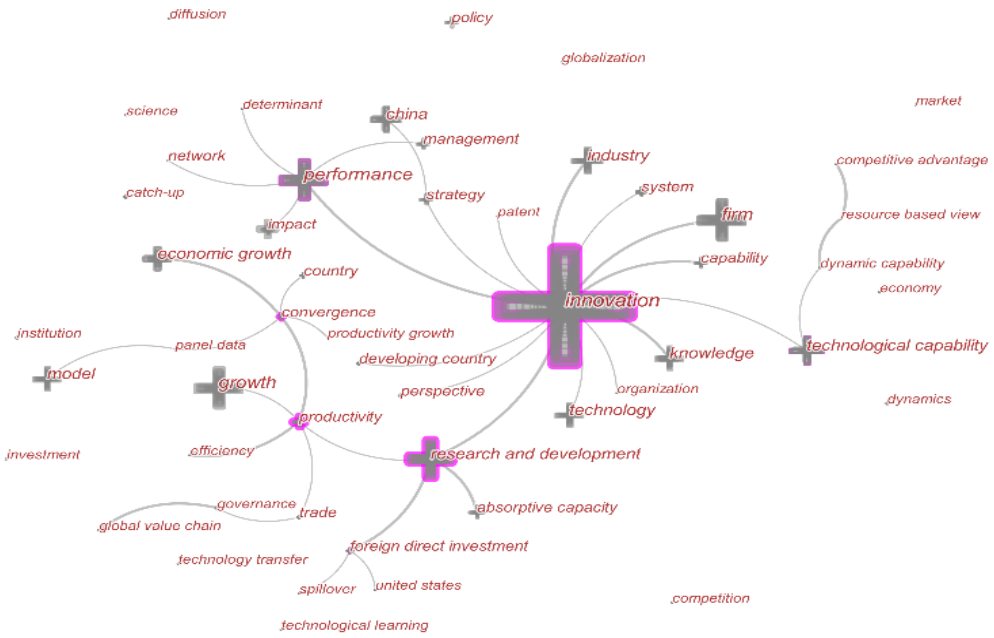


Source: authors' calculations based on data extracted from web of science

4.2. Keyword co-word analysis

Keywords provide information on the article's core content. Keyword co-word network analysis provides a picture of the linked topics and how research in the area is evolving (Callon, Courtial et al. 1991, He 1999, Su and Lee 2010). The WoS provides two alternatives for selecting keywords: the keywords suggested by authors ('author keywords') and the indexing keywords supplied by the WoS ('Keywords Plus'). The WoS provides only keywords for articles published since 1991, limiting our analysis to the post-1990 period. However, the number of papers published in the 1980s is very small and does not affect our results. The author's keywords are much more helpful for our analysis as the WOS words may often mislead. Figure 7 represents the results for author keywords where the size of the nodes is proportional to the co-occurrence frequency of the corresponding keywords.

Figure 7: Keyword co-word co-occurrence analysis[11]



Source: authors' calculations based on data extracted from web of science

Figure 7 shows that innovation (940 co-occurrences) is the most significant node, followed by growth (473), firm (438), performance (419), R&D (393), technological capability (362), and technology (359). These are generic terms likely to be found in publications on technological catch-up. The connections among keywords and the connections they form are of interest. The map shows four significant groups related to the central concept - innovation. On the right-hand side of the figure, innovation is linked to knowledge, technology capability, firm, industry, and innovation system. We understand these as determinants of innovation that operate at different levels. The bundle at the bottom of figure 7 shows that innovation is linked to R&D as central to innovation capability, which is connected to foreign direct investment

[11] As explained in relation to figure 6, purple indicates the pivotality and centrality of the points, while size indicates frequency ie. repetition. For example, a purple color and bigger sign denote higher importance of the topic.

and productivity. The group on the left-hand side relates innovation directly to performance which is linked to firm-level (management, network, impact) variables. The fourth includes economic growth and growth but with no direct link to innovation. This represents the growth econometrics-based literature with keywords such as convergence, productivity growth, model, and panel data. In growth econometrics, capturing the multidimensional nature of technology is quite challenging. We think this explains why growth links to innovation only indirectly and only to R&D. Technology is reduced to R&D as the most frequent determinant, which reflects both its knowledge generation and absorptive capacity property (Cohen and Levinthal 1989, 1990).

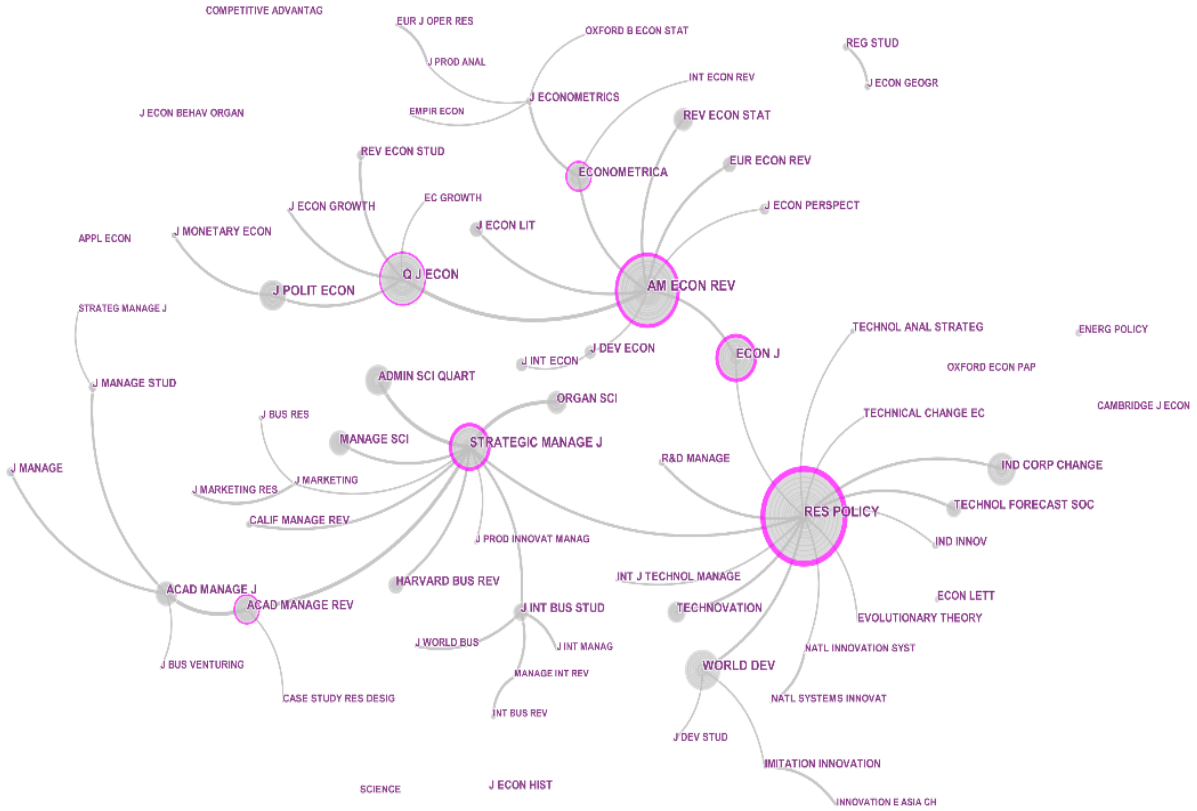
Our main keywords are innovation, R&D, and productivity. These keywords summarise the most significant concerns of technological catch-up literature cumulatively. However, as we show in section 4.4, there is a significant evolution of intellectual concerns and empirical issues in the literature on technological catch up which goes well beyond this generic triangle which mainly reflects past rather than the recent literature.

4.3. Journal co-citation network

Journal co-citation analysis identifies the journals that form the intellectual basis of technological catch-up research. Figure 8 depicts the merged journal co-citation network and shows a group of management journals around *Strategic Management Journal* (SMJ) and a group of economics journals around *American Economic Review* (AER) which are connected to *Research Policy* (RP) through *Economic Journal.* RP has the highest frequency of co-citations (1,786) in the field, followed by AER (1,447) and *Quarterly Journal of Economics* (1,105 co-citations). SMJ (1074), *World Development* (1049), *Economics Journal* (987),

Journal of Political Economy (879), *Industrial and Corporate Change* (831), and *Administrative Science Quarterly* (800) are ranked next for co-citation frequency. This shows the importance of *RP* in this literature and its bridging role between management and economics.

Figure 8. Journal co-citation network



Source: authors' calculations based on data extracted from web of science

There are three 'invisible colleges' in this area. *Research Policy* (RP) is the most central journal, followed by *Strategic Management Journal*, *American Economic Review* and *Economic Journal*. The first and the most coherent group is formed around the *RP*, linked to various innovation studies journals, including two development studies journals (*World Development*, *Journal of Development Studies*). There is an economics group around the

American Economic Review linked to the *Quarterly Journal of Economics (QJE), Economic Journal,* and *Econometrica*. There is also a group centred around *Strategic Management* journal with links to the several US and other international management journals (*Management Science, Administrative Science Quarterly, Organization Science*, *Journal of International Business Studies,* and *Academy of Management Review*). There are direct links between *Research Policy* and Strategic *Management Journal (SMJ)* but not *American Economic Review (AER)*. The co-citation network map suggests that these are three relatively autonomous invisible colleges that do not communicate frequently based on citations. This is significant since it shows that although specific journals may publish on the same topics, their intellectual attributions may differ. We observe a kind of 'scientific parochialism' or insularity in the three mainstream economic journals (*AER, Econometrica* and *QJE),* which do not 'communicate' with more heterodox journals clustered around *RP and SMJ*. This phenomenon of institutional stratification and self-referential intellectual community in economics is not surprising. It has been extensively documented by Aistleitner, Kapeller et al. (2019) and in references to their paper. However, our further analysis of citation links (communication) at the level of authors over four decades shows a trend of decreasing segregation and changing co-citation patterns. This would be expected given changing and pre-paradigmatic nature of technological catch up as a research area.

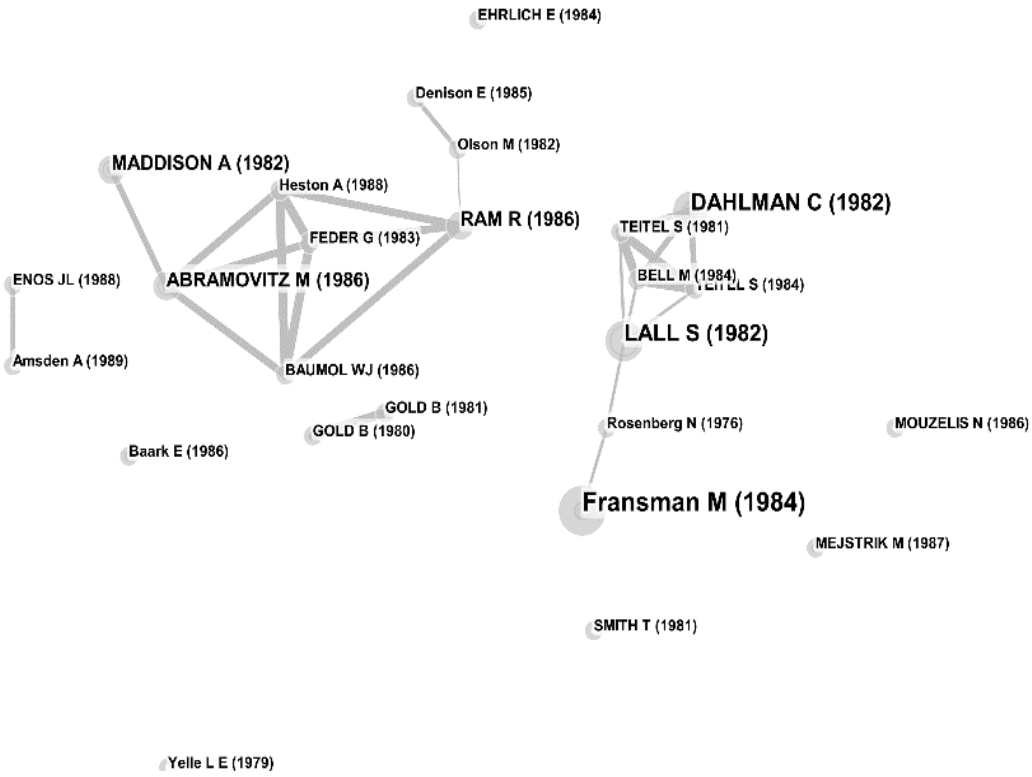
So far, our cross-section analysis has used data for the entire period. The following section explores changes in co-citations over time, which indicate changing dynamics of intellectual communities addressing technological catching up issues.

4.4. Evolution of the documents network

Figures 9-12 show how intellectual networks have developed since the 1980s[12]. They depict co-citation maps of the works in each decade and their respective focus.

Co-citation analysis enables tracking pairs of papers cited in a source article (Small 1973). If at least one other document cites the same two documents as the focal document, these documents are said to be co-cited and focused on a common theme. The more co-citations received by these two documents, the higher their co-citation strength and the more likely they will be related semantically. If the same pairs of papers are co-cited by many authors, this forms the basis for a strong connection between the two.

Figure 9. The authors' co-citation network of technological catch-up literature in the 1980s



Source: authors' calculations based on data extracted from web of science

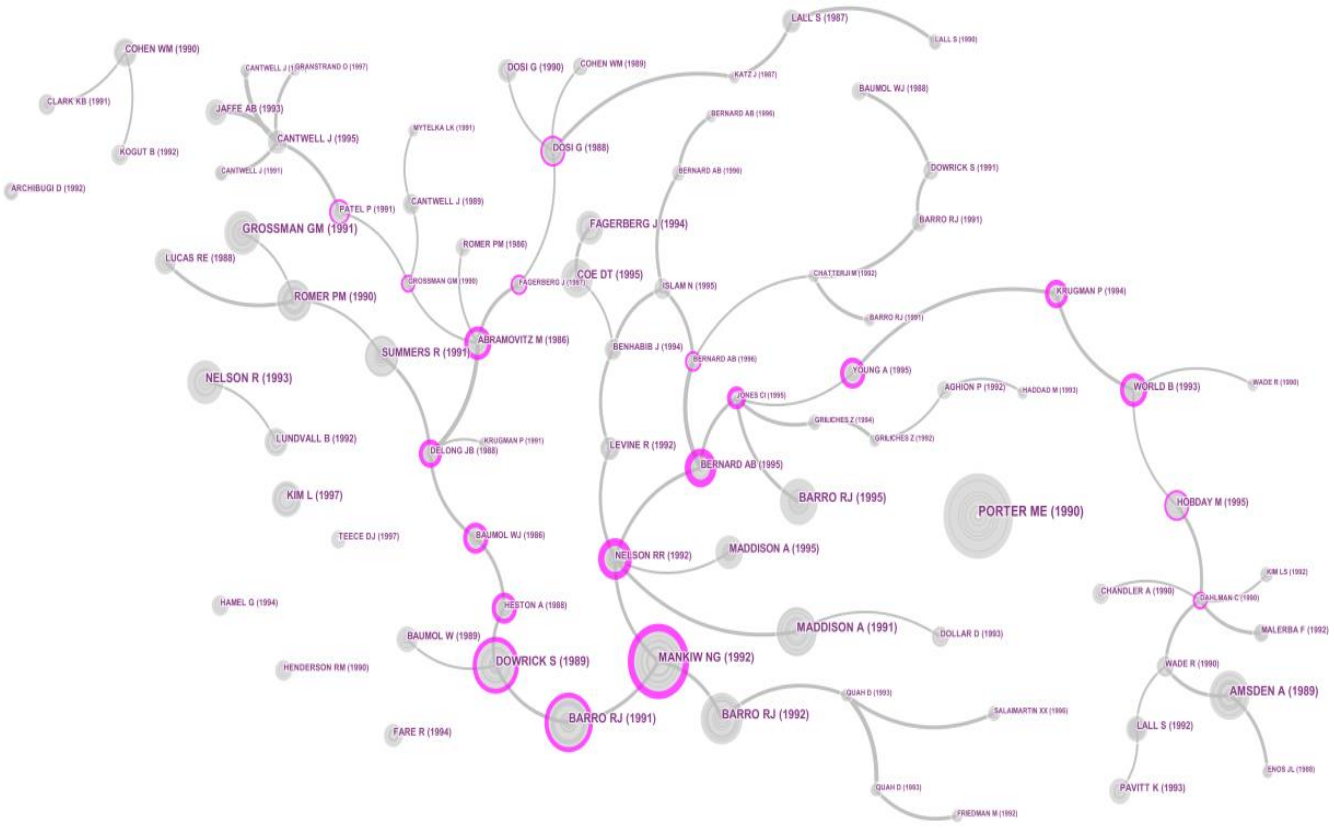
[12] As in Figure 5, names of authors refer only to first listed authors of multi-authored papers.

Our analysis shows that in the 1980s, two main unrelated intellectual colleges became established. The first contains works by US economists with a background in or strong interest in economic history and long-term growth (Maddison 1983, Abramovitz 1986, Baumol 1986, Maddison 1987). This work was often quantitative, and hence linked to historical and contemporary data analyses (Maddison 1983, Summers and Heston 1988), and linked to issues such as the optimal size of government (Ram 1986) and openness (Feder 1983). Abramovitz (1986) central role in exploring the issues of catching up in economic growth was essential. He proposed a theory of catching-up that considers time-specific effects, social capital, and technological congruence as critical determining factors. This work also played a crucial role in the 1990s' catch-up literature.

The second includes work on technological capability in developing countries described then as 'Third World' countries, on the issue of technology mastery, and the phenomenon of developing countries as technology exporters. Fransman (1984) book is the essential reference as it synthesised the work by all the major contributors at the time. As pointed out in the introduction to the book, research on 'Third World' technology focused mainly on technology transfer and choice of technology from abroad. Their volume focuses on how imported technology is assimilated and adapted to local circumstances, leading to various kinds of technological improvements. Central authors in this group are Carl Dahlman and Larry Westphal, Martin Bell, Simon Teitel, Nathan Rosenberg, and Sanjaya Lall, who can be considered pioneers of the technology capability approach. Their research was micro-based and demonstrated the intensive process of technological learning, classification of different types of acquired capabilities, and the organisational nature of technology capability building. The work of these scholars was the antecedent to what ten years later became the mainstream resource-based or capabilities view of the firm.

Other contributions occupy isolated enclaves, although some became more important in later decades. The volumes by Enos and Park (1988) and Bell, Eckaus et al. (1989) sparked interest in Korean catching up, while Baark and Jamison (1986) edited volume on India and China was the basis for similar research focused on those countries. Individual contributions by Czech economists reflected the interest in 'science and technology progress' and its forecasting. However, these works remained isolated from the two major intellectual colleges of the 1980s. Also, the two majors colleges – on technology capabilities and economic growth in the long-term perspective – were quite segregated, reflecting the micro-macro dichotomy and different epistemological bases of the two streams. With the advance of neo-Schumpeterian thinking in the following decades, this dichotomy became much less pronounced.

Figure 10. The Co-citation network of technological catch-up literature in the 1990s



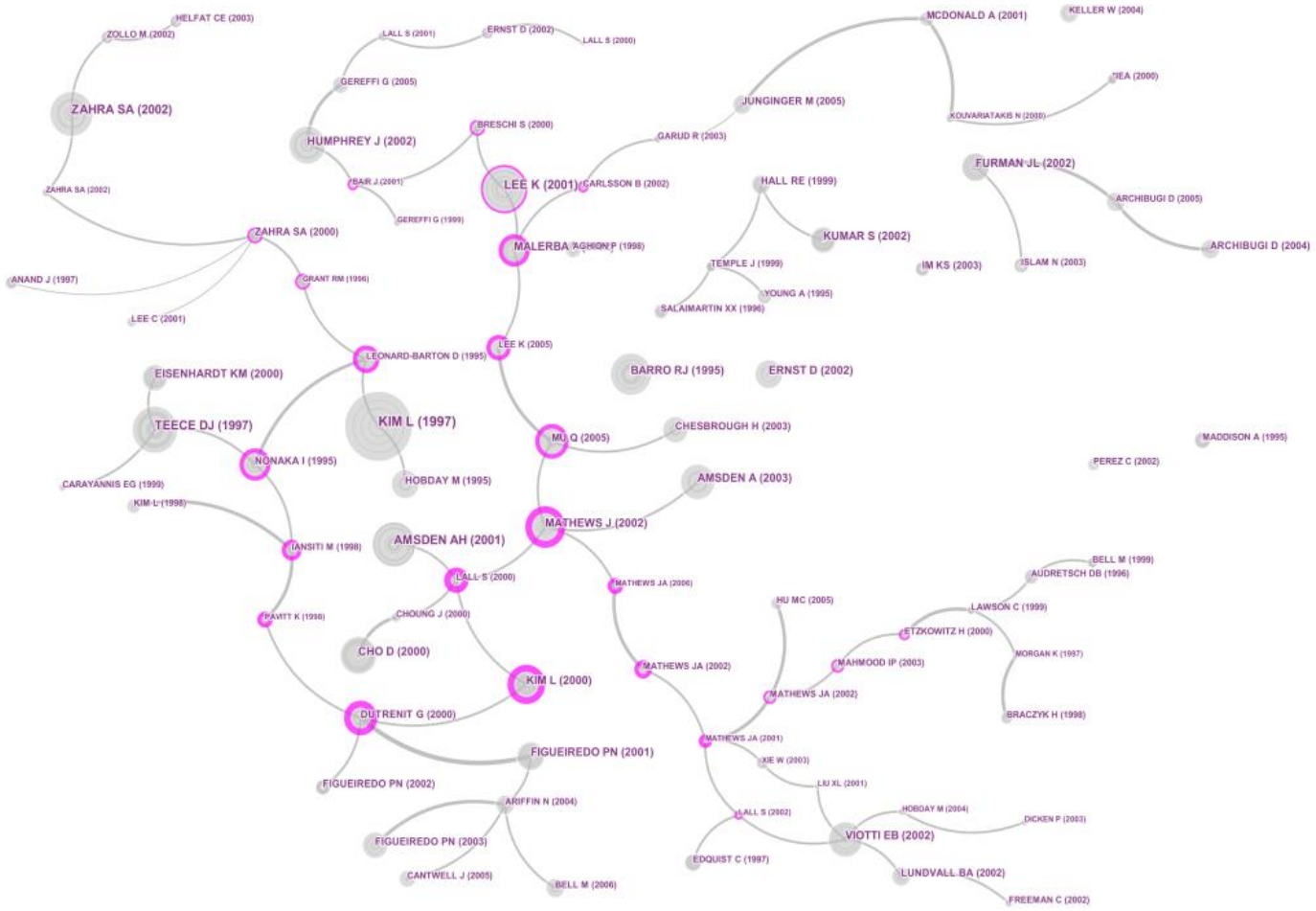
Source: authors' calculations based on data extracted from web of science

In the 1990s, technological catch-up research really took off. The number of co-citations increased from 83 in the 1980s to 948 in the 1990s, suggesting the emergence of a research community and a diverse research agenda. Another significant change was that the US group on economic growth and the technology capability group began to converge. Initial interest in long-term growth and its determinants was focused in the 1990s on the drivers of convergence/divergence in economic growth. The core of this group is around Mankiw, Romer et al. (1992), who showed that holding population growth and capital accumulation constant, countries converge at about the rate predicted by the augmented Solow model. The methodologies and approaches embraced in this work are related closely to Barro (1991), (1995) work on convergence and reaches similar conclusions. Barro's work built on Dowrick and Nguyen (1989), who demonstrated convergence among the OECD economies. These contributions build on Romer (1986), Grossman and Helpman (1990), and Lucas Jr (1993) endogenous growth models, and the Penn World Tables constructed by Summers and Heston (1988), which provide long-term data to test these propositions. For the first time, this approach to growth was linked to evolutionary and heterodox approaches to growth and innovation through two prominent authors whose work served to bridge these previously separate groups. Nelson and Wright (1992) *Rise and Fall of American Technological Leadership* served as an intellectual bridge to much more empirical work on growth by Islam (1995), Barro (1991), Coe and Helpman (1995), Fagerberg (1994), and others. Bernard and Durlauf (1995) paper proposed a new definition of convergence, explored trends in per capita output, and stimulated an alternative and broader literature on the empirics of growth. This body of work addresses the nature of East Asia's growth (Krugman 1994) which is debated in the famous World Bank (1993) *East Asian Miracle*. This study linked alternative and methodologically diverse explanations of east Asian growth, taking greater account of the role of the state (Wade 1992)

and technology capability building (Hobday 1995). Abramovitz (1986) links the more neo-classical economic growth literature on convergence/divergence with the new heterodox and empirical technology gap evolutionary approaches. His contribution is linked intellectually to Silverberg, Dosi et al. (1988) edited volume '*Technical Change and Economic Theory'* (see Radošević (1991) for an extensive review), to innovation and international trade (Grossman and Helpman 1990) and innovation and multinational enterprises (MNEs) (Patel and Pavitt 1994, Cantwell and Zhang 2011). This line of research expanded significantly in the 2000s (see further).

The most cited work in the 1990s is Porter (1991), *The Competitive Advantage of Nations* which remains isolated in terms of intellectual co-citation links. Porter's micro-based and empirically grounded approach to growth represents paradigmatic change rather than the outcome of the scholarly community developing its research ideas through conventional academic communication via journals. Other works isolated in the 1990s will play a critical role in the 2000s. These include two volumes on national innovation systems edited by Lundvall (1992) and Nelson (1993) with contributions from Linsu Kim, Teece, and others and Cohen and Levinthal (1990) work on absorptive capacity, which has become the standard reference in this literature.

Figure 11. The Co-citation network of catch-up literature in the 2000s



Source: authors' calculations based on data extracted from web of science

The mapping of intellectual colleges changed significantly in the 2000s with growth empirics and convergence and divergence no longer central. The only 1990s author to be cited in this context is Barro (1995) work on inflation and growth. There is a persistent growth empirics branch centred around Hall and Jones (1999) paper which recognises the role of institutions in growth, Kumar and Russell (2002) work on the role of capital for deepening in growth, and Temple (1999) review of the evidence of growth. However, none is intellectually linked to historical and region-specific (primarily East Asia and Latin America) research on growth which characterises the 2000s. The main feature of the 2000s is the dominance of work on

latecomer firms adopting a capability framework. This work focuses on the rise of East Asia but is linked theoretically to the dynamic capabilities view of the firm.

There is a new group on growth and technology using composite indicators and the concept of national innovation capacity (Furman, Porter et al. 2002, Archibugi and Coco 2004). Perez (2003) book on financial capital and technology revolutions and Maddison (1995) historical work have no direct intellectual linkages. Like Porter, Perez's work is a paradigmatic change that stems from her unique capability to synthesise into a radically new conceptual framework rich historical evidence. Unlike conventional academic discourse, which starts from the established theory, they both depart primarily from the empirical and historical evidence. A similar argument is relevant also in the case of Maddison statistically driven exploration of history.

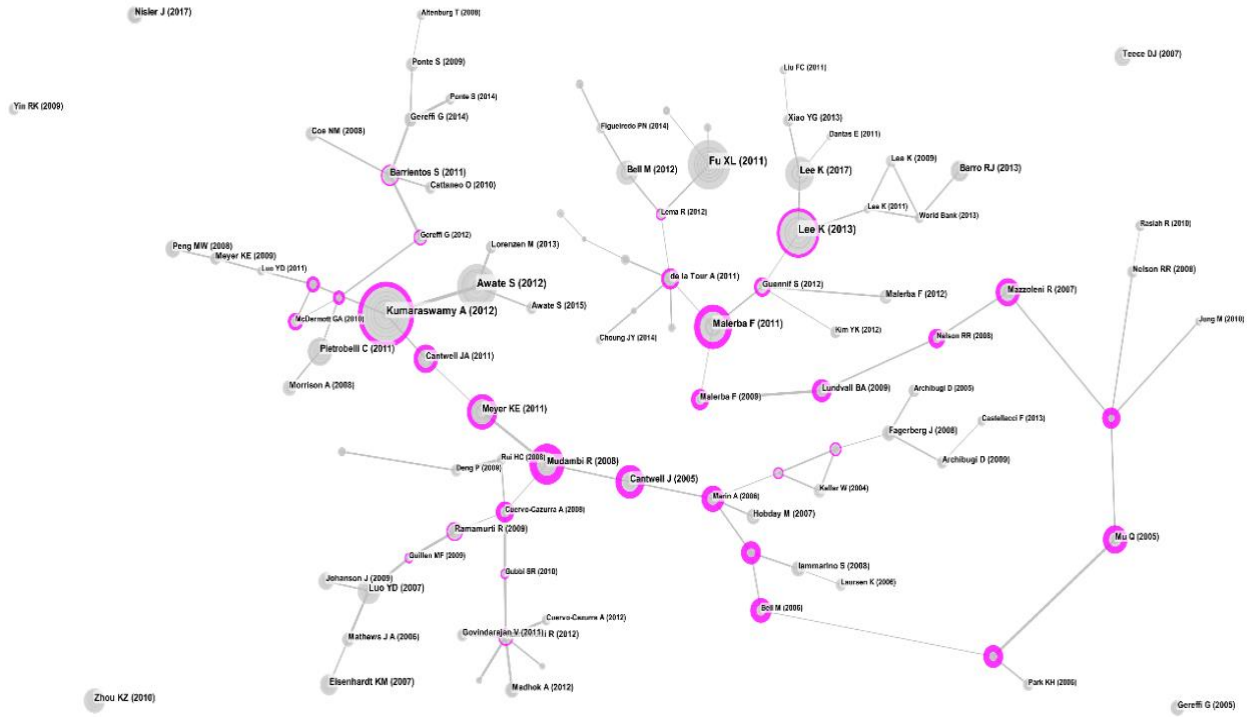
The 2000s network is centred around Mathews (2002) work on latecomer firms from a resource-based (capability) perspective. It triggered three intellectual streams. The right hand (southern) stream is linked to innovation systems and the triple helix (Etzkowitz and Leydesdorff 2000) and regional innovation systems literature. The latter includes a collection edited by Braczyk, Cooke et al. (2003) entitled *Regional Innovation Systems-The Role of Governances in a Globalised World,* Morgan (1997) work on regional innovation systems, and Lawson and Lorenz (1999) competence theory of regions. There is also a stream of work on innovation systems, including Viotti (2002) distinguishing between passive and active national learning systems.

The right hand (eastern) stream centred on Mathews (2002) is linked to an edited volume by Kim, Nelson et al. (2000) entitled *Technology, Learning, and Innovation: Experiences of*

Newly Industrializing Economies, whose contributors include Lall (2000). This workstream is linked to Dutrénit (2004) studies of Mexican latecomer firms, which is linked intellectually to work on capabilities in the context of Brazil by Paolo Figueredo. This body of research is related to the more theoretical literature on capabilities and dynamic capabilities by Teece, Pisano et al. (1997) , the knowledge-creating company by Nonaka, o Nonaka et al. (1995), and Dorothy Leonard-Barton (1995) *Wellsprings of Knowledge.* These contributions relate to Kim (1997) widely cited book on Korea and Zahra and others' work on absorptive capacities. The upper (northern) stream is linked to work on the technological regime and sectoral innovation systems by Keun Lee and Malerba. In conditions of increasing globalisation, this literature is connected to Bair and Gereffi (2001) *Local Clusters in Global Chains* and the global value chain literature. It also includes methodological studies of technological systems by Carlsson, Jacobson et al., often applied to the context of newly emerging energy technologies.

Apart from (Amsden 2001) *Rise of the Rest,* this period is not concerned with grand general theoretical issues and convergence/divergence. Instead, the new focus is on the different dimensions of latecomer firms in a system of innovation, sectoral, and global value chain context. In this period, we observe the dominance of heterodox neo-Schumpeterian approaches to all four levels of analysis (firm, sectoral, national, global).

Figure 12. The Co-citation network of technological catch-up literature in the 2010s



Source: authors' calculations based on data extracted from web of science

Co-citation networks in the technological catch-up area in the second decade of the 21st century have shifted very strongly towards the globalisation of the emerging economies and all the issues entailed by integration for firms and industry catching up. The dominant focus in the 2010s is at the mezzo level, considering either sectors or GVCs. In this period, the prevailing 'intellectual networker' is Mudambi (2008). He occupies the central position in the co-citation network focused on different variants of globalisation and technology upgrading. Mudambi is a co-author or author of eight of the papers in this network (Cantwell and Mudambi 2005, Mudambi 2008, Cantwell and Zhang 2011, Meyer, Mudambi et al. 2011, Awate, Larsen et al. 2012, Kumaraswamy, Mudambi et al. 2012, Awate, Larsen et al. 2015). Kumaraswamy et al.'s paper 'Catch-up strategies in the Indian auto components industry: domestic firms' responses to market liberalisation' is the most cited paper and was awarded paper of the decade by the

Journal of International Business Studies. Mudambi's intellectual links extend in three directions: lower right hand (southeast), upper right hand (northeast), and lower left hand (southwest). The lower righthand (southeast) link is via Cuervo-Cazurra (2012) paper, which reviews the different views on the theoretical novelty of the emerging market multinationals (so-called 'Goldilocks' debate). This stream involves two sub-streams, both linked to Ramamurti's edited book on emerging market multinationals (Ramamurti and Singh 2009) and his 2012 paper on 'What is really different about emerging market multinationals?'. Central in the first stream is the paper by Luo and Tung (2007), which formulates a 'springboard' theory of emerging market multinationals and is also awarded paper of the decade by the *Journal of International Business Studies*. The right hand (northeastern) stream of this network stems from Cantwell's (Cantwell and Mudambi 2005) paper on '*MNE competence creating subsidiary mandates*', and Marin and Bell (2006) paper on technology spillovers '*Foreign Direct Investment (FDI): the active role of MNC subsidiaries in Argentina in the 1990s*' and includes two substreams. One includes work on foreign direct investment spillovers (Smarzynska Javorcik 2004), R&D spillovers (Griffith, Harrison et al. 2006), and technology transfer (Keller 2004, Keller 2007). The other includes sectoral studies, several co-authored by Keun Lee, which explore the relationship between foreign and domestic knowledge in sectoral technology upgrading. The left-hand (southwest) intellectual stream starts with Mudambi (2008). It includes Lamin and Livanis (2013) research on catch-up and the 'liability of foreignness' in emerging economies, linking three perspectives on GVCs. The first stems from Barrientos, Gereffi et al. (2011) paper on '*Economic and social upgrading in global production network*'. The second builds on '*An institution-based view of international business strategy'* by Peng, Wang et al. (2008) . The third discusses the links between GVCs and innovation systems and the work of Pietrobelli and Rabellotti (2011) and GVCs and technology capabilities and the work of Morrison, Pietrobelli et al. (2008).

The second intellectual network is formed around Keun Lee and his work with Malerba, both empirically and conceptually firmly focused on the mechanics of technological catch-up at the sectoral level. Central to this is Lee (2013) *Schumpeterian Analysis of Economic Catch-Up: Knowledge, Path-Creation, and the Middle-Income Trap,* Lee and Malerba (2017) '*Catch-up cycles and changes in industrial leadership: Windows of opportunity and responses of firms and countries in the evolution of sectoral systems*' paper published in *Research Policy,* and Malerba and Nelson (2011) paper in *Industrial and Corporate Change* on '*Learning and catching up in different sectoral systems: evidence from six industries*'. Figure 12 does not depict Keun Lee's total contribution, although he is co-author of seven publications in the co-citation network map. Fagerberg and Srholec (2008) and Archibugi, Denni et al. (2009). form a small branch focused on measuring national innovation systems and capabilities.

In addition, there are several isolated contributions, including Mazzucato (2013) work on the entrepreneurial state, which we believe will be at the centre of new networks in the 2020s.

In summary, the co-citation analysis of documents by decades shows how the research area has expanded and evolved qualitatively. The intellectual, technological catch-up network has grown from 83 co-citations in the 1980s to 948 in the 1990s, 1,288 in the 2000s, and 2,160 in 2010s. The intellectual map of each decade is qualitatively different. The 1980s provided the intellectual foundations based on work on long-term economic growth and technology capabilities which emerged independently. However, in the 1990s, these areas came much closer to each other, driven by closer intellectual links between the growth empirics and neo-Schumpeterian evolutionary approaches. This decade is marked by a diversity of empirical and theoretical approaches.

In the 2000s, the focus on convergence issues waned. It shifted to the firm-level and catch-up issues, explored from a resource-based (capability) perspective related to latecomer firms and their institutional context. In the fourth decade (2010-2020), research focused on globalisation and emerging market multinationals and the relationship between globalisation and technology upgrading from a sectoral or mezzo perspective.

The diversification and transformation of research on technological catch-up have been accompanied by the involvement of more countries and institutions. For space reasons, we do not show the evolution of geographic and institutional networks. A research network has expanded from being dominantly the US and the UK in the 1990s to include the Netherlands and China in the 2000s, and by 2010 many more countries making it a genuinely global area. This country diversification is accompanied by similar diversification of institutions but concentrated within countries.

4.5. Author co-citation network[13]

This final analytical section explores the author co-citation network for the entire 1990-2020 period. Our focus is on the interrelationships among the authors cited by the papers (documents) which meet the criteria for inclusion in the technological catch-up literature. Note that these are authors not included in our reference database but have had a formative impact on the area. They are cited by scholars working on technological catch up which indicates that they have an intellectual influence on the research area. Author co-citation analysis is based on counting the frequency of co-citations of a particular pair of authors by citing documents in our case papers on technological catch-up (White and Griffith 1981). The more frequently two authors are co-cited, the closer they are related intellectually.

[13] We define co-citation taking account only of first authors. Based on our knowledge of the contributors to this area and their research we consider this to be an acceptable simplification.

Table 3 and figure 13 present the results of the author co-citation analysis. To measure an author's importance, we consider cumulative citation counts, intensity of citations during the period of study (burst), topological importance (centrality), and bursts of structural significance (sigma). The most central author is Richard Nelson, with an accumulated co-citation trail of 824, followed by Cohen, Lall, Porter, Teece, OECD, Kim, Dosi, Barro, Freeman and Pavitt, with more than 400 co-citations each (table 3).

The limitation imposed by only using citations is overcome by employing burst or intensity of appearance frequency during the 1980-2020 period[14]. The burstiness index indicates the (observed) frequency of author citing and reflects the interest in that author[15]. A high citation burst is evidence of the association of a particular author with citation surge. Abramovitz (1986) has attracted an extraordinary degree of attention from the technological catch-up community, followed by Romer and Freeman (table 3).

The centrality figure indicates the author's position on the shortest path between two other authors. We can identify the structurally most-significant authors based on their "betweenness centrality". They are authors who have had a major intellectual impact on the flow of ideas around the area. An author with a high value of betweenness centrality has considerably influenced the transmission of knowledge through the network. This person connects disparate clusters of authors who otherwise might be disconnected. Based on the frequency of appearance (824) and centrality (0.81), Richard Nelson can be considered the most representative author since the beginning of this literature.

[14] Burst is defined as (betweenness centrality + 1) to the power of burstiness (Chen, 2009)
[15]Burstiness values are normalized with respect to the highest possible burstiness state.

According to Chen, Chen et al. (2009), potentially transformative changes depend on (a) rapidly accruing citations combined with (b) high betweenness-centrality in a co-citation network. The sigma index combines centrality and citation burst (Chen 2006). Table 3 shows very high burst activity but low centrality for Abramovitz, suggesting that his contribution led to a surge in citations. However, these were not conceptually central to the literature.

Nelson (0.81) is the most central figure in the literature, followed by Lall (0.58), Dosi (0.55), Pavitt (0.54), Kim (0.51), Cohen (0.41), and Abramovitz (0.36). Some of these authors are included in the top 20 ranking for the number of papers on catch-up (Lall, Kim, Abramovitz), but some are not (Dosi, Pavitt, Cohen) (see figure 4). However, both lists show the importance of the other seminal contributions to the economics of technical change to the technological catch-up literature. We see strong integration between works on technological catch-up and broader innovation studies. This may be expected as technological catch-up issues are essentially techno-economic processes that share many commonalities with the general processes of technological change.

Table 3. Ranking the authors according to their frequency

Frequency	Burst*	Centrality	Sigma	Author
824		**0.81**	1	Nelson R
588		0.41	1	Cohen
547	4.67	**0.58**	**8.48**	Lall S
528	4.95	0	1	Porter ME
513		0.37	1	Teece DJ
497		0	1	OECD
488	3.75	**0.51**	4.67	Kim L
438	4.62	**0.55**	**7.47**	Dosi G
432	4.38	0.09	1.45	Barro RJ
414	**8.24**	0	1	Freeman C
410		0.54	1	Pavitt K
395		0	1	World Bank

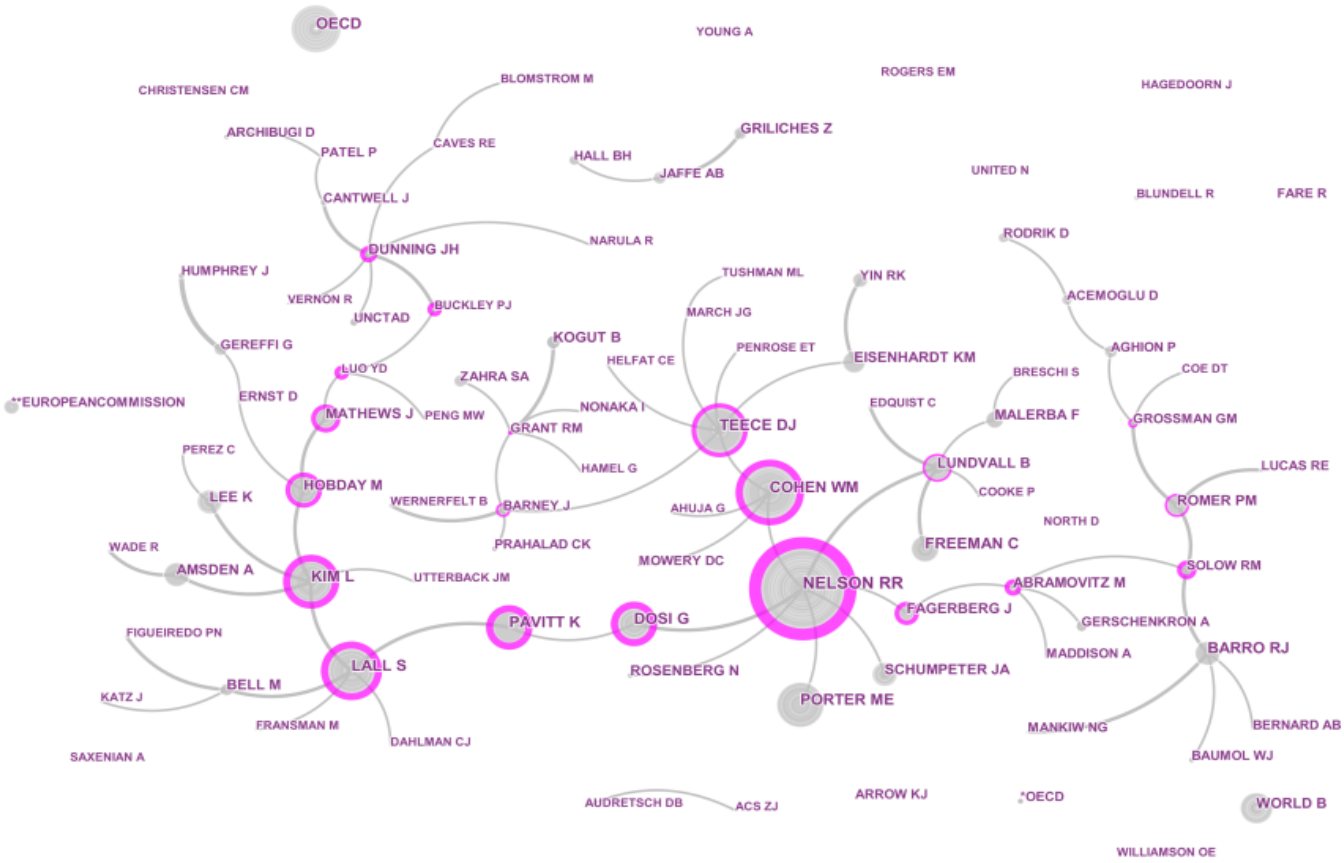
395	4.77	0.4	4.93	Hobday M
377	**6.22**	0.03	1.2	Amsden A
334		0	1	Schumpeter JA
329		0.17	1	Lundvall B
318	*8.7*	0.17	3.9	Romer PM
318		0.03	1	Lee K
300	4.02	0.03	1.13	Eisenhardt KM
291		0	1	Griliches Z
264	**13.72**	0.36	**64.74**	Abramovitz M

* Empty boxes for burst indicate that these authors did not record burst

Source: authors' calculations based on data extracted from web of science

Figure 13 shows the cognitive links among authors that underpin the literature on technological catch-up while not necessarily contributing directly to the area. The network nodes represent the authors, and the node's size is proportional to its co-citations with others in our local dataset. The bigger the purple rings, the higher the frequency. The thickness of the outer circles represents the between centrality. Authors with high centrality values are particularly relevant as they explain how groups are connected.

Figure 13: Authors co-citation network



Source: authors' calculations based on data extracted from web of science

Figure 13 shows Abramovitz as the most transformative author with the highest burstiness and sigma but low centrality (Table 3). His contribution has merged previously disparate streams of research of neo-classical economic growth literature on convergence/divergence with heterodox and empirical technology gap evolutionary approaches. Richard Nelson is central in the author co-citation network as he connects four different approaches to technological catch-up. These four groups represent four intellectual networks that underpin technological catch-up studies, and they are linked to Richard Nelson. First, the right-hand stream of work on economic growth stems from the link to Fagerberg, Abramovitz, Solow, Barro, Romer on one side, and on the other to Grossman, Aghion, and Rodrik. The second stream is innovation systems studies by Nelson and Lundvall, which are linked to the national (Freeman), regional (Cooke), and sectoral (Malerba) systems of innovation literature. The third stream from Nelson

leads to the knowledge management literature via Cohen and Levinthal's absorptive capacity perspective, Teece's dynamic capabilities and variants of the resource-based view of the firm. The fourth stream includes work on industry dynamics bridged by Dosi, Pavitt, and Lall to the literature on latecomer firms and GVCs (analysed in section 4.3). This stream links Mathews and Luo et al. to the international business literature centred around Dunning. Overall, comparing the journal co-citation network (figure 8) with the authors' co-citation network (figure 13), we see two qualitatively different pictures. The institutional stratification present in the case of journals does not seem to be so pronounced at the level of authors primarily due to 'bridging' authors. These scholars connect different intellectual communities. Partly, this can be attributed to the nature of the innovation studies, which almost by definition should be in a permanent pre-paradigmatic change. We consider this the best guarantee of its scientific vitality and social relevance.

Conclusions

This research aimed to provide a systematic examination of the evolution of the technological catch-up literature to highlight its history and likely future. We used advanced bibliometric techniques and built a database of the core catch-up studies based on a search of WoS data. The resulting 5,626 documents were analysed using co-occurrence and co-citation measures. The former is an older scientometric technique that identifies scientific fields and keywords co-occurrences. The latter is a more recent tool that identifies journals, authors, and documents co-citations.

The issue of technological catch-up emerged in the academic literature in the 1960s but only achieved critical mass in the 1980s. It increased further in the 1990s and has continued to expand. Our analysis provides several significant findings.

First, the most impactful ideas and research on technological catch-up are not necessarily published in innovation studies journals. Innovation studies journals tend to publish 'normal science' papers, i.e. those making incremental contributions to the existing knowledge. The most impactful innovation studies 'proper' journals are *Research Policy*, *Strategic Management Journal, World Development, Industrial and Corporate Change, Technovation, Technological Forecasting and Social Change,* and *Energy Policy*. The lack of concentration of the most cited papers in one particular journal suggests that technological catch-up scholars are not a closed community.

Second, the core disciplinary areas researching technological catch-up are economics, business, and management. Technological catch-up can be considered an interdisciplinary area with contributions from several areas of scholarship such as regional studies, environmental studies, operations research, and social sciences. The main keywords are innovation, R&D, and productivity which encompass the main issues in the area and present a limitation to the current research orientation.

Third, the co-citation network provides evidence of three groups that do not communicate intensively. There is a group around *Research Policy*, one around *American Economic Review* and a third around *Strategic Management journal* with links to the US and other international management journals. Although we identified convergence in topics, there is no evidence of convergence in intellectual attributions. This 'scientific parochialism' reflects the deeply

embedded social nature of science networks which justify calls for a re-examination of the dominance of impact metrics.

Fourth, our base period of analysis was the 1980s characterised by two unrelated ‘intellectual colleges’: the US economic works focused on long-term growth and a group focused on developing countries' technological capability. During the 1990s, when the technological catch-up literature snowballed, these two evolved further and began to converge. In this period, the common denominator was the drivers of convergence/divergence in economic growth, addressed from different methodological angles.

Fifth, during the 2000s, growth empirics and the issues of convergence and divergence were sidelined. The focus shifted to latecomer firms from a resource-based (capability) view, sectoral innovation systems and GVCs. The grand general theoretical problems and the convergence/divergence debate were abandoned in this period. The research focused on the different dimensions of latecomer firms within a system of innovation and sectoral and GVCs context. Also, in this period, heterodox neo-Schumpeterian approaches began to dominate the discourse on technological catch-up.

Sixth, the 2010s saw a substantial shift toward globalisation among emerging economies and what it entails for catching up firms and industries. In this decade, research focused on the mezzo sectoral and global value chain level. It also demonstrated the close linkages between global and national levels and how domestic and foreign firms interact in that multi-level framework.

Seventh, the evolution of technological catch-up research over four decades shows the quantitative expansion in terms of authors and countries and a qualitative evolution. The qualitative changes are characterised by a convergence between the economic growth and technology capabilities literature, a shift from the macro issues of growth and convergence to (latecomer) firm and sectoral level issues, and concern over the relationship between globalisation and technology upgrading at the sectoral or mezzo level. As part of research for this paper, we conducted a historical direct citation network analysis (not reported here) which shows that with the possible exceptions of Abramovitz (1986) and Dahlman, Ross-Larson et al. (1987), there are no discernible long term citation paths. The relatively 'short term focus is not surprising given the fairly significant changes in the research focus across the decades.

Eighth, analysis of the co-citation networks of authors whose research has influenced work on technological catch-up but who are not necessarily active (only) in that area showed that Richard Nelson is central in the authors' co-citation network. His work bridges four different approaches in technological catch-up studies: work on economic growth, systems of innovation, knowledge management, and industrial dynamics cum GVCs and latecomer firms.

We conclude by highlighting two important points. First, the predominant focus on catch-up and economic growth and the lack of attention to the nature of growth (cf. green growth) and the issues of social inclusion/exclusion and inequalities related to technology upgrading[16]. Our unsystematic monitoring of the current literature on technological catch-up suggests the possibility of another qualitative change in the second decade of the 21st century, which might result in a major re-focus on new issues. This could lead to a redefinition of the concept of

[16] For a recent state of the art review of this area that comes to a similar conclusion see Lee, J. D. L., S. Radosevic, D. Meissner and N. Vonortas (2021). "Technology Upgrading and Economic Catch-up." The Challenges of Technology and Economic Catch-Up in Emerging Economies: 1.

technological catch-up, which might involve the integration of work on technological catch-up and technology upgrading with social upgrading, equality, and resilience.

Second, a limitation of the bibliometric analysis is that it portrays the sociology of academic publishing and citations rather than providing evidence of a 'true' intellectual evolution. Citations can only partially capture quality aspects, especially originality and societal relevance (Aksnes, Langfeldt et al. 2019). They convey academic impact and academic relevance within the community, which is a social entity. As science (including economics) is a social phenomenon, researchers tend toward cronyism, that is, citing the members of their narrow social networks (D'Ippoliti 2020). Also, widely recognised academic works often gain reputation and may be cited regardless of whether the content justifies this (Mathew effect). On the other hand, our reading of the innovation studies literature suggests that metrics may underestimate the research impact of some scholars (e.g., Freeman). As we aim to trace the cognitive evolution of research on technological catch-up, it is essential to consider these limitations when interpreting results of bibliometric analysis.

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