Chapter 13

Technology and innovation management in a global perspective

Alexander Gerybadze

Abstract

This chapter analyzes major trends and structural changes related to technology and innovation management (TIM) for the period 1995 to 2018. For quite a while, TIM was characterized by an emphasis on R&D, and biases in favor of technology-push, home-country and lead-countries. Most research was concentrated in a few academic institutions in Anglo-saxon countries that acted as centers of excelence. Technological parochialism dominated our thinking about global innovation. Until about 2005, innovation remained centered in large multinational corporations from a small group of advanced nations. And these large corporations concentrated most of their R&D investments in a small group of target countries. This pattern has somewhat changed during the last fifteen years, and particularly during the last decade. The footprint of innovation activities has become much more global and diversified. An increasing number of countries have followed ambitious innovation strategies. And our concepts of managing innovation had to be refined: towards more open, more user-oriented and more boundary-spanning concepts. We have seen a persistent increase in the globalization of the R&D function and a greater diversity of target countries for new R&D locations.

Even though it is hard to predict future courses in periods of growing political instability, the globalization of R&D will most probably go on during the period 2019 to 2030. Long-term megatrends like climate change, urbanization and new mobility must be addressed from a global perspective, and the appropriate technological and social solutions need to be developed and implemented in many countries simultaneously. The global footprint of innovation activities will be extended and we will see a proliferation of new uprising nations that play an increasingly important role. Sometime during the next decade, China will surpass the United States in terms of GDP as well as R&D spending. Other emerging nations like India, Brazil, Indonesia, Taiwan and Malaysia will follow high-tech development strategies. It will be interesting to monitor country-specific processes of linking science and technology, human capital formation and R&D growth. A key issue will be whether catch-up nations are able to grow beyond the so-called middle-income trap and whether these countries can implement a sustainable growth path.

Keywords: Global Innovation; Technology and Innovation Management; Lead-country Bias; Internationalization of R&D

1 Introduction

Technology and Innovation Management (TIM) has become an important subject taught at business schools as well as engineering schools around the world. Prominent universities have established global master programmes with a focus on technology management. Global corporations need to build global teams of specialists with diverse backgrounds, and have to

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manage effective global networks of R&D centers in order to exploit diverse sources of knowledge. In the following paper, we describe how the TIM practice has become globalized during the last 20 years. This process did not just involve an increasing number of R&D centers worldwide, but a much wider scope of search activities involving multiple disciplines, multiple functions as well as diverse institutional settings. It was Cornelius Herstatt's contribution to develop TIM further towards a truly global discipline, and to promote the user perspective and the role of demand in fostering innovation activities.

For quite a while, our discipline was characterized by an emphasis on R&D, a bias on technology-push, and a home-country bias resp. a lead-country bias. Most research was concentrated on a few academic institutions in Anglo-saxon countries. Technological parochialism dominated our thinking about global innovation. Until about 2005, innovation remained centered in large multinational corporations from a small group of advanced nations. And these large corporations concentrated most of their R&D investments in a small group of target countries.

This pattern has somewhat changed during the last fifteen years, and particularly during the last decade. The footprint of innovation activities has become much more global and diversified. An increasing number of countries have followed ambitious innovation strategies. And our concepts of managing innovation had to be refined: towards more open, more user-oriented and more boundary-spanning concepts. Three major changes in our thinking about the TIM practice will be highlighted in our paper: (1) the new role of demand and research on lead-users in driving innovation processes. (2) the greater global dispersion of innovation activities across many countries and, in particular, stronger innovation activities in emerging countries. Inasmuch as innovation is no longer limited to a small "club" of affluent countries and user groups, (3) less expensive types of innovation and concepts of frugal innovation become more and more important. Cornelius Herstatt and his team at the Hamburg Institute of Technology have addressed these three important changes in technology and innovation management. He and his team have published widely on lead users and the role of demand in innovation.[1] Herstatt has also studied innovation management practices in advanced as well as in emerging countries.[2] And during the last years, frugal design and engineering has become a major research focus within his team (Herstatt and Tiwari 2017).

The paper is structured as follows: in section 2 we provide an overview on recent trends in the literature on global R&D management. Section 3 analyzes the major investors and the largest source countries for trans-border R&D investment within multinational corporations. The level of concentration of investor countries is still quite high, while more and more of these investments flow to a growing number of target countries. In section 4, we describe this process of global dispersion and the new division of labour between countries operating at the technological frontier on one side, and an increasing number of emerging countries on the other side. Section 5 then highlights the new role of emerging nations in attracting offshore R&D centers within multinational corporations. In section 6, we analyze a new diagnostic

[1] Cornelius Herstatt has worked within the "customer-active paradigm" developed originally by Eric von Hippel at MIT (von Hippel 1988). Herstatt developed von Hippel's research methods further and has extensively published on user-driven product development and innovation marketing (Herstatt, von Hippel 1992, Herstatt, Verworn and Nagahira 2004, Lüthje and Herstatt 2004).

[2] Two focus areas of his comparative international studies cover the Japanese innovation system, and more recently studies on frugal innovation in India. In addition, Cornelius Herstatt has completed empirical innovation research in many other countries.

toolkit for measuring distributed technological competences based on patent data. We conclude our paper with a summary of managerial challenges and with recommendations for further research.

2 The process of R&D globalization within multinational firms

In studying the process of R&D globalization and the sequence of developing the TIM practice into a truly global discipline, we may distinguish three major phases. During the early phase, i.e. between 1980 and 1995, multinational corporations followed a sequential process of international business expansion, while foreign R&D and innovation played still a minor role. Corporations from the U.S. and Europe typically started with export activities, which were followed by setting up offshore production units in foreign markets. During this early phase, however, the locus of innovation remained in their home base. New product development and R&D was most often concentrated near headquarter locations. At a rather low level, some adaptive work may have been dislocated to foreign production plants, if local customer preferences or regulation required some change.

This pattern of internationalization changed during the period 1995 to 2005, when R&D and innovation became of much greater concern for multinational firms. In this phase, we have observed a strong wave of globalization, the integration of former communist countries in the world economy, and the formation of complex and interconnected global supply chains. Large multinational corporations used to be the prime agents in this process, and they have continously extended their presence in foreign markets. And being active in foreign markets often implied to be present with foreign production as well as with foreign R&D. During this time, we have encountered a strong wave of foreign R&D investment within multinationals from Europe, the U.S. and Japan. In parallel, a growing number of scholars published books and articles on the globalization of R&D. Particularly during this phase 1995 to 2005, researchers in a growing number of countries including the U.S., Britain, Japan, Sweden, Germany and Switzerland became interested in this subject.[3]

The next wave of globalization and the new pattern of global R&D can be observed during the most recent period following 2005, and particularly after the financial crisis in 2008/09. While multinational corporations followed a sequential and evolutionary process of international expansion until then, the technological dynamism observed in several industries required to implement TIM in an integrated and global perspective. Very high fixed costs for product development in many industries together with the shortening of product life-cycles forced multinational firms to develop and launch products on a global scale. A typical example is the pharmaceutical industry, where high fixed costs amounting to more than a billion dollars for a major new drug led big pharma companies to organize multi-country clinical trials and to launch registered new drugs in several world markets simultaneously. Similar imperatives for global innovation are typical for many other industries, including automobiles, information technology and electronics.

This new technological dynamism coincided with a greater variety of innovation systems worldwide. More and more nations in the world wanted to participate in high-tech industries.

[3] Cornelius Herstatt became affiliated with research groups in St. Gallen and at the ETH Zurich, that were studying the R&D globalization process during his early academic and consulting work in Zurich.

Many governments in Asia, Latin America and Eastern Europe invested in their national innovation system as well as in science and engineering education. As their level of competence increased, multinational companies found it attractive to set up R&D centers in emerging countries, and to benefit from a globally-dispersed talent base.[4] Finally, the rapid development of advanced information and communication technology facilitated a greater degree of global dispersion of work and the decomposition of global value chains. The rapid diffusion of the internet, cellular mobile telephony, fiberoptics and satellite communication made it possible to distribute workgroups and R&D teams around the globe, and to effectively coordinate their work across distances. The generation and dissemination of knowledge and the communication between globally dispersed workgroups has since been facilitated.

As a result, we observe a continuous trend towards greater differentiation and globalization of the R&D function. In addition, advanced marketing and service concepts, joint problem-solving with customers, and simultaneous product and process engineering became as important as the R&D function. Multinational firms have thus established global networks and had to develop complex organizations with distributed sensory capabilities. We observe different patterns, however, if we analyze different industries, as well as source countries, and target countries for international R&D investment. In section 3, we will describe patterns of foreign R&D investment observed in major source countries. This is followed by an analysis of changes in the structure of target countries of foreign R&D investment in section 4.

3 Major source countries for foreign R&D investment

Major **drivers of outward foreign R&D** investment are (1) export and foreign production activities that need to be complemented by design and development; (2) expected stimuli and challenges from a dynamic innovations system in a lead country (3) access to technological assets and research competences available abroad; (4) search for skills and manpower due to limited resources at home and (5) a sequence of mergers and acquisitions that result in the need to integrate several pre-existing R&D units.

For a long time, foreign R&D investment was dominated by multinational corporations from the United States and from large Western European countries primarily active in selected R&D intensive industries. Between 1995 and 2005, Japanese corporations started to invest in foreign R&D centers in the U.S. and in Western Europe, while American as well as European corporations also stepped up their R&D investment abroad. Still today, the lion´s share of corporate R&D investment comes from multinational firms from the U.S., followed by corporations from Germany, Japan, Switzerland, France and Sweden. We will concentrate on the role R&D investors from the U.S., Germany and Japan, and will emphasize structural changes in foreign R&D investment within these three countries.

U.S. multinational corporations continue to dominate foreign R&D investment with approximately 36% of trans-border R&D investment worldwide. U.S. corporations have increased annual foreign R&D investment from 13.2 billion $ in 1995 to 54.8 billion $ in 2015. Their foreign R&D ratio, i.e their share of foreign R&D to the total worldwide R&D expenditures of U.S. corporations has increased from 12 % to 16 % during the same period (see table

[4] The UNCTAD published a major issue of the World Investment Report on the “Internationalization of R&D” and highlighted this trend to invest in R&D centers in emerging countries for the first time (UNCTAD 2005).

1). Major industries in which U.S. firms have strongly increased their foreign R&D investment are (1) pharmaceuticals, (2) aerospace, (3) software development (4) computer hardware and peripherals, followed by (5) motor vehicles and (6) IT services. Until about 2002, U.S. corporations used to invest about two third of their foreign R&D in Europe. Since then an increasing share of R&D is also being invested in Asian countries (26% in 2015). More recently, U.S. firms have strongly increased their R&D investment in China and India. Both countries have attracted more than 3 billion $ of R&D investment of U.S. MNC in 2015. Within Europe, U.S. firms have concentrated their R&D investment in Germany, the U.K., and more recently in Switzerland and Ireland.[5]

Table 1: Outward R&D investment of U.S. multinational corporations 1995 to 2015; Source: IMI Hohenheim University, based on data from BEA (2017), Mataloni (2007) and Mataloni (1997)

	R&D Expenditures in Billion €			CAGR in %
	1995	2005	2015	1995-2015
Foreign R&D Expenditures of U.S. Multinational Corporations	13.2	28.3	54.8	7.4
R&D Expenditures of U.S. Parents of MNC in the U.S	96.5	178.5	284.3	5.6
Total (Worldwide) R&D Expenditures of U.S. Multinational Corporations	109.7	206.9	339.1	5.8
Share of Foreign R&D to Total (Worldwide) R&D Expenditures of U.S. Corporations (in %)	12.0	13.6	16.2	

German multinational corporations represent the second largest group of investors setting up R&D centers abroad. They account for approximately 18% of trans-border R&D investment worldwide. German corporations have increased their annual foreign R&D investment from 5.1 billion € in 1995 to 24.1 billion € in 2015. The share of foreign R&D to the total worldwide R&D expenditures of German firms. has been increased from 23 % to 35 % during the same period (see table 2). Major industries with strong foreign R&D ratio are (1) pharmaceuticals, (2) motor vehicles, (3) electrical engineering and (4) machinery. German corporations. still concentrate about a third of their foreign R&D investment in the U.S, and another third in neighbouring European countries. During the last 10 years, German firms have increasingly also invested in R&D centers in China, India, Brazil, as well as in Eastern Europe.[6]

[5] This is mainly influenced by specific acquisitions of pharma and biotech companies in the case of Switzerland. The new role of Ireland as R&D center may be explained by tax-based relocation decisions of U.S. corporations.

[6] See the report on outward foreign R&D expenditures by German companies in EFI (2014, chapter A5) and in Gerybadze, Schnitzer and Czernich 2013).

Table 2: Outward R&D investment of German multinational corporations 1995 to 2015; Source: IMI Hohenheim University, based on data of the Stifterverband Science Statistics, Data Reports 1997, 2007, and 2017.

	R&D Expenditures in Billion €			CAGR in %
	1995	2005	2015	1995-2015
Foreign R&D Expenditures of German Multinational Corporations	5.1	11.1	24.1	5.2
R&D Expenditures of Parents of German MNC in Germany	17.0	26.8	44.6	5.0
Total (Worldwide) R&D Expenditures of German Corporations	22.1	38.2	68.7	5.1
Share of Foreign R&D to Total (Worldwide) R&D Expenditures of German Corporations (in %)	23.1	29.9	35.0	

Multinational corporations from Japan started to invest in foreign R&D in the mid-1990s, and have continuously stepped up their technological competences abroad. They invest primarily in the United States, in large Western European countries, and more recently in China, Singapore and India. Their foreign R&D investment is closely linked to their global production network in export-oriented industries like electronics, pharmaceuticals, automobiles and machinery. Major R&D investors from other source countries include Switzerland, France, the U.K., Sweden, and South Korea. To summarize, outward foreign R&D investment is still strongly concentrated among large industrialized nations with a strong endowment of multinational corporations.

4 Major target countries for foreign R&D investment

While the structure of source countries for trans-border R&D investment has remained comparatively stable over time, we observe considerable changes with respect to the location decisions for new foreign R&D centers. An increasing number of emerging countries have developed their national innovation systems, and are trying to attract R&D-intensive multinational firms to their shore. As a result, the global R&D footprint has become much more diverse and colourful, particularly during the last 10 to 15 years.

What are the **drivers of inward R&D** investment? What are the major location factors for attracting foreign multinationals? And how did these locational factors change over the last 15 years? Here we need to distinguish between target countries that operate close to the technological frontier, and those countries that attempt to catch up. The group of "advanced countries" which continue to operate at a very high level of competence is still rather small, and even the very large industrial countries have become specialized on few industries and technological fields. Multinational firms go to these "high-end locations" in order to participate in the innovation game. Foreign R&D is basically home-base augmenting and feeds into the corporate knowledge base.[7] On the other side, we have an increasing number of catch-up countries, which attempt to strengthen their technological portfolio. They are most often the recipients of international technology transfer, and they offer business opportunities, a rich

[7] For the distinction between home-base augmenting and home-base-exploiting R&D see Kuemmerle (1997, 1999), Criscuolo (2009) and Criscuolo, Narula and Verspagen (2005).

talent base and other incentives for investing in R&D centers. Multinational firms operate R&D units in these countries, but these are not as sophisticated and often of a home-base-exploiting nature.

Major **drivers of inward R&D for advanced target countries** which are close to the technological frontier include (1) the attractive size and growth potential of the market in this particular country and (2) the characteristics of a lead market with strong inducements for advanced product development; (3) furthermore, this country influences standards and business models which have a high chance of later a becoming worldwide standard; (4) Several advanced corporations in this country serve as challengers as well as a source of spill-overs; (5) innovation is supported through a world-leading science and research infrastructure and, last-not-least, (6) companies get access to highly-skilled scientists and engineers.

In Table 3, we have summarized the ranking of the major target countries for foreign R&D investment, based on published OECD data (OECD MSTI 2018/2). Reliable statistics on inward R&D investment are available only for OECD countries, and we need to assess the role of countries like China, India or Brazil based on complementary data sources (see section 5 and 6). While the "classical" target countries like the U.S., Germany, the U.K. and Japan continue to play a strong role, we observe considerable strong growth in Israel, Ireland as well as in Eastern European countries. In some of these countries, foreign subsidiaries of represent the dominant source of business R&D spending, and this is the case for the U.K., Israel, Belgium, Ireland, Austria as well as for Eastern European countries. In some cases, foreign multinationals represent between 60 and 70 % of business R&D spending, and this may indicate an unfavourable dependence on investment decisions of foreign investors. As an example, foreign R&D centers represent more than half of business R&D in the U.K., and it may be expected that foreign multinationals will reduce their R&D spending as a result of BREXIT.

Table 3: The largest target countries for R&D investment of multinational corporations 2005 and 2015; Source: IMI Hohenheim University, based on OECD MSTI 2018/2 and MSTI 2009/2

Country	R&D Expenditures of Foreign Affiliates 2005 (Million $)	Share of Foreign Affiliates in BERD (%)	Country	R&D Expenditures of Foreign Affiliates 2015 (Million $)	Share of Foreign Affiliates in BERD (%)
1. USA	31 099	13.8	1. USA	56 743	15.9
2. Germany	12 160	27.8	2. Germany	16 806	21.5
3. United Kingdom	7 595	39.1	3. United Kingdom	15 411	51.1
4. France	5 767	23.5	4. Japan	8 987	6.7
5. Japan	5 038	5.1	5. France	8 025	20.6
6. Canada	4 235	32.6	6. Israel	7 732	70.8
7. Sweden	3 530	41.5	7. Canada	5 194*	35.1*
8. Austria	2 408*	44.6	8. Austria	4 635	49.4
9. Belgium	2 406	56.8	9. Sweden	4 496	42.1
10.Italy	2 315	25.2	10.Belgium	4 453****	66.0****
11.Australia	2 000E		11.Italy	4 355	25.1
12.Israel	2 000E		12.Australia	3 547**	27.2**
13.Spain	1 869	26.2	13.Spain	1 964	38.4
14.Czech Republic	962	51.5	14.Netherlands	1 797	32.4
15.Ireland	924	70.3	15.Ireland	1 752	63.7
16.Finland	638	16.1	16.Switzerland	1 633	12.9
17.Norway	395	28.5	17.Czech Republic	1 231	61.4
18.Hungary	299	59.7	18.Poland	978	44.7
19.Poland	288	30.4	19.Finland	750**	20.4**
20.Portugal	237	34.0	20.Norway	679***	31.6***
Total (20 Countries)	86 165		Total (20 Countries)	151 080	

For many other important target countries, foreign R&D investment as well as R&D investments of local corporations represent complementary strategies. The U.S. still attracts the lion´s share of R&D investment of foreign multinationals with 56.7 billion $ in 2015. The share of foreign firms in BERD has gone up from 13.6 % in 1995 to 16.7 % in 2015, and this process is heavily debated in U.S. science politics. Japan has always followed a cautious strategy of attracting foreign R&D primarily in areas which complement national R&D capabilities. The share of foreign R&D in BERD in Japan is still at a rather low level (6.7 % in 2015), but has been increased steadily (from less than 1 % in 1995 and 5.1 % in 2005). Germany is still a major target for R&D investment of foreign multinationals, even though the strong growth of inward R&D investment between 1995 and 2005 has not been continued during the last decade.

In Table 4 we analyze structural changes of inward R&D expenditures of foreign multinationals in the United States. From an annual level of 15.6 billion $ in 1995, foreign firms have increased their R&D investment more than threefold to a level of 56.7 billion $ in 2015 (BEA 2017b).[8] About 35 % of inward R&D investment comes from foreign pharmaceutical firms who still consider the U.S. as the leading research base for health research and biotechnology, as well as the leading market for health products and services. 13 % of inward R&D is contributed by foreign firms in electronics and information technology, where the U.S. is still a dynamic market as well as a leading technology base. Other industries that attract significant shares of inward R&D investment are motor vehicles (9 %), scientific and technical consulting (7 %), machinery (4 %) and chemicals (3 %).

Table 4: The role of inward foreign R&D investment in the United States / structural changes between 1995 and 2015; Source: IMI Hohenheim University, based on data from BEA (2017b), and BEA (1997), and Anderson (2007)

	R&D Expenditures in Billion €			CAGR
	1995	2005	2015	1995-2015
R&D Expenditures of Foreign Corporations in the U.S.	4.3	10.6	13.1	5.7
Domestic R&D Expenditures of U.S. Corporations	22.4	27.6	47.5	3.8
Total Business R&D Expenditures in the United States	26.7	38.2	60.6	4.2
Share of Foreign Corporations in Business R&D Expenditures in the United States (in %)	16.1	27.8	21.6	

U.S. affiliates of foreign multinationals from seven countries still account for 80 % of inward R&D investment flows in the U.S. Foreign corporations from Switzerland and the U.K. together account for 31 %, the large majority of this includes pharmaceutical companies that have set up research centers in North America or that have acquired U.S. based pharma and biotech firms with advanced research capabilities. Japan and Germany still account for a considerable share of R&D investments in the U.S., and their R&D portfolio is somewhat more diversified, reflecting the trade and foreign investment structure of these two countries. Other significant R&D investors come from the Netherlands and Ireland, even though this may be

[8] This represents an annual growth rate of 6 %. Inward R&D investments of foreign firms were growing at a much higher rate than R&D investments by U.S. corporations within the U.S.

somewhat misleading, since this includes holding companies which simply have chosen their headquarters here primarily for legal and tax purposes.[9] Other relevant R&D investors in the U.S. are corporations from South Korea, Israel, Canada and Sweden. Investors from emerging countries like China, India, Singapore are not yet very active with setting up R&D activities in the U.S., but they are nonetheless keeping a window on U.S. technology following other strategies.[10]

Table 5: The Role of inward foreign R&D investment in the Germany / structural changes between 1995 and 2015; source IMI Hohenheim University, based on data from SV-Wissenschaftsstatistik, data Reports 2003, 2007, and 2017

	R&D Expenditures in Billion €			CAGR
	1995	2005	2015	1995-2015
R&D Expenditures of Foreign Corporations in Germany	4.3	10.6	13.1	5.7
Domestic R&D Expenditures of German Corporations	22.4	27.9	47.5	3.8
Total Business R&D Expenditures in Germany	26.7	35.5	60.7	4.2
Share of Foreign Corporations in Business R&D Expenditures in Germany (in %)	16.1	27.6	21.6	

Table 5 analyzes changes in the structure of inward R&D investment in Germany between 1995 and 2015. Foreign multinationals have increased their R&D spending in Germany at an average annual rate of 5.7 % between 1995 and 2015. Meanwhile, domestic firms have increased their R&D spending in Germany only at 3.8 % p.a. The share of foreign firms in business expenditures in Germany thus rose from 16.1% to 27.6% during this first ten-year interval. During the financial crisis in 2008-09, German firms kept their R&D spending rather stable, while foreign multinationals reduced their R&D spending in reaction to a sudden business downturn. When business picked up again, German corporations increased their spending on R&D, while foreign investors still remained rather hesitant. While German firms were increasing their R&D investment between 2011 and 2015 at an annual rate of 6.5%, foreign firms merely increased their R&D spending for German labs at a nominal rate of 0.6 %. In real terms this led to a reduction in R&D personnel within subsidiaries of foreign corporations. As can be seen in table 5, the share of foreign R&D expenditures was reduced from 27.6 % to 21.6 % between 2005 and 2015.

Major source countries for R&D investment of multinational firms in Germany are (1) the United States, (2) Switzerland, (3) France, (4) the Netherlands, (5) Japan as well as the Scandinavian countries. In several high-tech industries like IT, pharma and aerospace, Germany tends to be strongly dependent on R&D investment of foreign firms. By contrast, R&D ex-

[9] In the case of Ireland, several U.S biomedical companies such as Allergan and medtronics have transferred their legal headquarters to this country primarily for tax purposes. These new legal Irish companies cannot reasonably be considered Irish corporations. As a result, the published figures for trans-border R&D investment are overestimated in the case of Ireland.

[10] This includes strategies to attract returnees from U.S. universities and corporate R&D labs, as well as licensing and other modes of technology acquisition.

penditures of German corporations are still heavily concentrated on medium-tech manufacturing industries like automobiles, machinery, chemicals and metal-processing. This tends to replicate a "competence-trap": while foreign firms consider Germany as an attractive R&D location in traditional fields like motor vehicles, machinery and chemicals, the country does not seem to attract enough foreign R&D in digital technologies, biotechnology and other dynamic fields.[11]

Japan is still the fourth largest target country for trans-border R&D investments of global corporations. Even though the country has always been quite hesitant in opening up national markets and research systems to foreign firms, R&D labs of foreign high-tech firms were regarded as an important source for inward technology-transfer. Since the early 1990s, multinational corporations from the U.S. and from Europe opened up new R&D centers in Japan, in order to learn from advanced business practices. The Japanese market was considered to be an interesting lead market, especially for consumer electronics, display technologies and for semiconductors. Cornelius Herstatt became interested in Japanese management of technology through his Ph.D. advisor Prof. Hugo Tschirky at the ETH Zürich, and has since then studied Innovation and new business practices in Japan. He became especially interested in studying the role of the Japanese lead market in triggering off new products and business concepts for foreign multinational firms.[12] Foreign firms became particularly interested in learning from advanced management techniques such as simultaneous engineering, managing the fuzzy front-end, as well as the linkage between quality management and product innovation. The proficiency of Japanese innovation management practices was well documented in several publications of Herstatt and his team.[13]

Table 6: The role of inward foreign R&D investment in Japan / structural changes between 1995 and 2015; Source: own calculation based on data from OECD MSTI 2004/2 and OECD MSTI 2017/2

	R&D Expenditures in Million €			CAGR
	1996	2005	2015	1996-2015
R&D Expenditures of Foreign Corporations in Japan	548	5 038	8 987	15.9
Domestic R&D Expenditures of Japanese Corporations	51 164	93 346	124 191	4.8
Total Business R&D Expenditures in Japan	51 712	98 384	133 178	5.1
Share of Foreign Corporations in Business R&D Expenditures in Japan (in %)	0.9	5.1	6.7	

Due to this important role of the Japanese innovation system, foreign multinationals increased their R&D investment in Japan, particularly during the ten-year period following 1995. As can be seen in table 6, R&D expenditures of foreign corporations were growing at an annual average rate of 28% between 1996 and 2005. They continued to grow after 2005, even though

[11] For a discussion of this „competence trap", see EFI 2013, chapter B.1 and EFI 2014, chapter A.5.

[12] See Beise (2006), Reger (1997), Beise and Rennings (2004), Herstatt, Stockstrom et al. (2006) and Gerybadze (2006) for their studies of the Japanese innovation system, and their analysis of the functioning of lead markets in Japan.

[13] See Herstatt and Stockstrom (2006), Herstatt, Stockstrom et al. (2006), Verworn, Herstatt and Nagahira (2008) for detailed studies of Japanese innovation management practices.

at a lower pace, and have reached a level of 9 billion $ in 2015. A survey on trends in business activities of foreign affiliates published by the Ministry of Economics, Trade and Industry showed that 670 of the 3300 foreign multinationals in Japan operate their own R&D centers in the country (METI 2015). Even though this R&D investment of foreign affiliated companies still just represents 7% of total business expenditures of R&D in Japan, foreign multinationals still consider Japan as a major R&D hub in Asia.[14] For companies in optoelectronics, communication and advanced materials, Japanese innovation is still leading edge. In certain fields of automotive technology like hybrid engines and fuel cells, Japan is considered to be the "hot spot" and a major lead market. The same is true for robotics as well as for consumer product companies developing products for the so-called "silver market" in Japan.[15]

5 The new role of emerging countries in attracting foreign R&D centers

So far we have concentrated on foreign R&D locations mainly in advanced industrialized countries. The literature on Global R&D still underestimates the growing role of emerging countries as potential new target locations for R&D centers. During the last ten to fifteen years, we observe stronger R&D investments of multinational firms in emerging and uprising nations. The major drivers for the location of R&D centers in emerging countries, however, are different from the drivers of foreign R&D in lead countries that we have analyzed in the preceding chapter 4. The prime emphasis is not so much on knowledge sourcing at the frontier of technological change. Instead, foreign corporations that invest in new R&D centers in emerging nations want to benefit from a dynamic market and a resource-rich environment. Major **drivers of foreign R&D in emerging countries** are:

1) Foreign multinationals want to get access to a large and fast-growing national market where products need to be adapted to local conditions.
2) Companies often emphasize frugal innovation concepts, i.e. products and services that are well-adapted and tested for lower-income customer-groups.
3) Companies set up local production units and need to establish engineering centers in close proximity to manufacturing plants.
4) Companies want to get access to large talent pools, especially to science and engineering graduates with a still favourable wage-structure.
5) Target countries often follow ambitious policies for industrial development in high-tech industries combined with efforts to expand private as well as public R&D.
6) Often this goes hand in hand with strong national as well as regional incentives for localizing R&D.

An increasing number of emerging countries have thus followed a sequential process of competence-building, and have strongly emphasized R&D investment and the formation of knowledge-intensive industries. While they have often started with low-tech manufacturing, they tend to invest in research and development and in science and engineering education.

[14] A recent survey of JETRO (2016) asked 222 global corporations active in Asia about their assessment of R&D locations in different Asian countries. 43% of the companies mentioned Japan as the preferred R&D location, followed by Singapore (15%), India (15%) and China (10%).

[15] Japan with its ageing society is seen as a test ground for other markets in the world that will encounter similar demographic problems with a time lag. See Herstatt's studies on product development for the "silver market" in Japan in Kohlbacher and Herstatt (2011) and Kohlbacher, Herstatt and Schweisfurth (2010).

This allows them to move up into the formation of more advanced high-tech industries. These again build on home-grown national R&D capabilities as well as on inward technology transfer. Increasing strengths of a growing high-tech manufacturing and export sector then feed into the national R&D and university system and this creates an upward spiral.

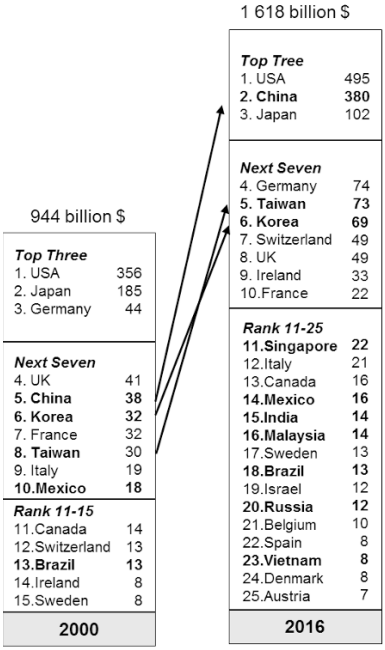

Figure 1: Structural changes in high-tech manufacturing / the new role of emerging nations in the periods 2000 and 2016; Source: Own illustration, based on data from NSF, science and engineering indicators 2018.

During the years 2000 and 2016, global spending on business R&D was growing from 465 billion $ to a level of 1 230 billion $. While BERD was still dominated by advanced industrialized countries in 2000, only two emerging nations were represented in the list of top 10 countries (China and South Korea). Fifteen years later, five emerging nations were represented in this list of the leading BERD investors. China has risen to second place closely following the U.S, South Korea attained rank 5, followed by Taiwan, Russia and India at positions 8 to 10. The group of emerging countries has realized much higher growth rates of business R&D spending than the former advanced nations, and this trend tends to continue. In figure 1, we analyze structural changes in the ranking of emerging countries and former industrialized countries. We use data on value-added in high-tech industries. Emerging nations have strongly invested in information and communication technology, electronics, pharmaceuticals, biotechnology and other R&D-intensive industries. In some specific high-tech industries, some countries have developed technological capabilities close to the technological frontier. Think of mobile communication from China and South Korea, IT services and

software development from India, or security systems from Israel. In these specific fields, foreign multinational corporations have established world renowned competence centers in these countries.

A specific strategy that has become promoted through subsidiaries of multinational strategies in emerging countries involves frugal product design and **frugal innovation.** Multinational companies had to develop products particularly suited for the large potential markets in China and India. Products were characterized by modest technology levels ("just good enough"), by acceptable price-levels and by robustness. There are numerous case descriptions of successful frugal product development in China including computer tomography, automotive components and photovoltaics.[16] In most cases, these firms had to transfer product development capability to China, because their European engineers were just not prepared to develop products below certain performance standards and at the appropriate cost. Engineers in China were closer to the "voice of the customer" and ready to compromise with respect to technical performance. As it turned out later, frugal products developed for the Chinese market were then successfully launched to other parts of the world. Herstatt and Tiwari (2017) have studied similar projects in India, and have highlighted India's new role as a lead market for frugal innovations. In many cases, multinational companies from Europe and the U.S. have developed products in their R&D unit in India. Quite often, these robust products first introduced in the market in India have later become successful products in many other countries in the world. A typical example is Nokia with its development of affordable cellular mobiles, which later became successful in other Asian and African countries.[17]

6 Structural trends based on patent data

Patent data provide a reliable data source for studying the global distribution of innovation activities, since these are more widely published than data on R&D expenditures. Patent data published by the European Patent Office (EPO), and the Patstat database of the OECD distinguish between the location of patent applicants and the residence of individual inventors. Careful analysis of this information allows to assess the extent as well as the specific content of trans-border R&D flows within multinational corporations.[18] We compare patent filings and structural changes in inventor locations for two three-year periods (2011-2013 vs. 2000-2002). U.S. based multinational firms have stabilized their foreign inventor ratio at a level of 18% in both periods. During this period, however, foreign inventorship was moving to emerging countries, with a growing presence in China, India, Israel, Singapore and Russia. The share of foreign inventors from emerging nations in all foreign inventors went up from 14% in 2000-2002 to 36% in 2011-2013. During the same period, some former important inventor locations like Japan, the U.K. and France were becoming less relevant within U.S. firms. Meanwhile, China attained rank three of all foreign inventor locations within U.S. firms, and

[16] See the Ph.D. study of Schanz (2008) describing cases of product development Siemens' Chinese R&D lab, as well as the journal articles on low-cost innovations from R&D labs in emerging countries (Herstatt and von Zedtwitz 2014, Gerybadze and Merk 2014 and Schanz, Hüsig, Dowling, Gerybadze 2006).

[17] See Tiwari and Herstatt (2013), Tiwari (2013) and Tiwari and Herstatt (2017)

[18] This method of analyzing trans-border R&D activities based on patent data has originally been developed by Cantwell (1989) and Guellec and Pottelsberghe de la Potterie (2001). For a more recent development of this analytical tool see Gerybadze and Sommer (2017) and Dominguez Lacasa et al. (2013).

India attained fifth position. This corresponds to the new role of these two countries as R&D locations, as has been outlined in section 5.

For German corporations, the foreign inventorship ratio has gone up from 14% in 2000-2002 to 18% in 2011-2013. These figures are somewhat lower than the overall shares of foreign R&D spending. However, patent data allow for a more detailed analysis of inventor countries, and these provide data for a number of emerging countries in particular. While only 10% of foreign inventors in German firms came from emerging countries in the earlier period, their share has been increased to 20% in 2011-2013. Inventors from China and India played an increasingly strong role. We also observe quite a strong growth of inventor locations in the Czech Republic, in Hungary, Poland, Turkey and Romania, which corresponds to typical outsourcing locations for German manufacturing firms.

Japanese multinational firms have moderately increased their R&D spending, and this corresponds to a foreign inventorship ratio of 4.2% resp. 4.8% in the two consecutive periods. The former strong dominance of the U.S. as inventor location (with 57% of all foreign inventors in Japanese firms) has become somewhat reduced to 35% in 2011-13. Meanwhile, inventors from the EU have increased their share from 35% to 46% in 2011-13. Similar to trends observed for U.S. and European firms, Japanese multinationals have turned their attention to new inventor locations in emerging countries. The share of foreign inventor locations in emerging nations increased from 9% to 20%. China in particular has become very important as inventor location for Japanese firms. Other relevant inventor locations for patents filed by Japanese firms in 2011-13 are Singapore, South Korea, Thailand, Taiwan and India. These developments just describe overall structural changes, but this instrument of host-country patenting allows for much more detailed investigations of trans-border inventor activities for different patent classes, as well as for specific corporations.

7 Conclusions

Our paper has analyzed major trends and structural changes related to technology and innovation management for the period 1995 to 2018. We have seen a persistent increase in the globalization of the R&D function and a greater diversity of target countries for new R&D locations. Even though it is hard to predict future courses in periods of growing political instability, the globalization of R&D will most probably go on during the period 2019 to 2030. Long-term megatrends like climate change, urbanization and new mobility must be addressed from a global perspective, and the appropriate technological and social solutions need to be developed and implemented in many countries simultaneously. The global footprint of innovation activities will be extended and we will see a proliferation of new uprising nations that play an increasingly important role. Sometime during the next decade, China will surpass the United States in terms of GDP as well as R&D spending. Other emerging nations like India, Brazil, Indonesia, Taiwan and Malaysia will follow high-tech development strategies. It will be interesting to monitor country-specific processes of linking science and technology, human capital formation and R&D growth. A key issue will be whether catch-up nations are able to grow beyond the so-called middle-income trap and whether these countries can implement a sustainable growth path.

There are still some white spots in our studies on global R&D. We know quite a lot about multinational corporations active in advanced OECD countries. There are still not enough

studies on business R&D and the role of multinationals in emerging nations. Published data on R&D expenditures are available for inward R&D investments, but rather sketchy for outward R&D investments, and particularly for R&D flows to emerging countries. And even though multinational firms from China, India, Taiwan and many other emerging nations are increasingly active in global markets, the role of foreign R&D within these firms is not well documented. Complementary data sources as outlined in section 6 could be used to monitor inventive activities and patenting within these newly emerging multinationals. And it would be interesting to combine different data sources linking R&D spending patterns with patent as well as publication data.

Innovation research also requires a combination of analytical and appreciative research. Publication imperatives and scientific ranking procedures may have led to an overemphasis on quantitative studies using large data sets. Technology and innovation management in a global perspective would certainly benefit from a mix of research methods combining different types of quantitative data, as well as field studies, expert interviews, and solid case research. Cornelius Herstatt and his fellow researchers at Hamburg Institute of Technology were always promoters of such comprehensive studies of innovation.

We also need more insightful studies on the role of foreign lead markets, the characteristics of lead customers as well as the influence of lead regulation. Through which practices are firms able to absorb relevant knowledge and how do they manage to transfer novel practices across countries? The examples of lead markets in Japan, India and South Korea were addressed in recent studies, but could certainly be enriched through intra-organizational studies of learning and innovation within firms. The concept of frugal innovation in driving markets like India and China is such a case. The effectiveness of frugal innovation would require that multinational companies are able to transfer design rules and engineering practices across different locations. How can firms in Europe effectively use their counterparts in India and China, and build powerful global development teams that launch products for growing world markets?

Effective cross-country learning strongly depends on the mobility of people and on shared understanding across cultures. This has been facilitated through the globalization of university education. More recently, we have many students that complete their bachelor studies in one country and then continue to study for a master's degree in another country. In some cases, Ph.D. studies and post-doctoral activities are later continued at a third location. Global master programmes like the one implemented at Hamburg Institute of Technology facilitate such multi-cultural and multi-disciplinary career-tracks. Many of these young scholars are interested in case studies and in experiences on the global management of technology. They are also important contributors, since students writing bachelor, master as well as Ph.D. theses will help to extend the repository of knowledge on global innovation projects. Novel case studies involving describing TIM practices in a wider sample of countries and in new dynamic fields of technology are necessary to widen the scope of business and engineering education. In this sense, the research programme developed at Hamburg Institute of Technology during the last two decades will have a bright future during the coming decade.

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