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German-Sino collaboration in science, technology and innovation

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1 Introduction

Until recently Germany was the largest exporter of processed goods and commodities in the world. As an exporting country it has a natural international orientation and a need to keep itself open towards international markets, and international partners. In the year 2010 Germany was overtaken by China as the largest exporting country even of high-tech goods (see Figure 6). The Chinese ambassador to Germany recently summarized the commonalities of the two countries as being the largest "real economies" in the world. Furthermore, China had become one of the most important partners for German research institutions as well as for German industry collaborations. The Chinese market is and was very attractive to German companies. Vice versa, the German market, as the largest national market in Europe, is an attractive location for Chinese companies to set up R&D centers, to enter the European market, to acquire technologies, or more recently also to acquire Germany-based companies. The foreign direct investment from China has risen considerably in the recent years. In sum, the two countries have several things in common, have mutual interests, show some overlap and therefore competition, but – and this will be shown in the further course of this paper – have many opportunities and complementarities that foster the further exchange and will even deepen the collaboration between China and Germany in the future.

The German High-Tech Strategy 2020 that was released in 2010 currently sets the framework for the German science and innovation policy. It continues the core pillars and core philosophies of the former High-Tech Strategy released in 2006. This first strategy introduced means and measures to coordinate the decentralized innovation policies on the national level. Coordination of a number of departments involved in innovation policy making were the main and new contribution of this strategy (Bundesministerium fuer Bildung und Forschung (BMBF) 2006). While the former version was still technology and sector oriented, the biggest change of the High-Tech Strategy 2020 was the introduction of a mission orientation also in policy making – a perspective that was implemented in other parts of the innovation system even before (Bundesministerium fuer Bildung und Forschung (BMBF) 2010; Frietsch, Schubert 2012). This strategy uses a systems perspective and aims at reflecting the complexity of the innovation processes also in policy making and innovation funding. It formulates global challenges as the overall strategic goals. These big challenges are addressed in the so called demand areas, where it is not particular technologies or sectors, but technology and innovation based solutions that are supported and funded. The demand areas are: energy production and provision, mobility, communication, health, and security and safety. So instead of a technology or sector perspective it takes the solution or mission perspective. The basic idea is to move away from offering isolated technological solutions, towards an application and implementation of technologies. In consequence, also the commercialization- and application-oriented policies gained additional emphasis in the STI programs in Germany.

In addition and against this background, the Federal Ministry of Education and Research (BMBF) formulated a "Strategy of the Federal Government for the Internationalization of Science and Research" in 2008, applicable by all governmental departments – not only by the BMBF itself. This Internationalization Strategy today builds the basis for all science, technology and innovation collaborations with other countries. It provides the actors a rationale and sets the framework for achieving common goals. The Internationalization Strategy also allows for a common sense, in which cases international collaboration might not get the support of the German government or does not lie in Germany's interest in general.

So far, Germany or the BMBF do not have an explicit strategy for the cooperation with China. It is expected that in 2014 an update of the Internationalization Strategy for science and technology or more topical implementation rules will be published. One could then also expect that country-specific strategies or strategic goals and instruments are to be released as well.

Yet, different to some other countries, Sino-German scientific relations were very little influenced by political disturbances and especially not by many trade disputes since their formal establishment in 1978. So China and Germany are looking at rather stable and long term scientific relations.

This paper describes the current STI policies of the Sino-German collaboration from a German perspective. It starts with the policies and the actions on the governmental level. Section three tries to briefly depict the effective implementation and the outcomes of these policies and individual actions. It uses empirical data to describe the current status and the evolution of the Sino-German exchange in science, technology and innovation. Scientific publications and especially co-publications provide a sketch of the science collaborations. Patents and co-patents offer an indication of the technology collaboration as well as an assessment of the attractiveness of the (technology) markets. Finally, foreign trade data also offers a view on the industrial exchange. Profiles in all three dimensions convey a broad picture of complementarities and competition between China and Germany. Section four discusses and summarizes the findings.

2 Collaboration on governmental level

The Internationalization Strategy sets the framework for the international collaboration of public, but also private actors in STI. However, even before its release in 2008 several mechanisms and policies were at play that defined the international collaboration and provided the basis for international exchange, especially in science and technology. These are the Inter-governmental Agreement on Scientific and Technological Cooperation that Germany nurses with many international partner countries, among them also China. This agreement is signed and implemented by BMBF, usually with its counterpart ministry in the partner country. In the case of China this is the Ministry of Science and Technology (MOST). Since a few years, Germany and China also hold inter-governmental consultations, which resulted in another boost of the STI collaboration between these two countries.

This section briefly introduces these three policy frameworks for the Sino-German STI collaboration and discusses the added value of each of these columns for the current and future exchange. It starts with a short overview of the evolution of the Sino-German STI collaborations and provides a first idea of an overall spirit of the collaborative policies.

2.1 The evolution of STI collaborations with China

Today Germany is the most important trade partner of China in the Euro-Zone. As China is investing heavily in its science, technology and innovation system, especially through funding and education of personnel, it gains impact in the international research arena and therefore is becoming an increasingly strong partner for Germany in STI.

When the first research and technology collaborations with China started, the relation was very much shaped by the differences in the economic development level of both countries. China was in the role of a developing country, while Germany offered much assistance and technology transfer as one of the most industrialized countries in the world. A lot of projects were supporting the development of China in the science and technology arena, addressing global challenges and areas of basic needs, like water technologies and infrastructure, energy supply, or agriculture.

In 2008 the German Ministry for International Cooperation, in charge for international development aid in Germany, announced that China has been removed from the list of countries to receive development aid. So China is not seen as a developing country anymore and is treated like any other developed country since. Traditional instruments of developmental aid were abandoned, while the technical cooperation still continued until summer 2011. By then, also the technical help for China was stopped; mainly because by the time China has become a huge contributor to development aid itself, especially in Africa. At that time, the German government decided that its development aid should be directed to countries far less developed than China.

This change of China's status had direct effects also for other policy activities and governmental departments, among them the Federal Ministry of Education and Research (BMBF) as well as the Ministry of Economic Affairs and Technology (BMWi), recently renamed to Ministry of Economic Affairs and Energy, who are the main actors for science and technology policies in Germany – apart from the technology- or specific task-oriented departments like the Ministry of Environment and Natural Resources or the Ministry of Traffic and Infrastructure, who both have minor budget appropriations for S&T. Since then, China was treated as a partner on eye-level in all aspects, including the expectations on financial contributions to projects and activities of mutual interest. For example, in publicly funded R&D or S&T projects the Chinese side is expected to pay its own researchers and make its own financial contributions, while before that it was possible to apply for travel budget, daily allowance etc. at the BMBF for Chinese researchers visiting Germany.

2.2 BMBF strategy for internationalization of S&T

The German Ministry of Education and Research (BMBF) had formulated the first internationalization strategy for science and technology called "Strengthening Germany's role in the global knowledge society" on behalf of the Federal Government in 2008. There were four columns of international collaboration in science and technology defining the goals and targets of this strategy: 1) Strengthening research cooperation with global leaders; 2) International exploitation of innovation potentials; 3) Intensifying the cooperation with developing countries in education, research and development on a long-term basis; 4) Accepting international responsibility and mastering global challenges. While the columns 3 and 4 are rather general and are also motivated by additional political goals in the context of development aids, the first two columns directly focus on research and innovation. The first column deals with the international collaboration in science, while the second column is concerned with the collaboration and exchange in technology production, applied sciences and especially with the company and firm level. The first column defines Germany's openness in both directions – inward and outward research cooperation. The German science system seeks collaboration with the worldwide best researchers in particular areas. Furthermore, Germany also strives to become an attractive location for international scientific talents to move to Germany, claiming to be one of the best science systems in the world. The second column encourages German companies to link with international leaders in the innovation chains. This is, for example, done by strengthening national competence networks by international collaboration, encouraging German mid-tier companies to systematically enhance their value and innovation chains by international competences, or also to use international platforms and programs to enrich the national knowledge creation processes.

The basic idea – being permeable in both directions – secures the research and innovation location in Germany as well as helps to tackle global challenges. The role of the political system is to foster and to mediate the engagement of the scientific and economic actors in the innovation system. The Internationalization Strategy formulates this very precisely: "The political community will coordinate and focus political activities beyond departmental borders in order to increase Germany's strength in the global knowledge society" (Bundesministerium fuer Bildung und Forschung (BMBF) 2008).

2.3 Inter-governmental Agreement on Scientific and Technological Cooperation between BMBF and MOST

In general, the Sino-German Scientific and Technological collaborations are based on the Inter-governmental Agreement on Scientific and Technological Cooperation of 9th October 1978. For the first twenty years the cooperation was focused on visits from individual scientists. From the 90s onwards, project related cooperation gained importance. While project cooperation is still the dominant form of collaboration, institutional collaborations have been added since the new millennium, e.g. the establishment of joint institutes or research groups.

The Joint Institute for Information Technology between Fraunhofer and the Aeronautics and Astronautics University in Beijing, as well as the CAS-MPG Partner Institute for Computational Biology in Shanghai are maybe the best examples, and have both been strongly supported by BMBF and MOST. Most recently the ministries put more emphasis on the inclusion of companies in its activities, a trend which is slowly followed by MOST[4]. This is a traditional policy tool in Germany already in action since the late 1990s. The so-called 2+2 project principle was also transferred to the international collaboration policies in S&T with China (and several other countries), which requires that public research as well as industry partners from both sides are involved. Each country funds its own researchers and in some cases even industry, while it is also expected at least on the German side that the German industry partner also contributes financially to the project – either directly or indirectly via own labor input. For several reasons, among them cultural and institutional differenced in China, this policy tool is not among

4 http://www.internationales-buero.de/de/1279.php

the most successful in Sino-German collaboration. IPR issues and often a lack of a long-term trustful relationship – as the reliability of contracts and institutional settings are different in China and Germany – are additional hampering factors. Besides, meeting the expectations of at least four different partners in such projects has proven to be a rather challenging task, as both, company and research partners might have very diverging interests in such collaborations.

Based on the Inter-governmental Agreement on Scientific and Technological Cooperation, the German and the Chinese ministries in charge of S&T (MOST and BMBF) have established a joint committee for science and technology ('WTZ committee'), which meets every two years. As the cooperation has become rather broad and touches nearly all scientific topics, the joint committee has established topic focused subgroups, the so called steering committees. Steering committees also meet every two years, usually before the meeting of the joint committee in order to report their results to the joint committee. The following steering committees exist:

- Biotechnology
- Geosciences
- Information technology, micro-systems technology
- Protection of cultural heritage
- Laser and optical technologies
- Materials science, nanotechnology
- Marine science and technology
- Environmental technology and ecology
- Production research

Besides these topics, also projects and activities in the fields of health related research, biodiversity, engineering, physics, chemistry as well as social sciences, cultural studies, law, economics etc. are supported.[5]

The role of the WTZ meetings can be seen as being an important coordination instrument for the bilateral cooperation. With its federal structure, especially regarding higher education in Germany, there is no other central structure that has this function. The process on the German side varies from steering committee to steering committee, but in general the ministry gathers information about all BMBF funded projects that have Chinese partners and invites some of the actors to join for the meetings. The Chinese

5 http://www.internationales-buero.de/de/1279.php

ministry does the same and invites their key players to the meetings as well. These steering committee meetings are then used to report about the current collaborations in STI, but also to discuss new initiatives and make sure, that both governments agree with them. This gives both ministries the opportunity to get more detailed information or raise their concerns towards the scientists in a stage where they still design their project ideas. It also helps to understand the priorities of each ministry in science and technology and avoids costly activities on one side, which might then find no response on the other side.

For a few years now the German side aims at establishing joint calls, which could be discussed and agreed in these steering committees, yet so far the internal processes of granting and evaluation of calls in both countries have been preventing them[6].

German-Chinese Year of Science and Education

In 2009/2010 BMBF and MOST as well as MOE (Ministry of Education) held the first 'German-Chinese Year of Science and Education' with more than 150 workshops, seminars and conferences. The week long events in Wuhan and Shenyang, for example, drew more than 300,000 participants each. The official webpage of this "Science Year" was visited more than 2.3 million times. In parallel, more than 45 German Universities celebrated a 'China Week' in the summer term 2010 and BMBF funded projects with China with a total budget of more than 2 million Euros.[7]

This "Science Year" can be seen as one of the strongest activities to promote the scientific and educational cooperation of both countries to a broader and more public audience. The exhibitions in China attracted many visitors who might have otherwise had no contact with German science and technology. In parallel, the China weeks at the German universities reached out to many students still unfamiliar with China.

2.4 Sino-German intergovernmental consultations

The German government has only a small number of cooperation partners, with whom they hold so called intergovernmental consultations. These consultations usually include the highest government leaders of each partner and include almost all ministers

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6 The only exception as to our knowledge from this being the joint calls from the Sino-German Center for the Promotion of Sciences, a joint venture between the German Research Foundation DFG and the Chinese counterpart NSFC (http://wwwsino germanscience.org.cn). Applications for workshops, seminars, conferences and projects are jointly evaluated.

7 http://www.bmbf.de/de/818.php

(Secretaries of State). These consultations allow a more coordinated cooperation and increase transparency of the ministerial goals among the governments. Besides, it shows a very high level of political importance of the respective partner for Germany and also vice versa. As by March 2014 Germany has established intergovernmental consultations with: Italy (29 meetings so far), Spain (24 meetings), Russia (‘Petersburger Dialog’, since 2001, 13 meetings), Poland (11 meetings), Israel (since 2008, 5 meetings), India (since 2011, 2 meetings), China (since 2011, 2 meetings), and with the Netherlands (since 2013, 1 meeting so far).

In June 2011 the first intergovernmental consultations between China and Germany opened a completely new chapter in their relations. China is one of the few countries with which Germany has such high level meetings, which include the German Chancellor Angela Merkel and then Chinese Prime Minister Wen Jiabao as well as more than ten Secretaries of State on each side. Since 2004, Sino-German relations have been described as a "strategic partnership in global responsibility", and the intergovernmental consultations have supported this view.

These meetings have also intensified the science and technology cooperation between both countries, especially through specific memorandums of understanding. BMBF has signed with the Chinese Ministry of Education (MoE) as well as the Ministry of Science and Technology (MoST) a total of five Joint Declarations on Education and Research.[8]

These declarations are the following:

1. Joint Statement on the funding of extensive co-operations and the establishment of a strategic partnership in higher education
2. Joint Statement on the establishment of a German-Chinese alliance for vocational education and training (VET)
3. Joint Statement on the German-Chinese Life Sciences Innovation Platform
4. Joint Statement on the Establishment of a German-Chinese Innovation Platform
5. Joint Statement on the German-Chinese Research and Innovation Programme "Clean Water"

While there were already bilateral WTZ steering committees for life sciences (biotechnology) and clean water (environmental technology and ecology), the agreement on establishing a joint innovation platform was a new initiative at that time and brought new players on both sides to this cooperation. This can be seen as a development that was, on the one hand, bottom up, as the collaborations between the innovation re-

8 http://www.internationales-buero.de/de/1279.php

searchers in both countries were growing stronger year by year. On the other hand, it was a top-down process due to the growing demand in both governments to better understand the mutual innovation system, innovation policies, and innovation mechanisms in order to strengthen the science, technology and innovation collaboration between China and Germany.

The life science joint steering committee has been existing for a rather long time already and the research collaborations between the two countries were also supported by special DAAD programs funding the exchange of scientists in this field as well as establishing bilateral joint research groups.[9] This long-term cooperation has then led to the joint agreement. These scientific collaborations were highly visible as a matter of fact that the six agreements were signed during this particular intergovernmental meeting. The same can be said for the clean water agreement, where a long-term collaboration already existed beforehand.

Besides the increase in visibility of these STI activities, the intergovernmental meetings almost guarantee that the agreements are indeed implemented. This has been shown in the second meeting, where the results from the first year of the implementation have been reported in front of all participants.

The second round of German-Chinese intergovernmental consultations was held in Beijing on 30th August 2012. A total of 17 agreements were signed, the majority on economic topics. From the view of the Ministry for Education and Research, the main achievements since the first meeting were presented in all five areas where joint agreements had been signed in 2011. In addition, LED technology and oceanography were discussed as new topics to be included in the Sino-German science and technology cooperation. New agreements were signed in these two areas. The third intergovernmental consultations are to be held in Germany in 2014.

2.5 Summary of STI policies

So far it can be summarized that the long-term collaboration in STI between China and Germany was mainly managed by the two ministries MOST and BMBF. With the change of the status of China and acceptance as a developed, industrialized country, and especially with the major role of STI in the intergovernmental consultations on the highest levels of the recent years, the policy support and the visibility of the political as

9 http://www.kooperation-international.de/detail/info/daad-foerdert-deutsch-chinesische-forschungsgruppen-in-der-biotechnologie.html

well as the scientific actions is extraordinary. This raises high hopes for the future and provides confidence in achieving the high aims.

The German Government's internationalization strategy for science and technology provides the overall framework also for the Sino-German collaboration. The two main pillars relevant for the collaboration with China since its change of status to a developed country in 2008 are "Cooperation with the best" and "Raising international innovation potentials", where the former mainly defines the collaborations of public research and universities, while the latter targets at industrial collaborations (with political and scientific support). It needs to be stressed at this point that the overall STI policy in Germany is of a rather interventionistic nature and follows at least implicitly the Innovation Systems (Edquist 1997; Lundvall 1992; Nelson 1993) heuristic. STI policy in Germany aims at providing the best foundations and seed-beds for science, research and also development. State intervention is reasonable and not only acceptable, but even expected where market failures are at play or overall social interests – among them securing jobs by raising/keeping the high level of scientific and technological competitiveness of Germany as a whole – or social needs like energy or environment require governmental action. This is mainly on the level of science and pre-competitive research, as WTO and European regulations prohibit direct support and funding of market and competitive action. Therefore, the overall spirit can be characterized as nursing a rather open innovation system and especially an open science and (public) research system. The two pillars of the internationalization strategy reflect this overall spirit.

3 Empirical evidence on the outcome of collaborations

This section tries to shed some light on the real or effective collaboration activities and the collaboration patterns. Empirical evidence is presented that allows an assessment of the past and current status of the STI collaboration between China and Germany, not only for public research and public policy, but also for industry and market activity. Scientific publications and international co-publications – defined as papers with authors from institutions located in at least two different countries – provide the data to assess the public research systems. Transnational patents (Frietsch, Schmoch 2010) – defined as patent applications at the EPO or via the PCT procedure at the WIPO, thereby focusing on internationally oriented IPR protection – as well as patent profiles at the State Intellectual Property Office (SIPO) allow a characterization of the industrial activities and the industrial collaborations. Export data on high-tech goods and commodities (Gehrke et al. 2013; Legler, Frietsch 2007) – defined by their mean R&D expenditures over turnover beyond a level of 2.5% – show commonalities and competition in certain fields as well as the market attractiveness. FDI data supports the assessment of this latter dimension.

3.1 Scientific collaborations between China and Germany

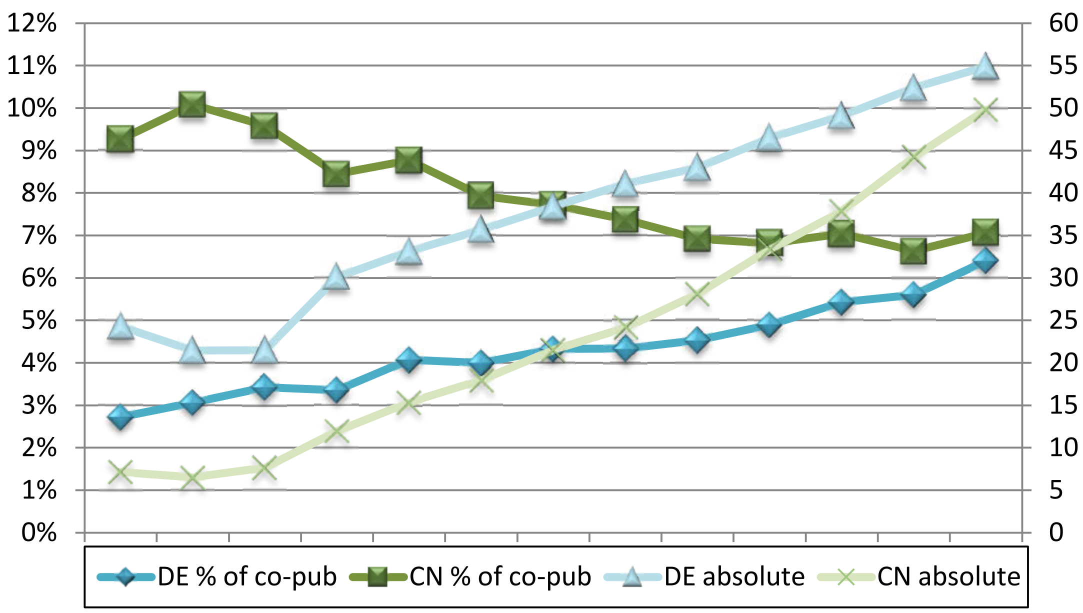
There has been scientific exchange between China and Germany over many decades that slightly accelerated after the Chinese opening-up in the late 1970s, but was boosted in the late 1990s and early 2000s, when the new reforms and the further opening of the Chinese system occurred. One of the first collaborators in the basic natural sciences were the Max-Planck Society and the Chinese Academy of Sciences, starting with exchange of scientists as early as 1974. Over the time, guest laboratories, partner groups and in 2005 the first partner institute followed. In the area of applied sciences, the Fraunhofer Society also started collaborating with the Chinese Academy of Sciences in 1980. Similar to basic sciences, scientific exchange was the dominant mechanism in the beginning, followed by a more proactive presence with a representative office in 1999 and joint institutes in 2002. Since then, several agreements with national as well as regional actors have been signed and the collaborations on the project level have increased considerably, especially since 2009.

As the universities in Germany are under the responsibility of the regional governments, BMBF does not have special measures for the university collaboration with China in place, nor is it possible to find a general overview of where the German universities collaborate with China. Yet, through the normal competitive funding instruments of BMBF, the universities do strongly participate in the Sino-German collaboration and there is a vast number of joint projects and scientific exchange. Today all key scientific actors in Germany are collaborating with China on many different levels and through different schemes and mechanisms.

China's scientific and research capabilities quickly caught up in several disciplines and fields especially in the second half of the first decade in the 2000s, for example in the fields of material science, genetics, chemistry, or physics (Frietsch et al. 2008). Nowadays, several Chinese research institutions are on eye-level with the top research institutions worldwide in a number of scientific areas. However, there are still some fields that do not belong to the particular strengths of the Chinese science system (Commission of Experts for Research and Innovation (EFI) 2012; Edler et al. 2011; Puuska et al. 2014; Schmoch et al. 2012). As a matter of fact, the collaboration between Chinese and German researchers intensified considerably in the past years in absolute terms, but lost some of its relative meaning from a Chinese perspective. The internationalization of knowledge and the intensification of collaborations between national and especially international institutions is a well-known and well elaborated phenomenon of the last decade or so occurring in most science oriented countries (Edler et al. 2011; Michels et al. 2013). This also holds for China and Germany.

Figure 1 depicts the absolute number of international co-publications by China and Germany (right axis) and also the shares of Sino-German co-publications in all international co-publications (left axis) of the respective country. The absolute number of publications originating in China is meanwhile much higher than that stemming from German authors. In 2012 Chinese authors published about 274.000 articles, which is more than twice the number of German publications (113.000). The absolute number of international co-publications is, however, almost the same and even higher in Germany. Both countries have enormously increased their international co-publications in general as well as their joint publications, which increased from less than 700 in the year 2000 to more than 3,500 in 2012.

Figure 1: Number of international co-publications by China and Germany and shares of the respective partner in total international co-publications, 2000-2012



Source: Elsevier – SCOPUS; Fraunhofer ISI calculations.

As Table 1 shows, the role of Germany has declined in the portfolio of international collaborations of China. Taking the German perspective, China occurred in the list of the top 10 collaborating partner countries in 2012 for the first time.

Table 1: Top 10 collaborating partner countries of China and Germany

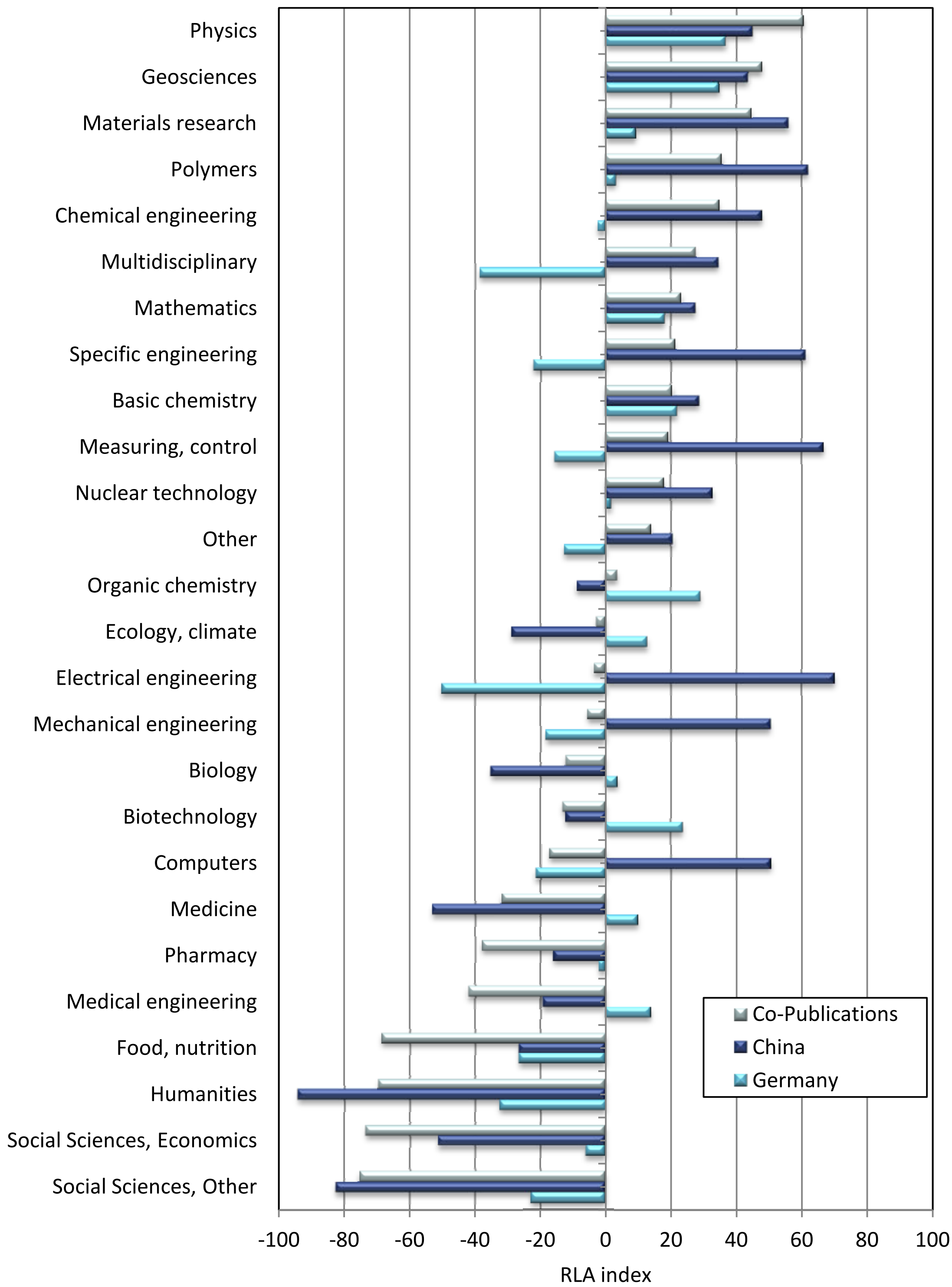
	China			Germany		
	2000	2006	2012	2000	2006	2012
1	US	US	US	US	US	US
2	HK	HK	HK	GB	GB	GB
3	JP	JP	GB	FR	FR	FR
4	DE	GB	JP	RU	CH	CH
5	GB	DE	AU	CH	IT	IT
6	CA	CA	DE	IT	NL	NL
7	FR	AU	CA	NL	RU	ES
8	AU	FR	FR	JP	ES	AT
9	SG	SG	KR	AT	AT	CN
10	KR	KR	SG	ES	CA	CA

Source: Elsevier – SCOPUS; Fraunhofer ISI calculations.

It is interesting to note that the co-publications mainly occur in areas of relative strengths or intensive research activity in China, whereas the profile of mutual collaboration between China and Germany is less pronounced in the particular areas of German strengths. Figure 2 displays the publication specialization profile of the Chinese and the German science system as well as the pattern of co-publications compared to all co-publications in the world. Values above zero indicate an activity level above the worldwide average and values below zero indicate fewer activities than would be expected based on the distribution of scientific fields in the world, respectively. This indicator allows the assessment of the fields beyond size and scale effects. Especially in basic research fields like physics, mathematics, or basic chemistry, where both countries show a prolific portfolio, the collaboration is most intensive. Furthermore, a rather intensive collaboration is also visible in some more applied-oriented fields, where China reaches an outstanding profile, but Germany is not that much active. This includes material science as well as polymers. On the other hand, the collaboration between the two countries is less remarkable in such areas that do not belong to the German scientific strengths, like electrical engineering, computers, or even mechanical engineering. Exceptions are biology, biotechnology, medical engineering or medicine. In this area, however, a particular policy was started in 2011 with the Sino-German Innovation Platform Life Sciences (see policy discussion) to overcome this deficit. The relative weakness of mechanical engineering in Germany might be astonishing against the background of a strong industrial position on national and international markets in this field. One explanation is that the data source misses a large number of German engineering publications that are published in other sources – mainly national journals. It also misses the conference proceedings here, which are a substantial part of the science communication, but which were not taken into account here. This is even more the case for electrical engineering and computer sciences. Finally, it is indeed the case that – compared to the scientific activities in basic research fields – the scientific activities in mechanical engineering play a minor role in Germany. The majority of science and especially research and development is conducted in companies or in collaboration with companies and is therefore not published at all.

To summarize the science collaborations between China and Germany, one could say that it took a positive development over the recent years and is especially pronounced in basic science areas, in fields where China's researcher have already reached a world-class level and where German researchers offer particular scientific capabilities. So it seems that the collaboration follows a mutual benefit strategy.

Figure 2: Revealed Literature Advantage (specialization profile) of China and Germany, 2010-2012



Source: Elsevier – SCOPUS; Fraunhofer ISI calculations.

3.2 Technological collaborations and market action abroad

As was shown above, the collaboration started with basic research activities and later on entered into more application-oriented activities. This, first of all, holds for public research organizations and universities. On the other hand, several German companies had been active on the Chinese market for many years and even decades, but only recently started to enter into research and collaboration activities in China, setting up "real" R&D centers. In the mid 2000s already a large number of more than 750 centers and labs were officially listed in the statistics, while only a few of them were effectively conducting R&D (Schwaag Serger 2006). This was also true, even until recently, for the majority of German companies. Collaboration between science and foreign industry was also established several years ago, but with an increase of the "real" R&D activities in China and a catching-up of the scientific capabilities in several scientific fields, the quest for collaboration partners became more serious. Since only a couple of years – also driven by a worldwide trend for worldwide knowledge sourcing – the companies have intensified their scientific and technical exchange not only with the ivory league of Chinese research institutions and universities, but they also more and more regionalize and diversify their knowledge networks. One of the reasons for this strategy is that the premier league of Chinese institutions and especially of Chinese researchers is supposed to be over-committed in collaboration agreements. Furthermore, collaboration between science and industry – similar to collaboration between industry and industry – highly relies on trust and experience. If there is an over-commitment with international and also national industry partners, the collaboration with one particular partner might not be highly valued. In the second tier institutions in the provinces it might still be easier also for Germany companies to become such a valuable industry partner. And these second tier institutions are meanwhile excellent or at least good enough to partner with, especially as China is not the only knowledge source for multinational companies worldwide.

The fact that Chinese researchers meanwhile act on a scientific level like researchers in any other country – and some even beyond the worldwide average – leads to the fact that international companies also from Germany seek more collaboration partners in China. So the increase in collaboration between national science institutions and foreign industry in China is not only driven by the demand side, but also by the supply side. And the science system is meanwhile not only capable of providing sufficient scientific competences, but also the administrative and professional capabilities can be found to handle such international research collaborations in a satisfying manner (for the companies). In this regard, the Chinese scientist that study abroad and return to China have been of indispensable value for collaborations, as they often become the core of these collaborations, even with partners from countries they haven't studied in.

The other way around, Chinese companies conducting research in Germany are still the exception and not the rule. Huawai, Haier, or Sany, for example, have research facilities in Germany. Many more Chinese companies have representatives or sale posts in Germany, using the geo-strategic position and the well-equipped infrastructure as a hub to the European market.

According to data provided by the Worldbank, about 16-17%[10] of worldwide FDI targeted China in the recent years. A recent study[11] by CDRF and PWC, surveying and interviewing a number of CEOs of multinational companies, concludes that China will be an attractive location for FDI also in the future, though it might take time to let the reforms and adaptations of the system take effect. However, it also stresses that the pace of liberalization, the non-compliance with international standards like some of the WTO rules or effective IPR protection are seen as hampering factors also in the future. However, with China signing the TRIPS agreement in 2001, it became an attractive destination for FDI also from Germany, although some large companies like Volkswagen or BASF were investing in China even before (Chen et al. 2014). According to the data used in Chen, Lan and Schüller 2014, based on statistics provided by the National Bureau of Statistics (NBS) and MOFCOM, German investment inflow amounted to more than 1.1 billion USD in 2011, adding to a stock of almost 20 billion USD.

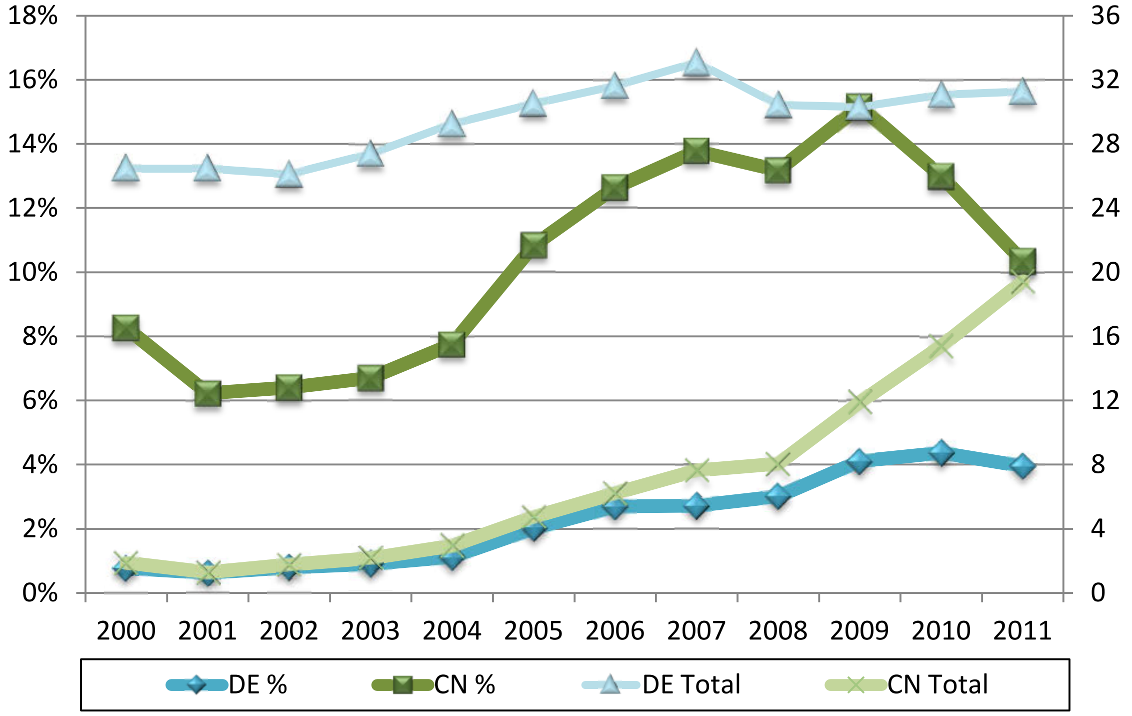
The results of the R&D activities within multinational companies can be approached when international co-patents are analyzed. However, in most of the technological fields the scientific gap between Chinese and German companies is still large. So effectively, it is German (or foreign) companies who are responsible for the majority of co-invented patents of Chinese and German inventors.

The Chinese patent law with its reform in 2009 (and the implementation rules released in 2010) might have had a negative impact on the R&D activities in China. The layout and the impacts of the IPR system are discussed elsewhere (Frietsch et al. 2012a; Frietsch, Wang 2007), but what is reported by companies and spectators of the patent system is that the mandatory priority filing with the SIPO of any invention made in China, together with a necessary allowance by the Chinese authorities to file this invention abroad, a great distortion and especially uncertainty was introduced mainly hitting foreign multinational companies.

10 Source: own computations based on Worldbank: http://data.worldbank.org/indicator/BX.KLT.DINV.CD.WD, last visited: 25th Match 2014.

11 Source: CDRF, PWC (2013): Choosing China: Insights from multinationals on the investment environment; http://www.pwccn.com/home/eng/cn_dev_rpt_2013.html, last visited: 25th March 2014.

Figure 3: Absolute number of Transnational* patent applications and shares of Sino-German co-patents in high-tech fields, 2000-2011



* Transnational Patents are patent families with at least a family member at the EPO or via the PCT procedure at the WIPO (Frietsch and Schmoch 2010).

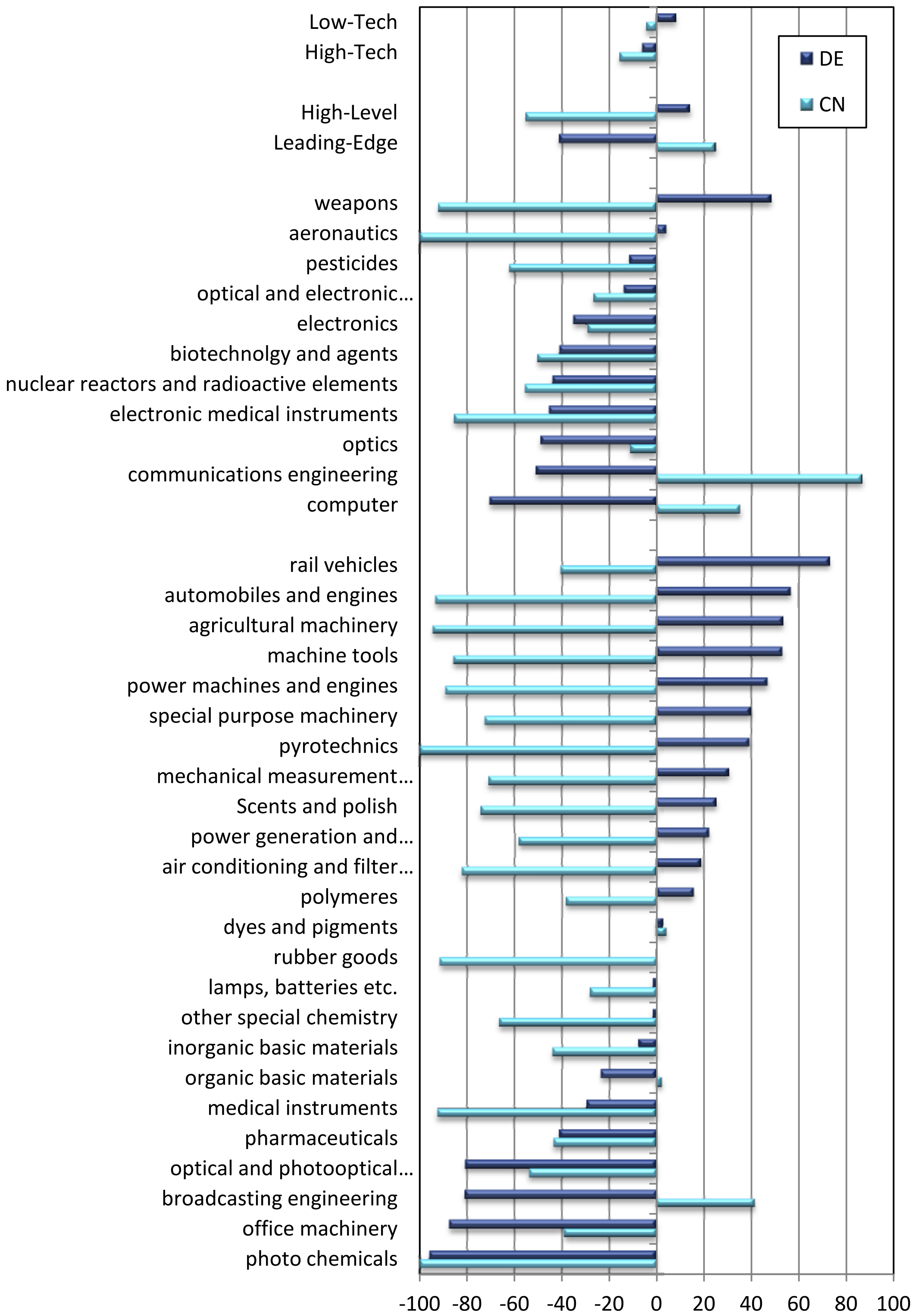
Source: EPO – PATSTAT; Fraunhofer ISI calculations.

The market perspective is depicted in the patent filings in the respective foreign market. Chinese filings in Europe and in Germany have been growing considerably (Frietsch et al. 2012a). China caught up very quickly and is meanwhile filing more patents in Europe than France or the United Kingdom, for example. China, on the other hand, has been an attractive technology market also for German companies, especially after WTO accession in 2001. The numbers of foreign patent applications to the SIPO were higher than the number invention patents filed by national applicants until about the priority year 2006 (Frietsch, Wang 2009). Several Chinese policies have been successful in boosting not only the foreign or PCT applications by Chinese applicants, but also the national applications to the SIPO, meanwhile outnumbering the foreign invention patent filings by more than a factor 3. The foreign applicants have also been able to increase the absolute number of annual patent applications, but they are strongly outperformed by the growth of Chinese invention patents. The patent statistics for foreigners show that China is still an interesting and growing market for technologies. This, again, also holds for German companies or is even more true for Germans as the exports as well as the direct investments are mainly done in technology-oriented areas and manufacturing in general, where the German business model highly relies on technological advantages and high quality technological solutions. The exports in high-tech areas are clearly preceded by patent applications, thereby opening and securing these markets (Frietsch et al).

The Chinese and German patent portfolios at the European Patent Office (EPO) are depicted in Figure 4. Given the overall increase in the absolute number of patent applications to the EPO by Chinese inventors, the profile is rather limited and selective. As can be seen, China focuses on leading-edge technologies – these are very R&D-intensive areas with expenditures of more than 7% over turnover – driven almost only by patent filings in communication technologies and computers, as well as some activities also in optics and optical electronics. In the medium-tech fields (high level technologies), it is only broadcasting technologies that reaches out in the Chinese profile. Some average activity is also visible in organic materials and dyes and pigments.

Germany, on the other hand, has almost no prolific activity in the leading-edge fields, while it is strongly oriented towards certain fields of the high level technologies, namely transport (rail vehicles and automobiles), machinery, as well as some areas of electrical engineering (power machines, power generation, lamps etc.) as well as average engagement in some parts of chemistry.

Figure 4: Revealed Patent Advantage (RPA): Chinese and German patent portfolios at the EPO, 2009-2011



Source: EPO – PATSTAT; Fraunhofer ISI calculations.

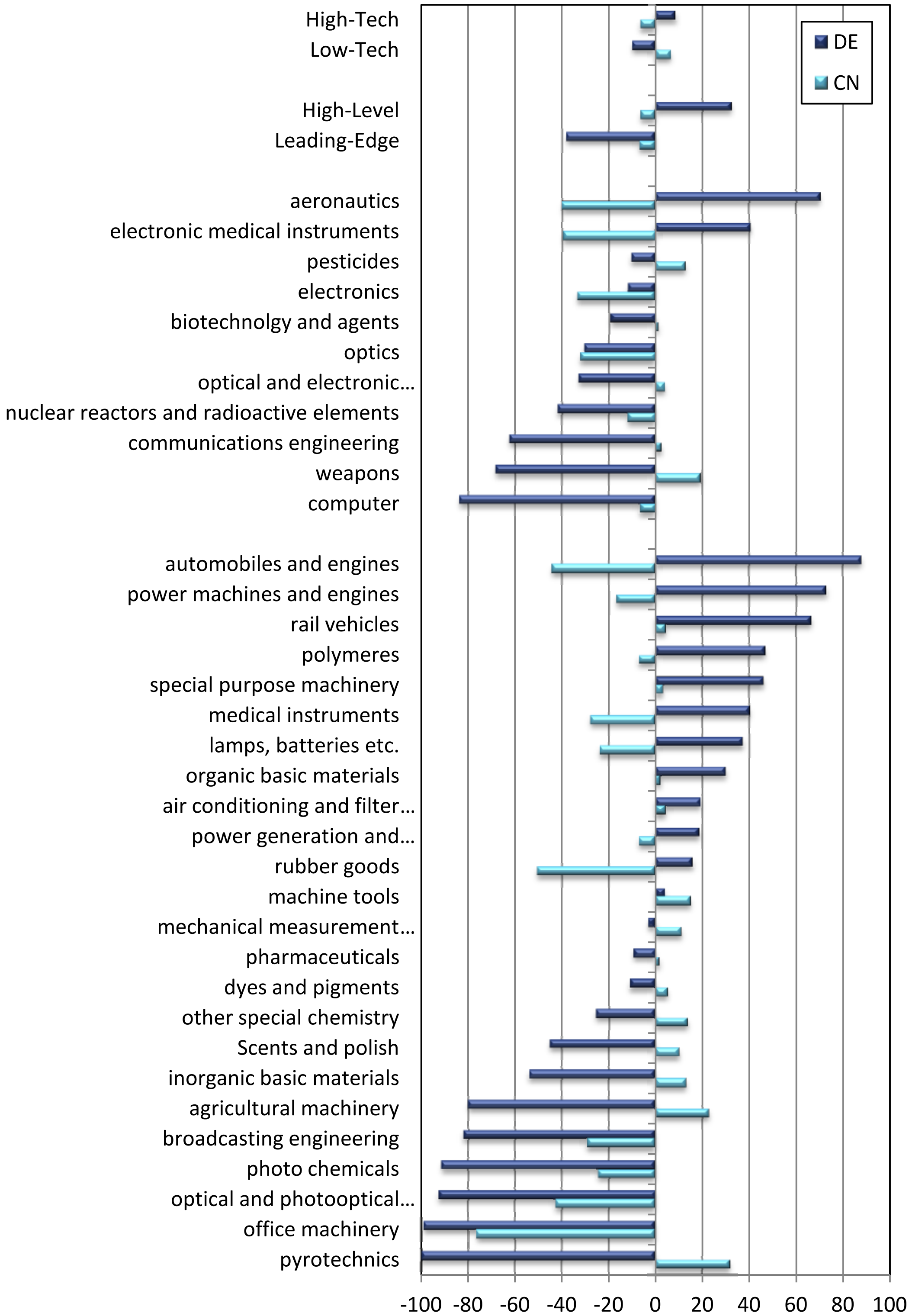
The technology portfolios of Germany and China at the SIPO are displayed in Figure 5. China has, of course, a clear home-advantage at the SIPO and therefore shows a broad array of technological activities. This is the home market for Chinese companies and Chinese inventors, which they know best, can access most easily and where the distribution networks are well established. German companies, on the other hand, are alien to the Chinese market, even if they are very active and very experienced in China. It will always be a foreign market where the action and activity is selective and purely market and application oriented – and not necessarily a market to generally secure basic technological achievements. This makes the two profiles hardly comparable. The same also holds for the Chinese and German activities at the EPO. However, for China the SIPO analysis allows an assessment of the overall technological profile and for Germany it provides a picture of the technology market in China from a German perspective.

At home, Chinese inventors are specialized on several areas of chemistry as well as – to some extent – on certain kinds of machinery. The internationally visible strength in ICT and electronics is not so obvious in the patent portfolio at the SIPO. Obviously, also other countries – among them the USA, Japan, Finland or Sweden – are focusing some of their technological activities in China also on ICT and electronics, thereby competing with national actors.

Germany, on the other hand, arrives in China with a profile that resembles the profile at the EPO, but seems to be more pronounced in some fields. Transport (rail vehicles and automobiles) are again the most outstanding areas in the German profile, accompanied by several sub-fields of machinery or mechanical engineering. Polymers as well as lamps and batteries are also focal points of the German technological activities at the Chinese market. In addition to these fields that were mostly also visible in the profile at the EPO, in medical instruments and electronic medical instruments the Revealed Patent Advantage of Germany is outstanding. This latter effect is devoted to a general international competition in these fields and a specific attractiveness of the Chinese market for medical instruments, also shaped by the fact that Chinese companies are hardly competitive with their technological offers (Frietsch et al. 2012a; Frietsch, Meng 2010).

In sum, the Chinese and the German technological profiles at the EPO as well as at the SIPO are more complementary than competitive, which is one of the foundations for fruitful and successful collaborations. In addition, specific mutual market attractions make the two countries further hone their profile abroad – in the field of ICT for China in Europe and in the field of medical instruments for Germany in China – which is again no harm to the STI relationships, as these are also not the core competences of the respective partner.

Figure 5: Revealed Patent Advantage (RPA): Chinese and German patent portfolios at the SIPO, 2009-2011

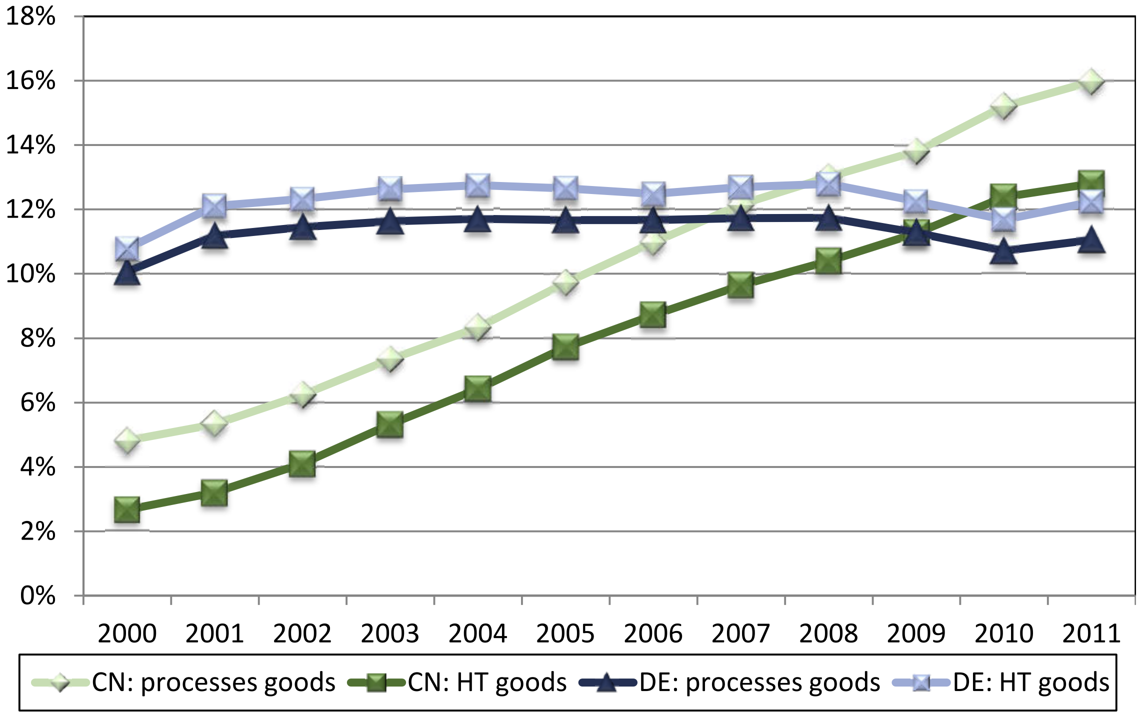


Source: EPO – PATSTAT; Fraunhofer ISI calculations.

3.3 The largest exporting countries in the world

These patent portfolios are also resembled in the export portfolios of China and Germany (Figure 7). Although both countries are the largest exporting economies in the world in absolute terms (Figure 6), the competition between the two is rather limited and focuses on only a few areas. Essentially, it is only dyes and pigments where both countries show a positive specialization index. Of course, they show also some similar patterns in non-activity like in optical devices or even electronics. The complementarities, on the other hand, are much larger and the intersection and bilateral trade relationships support the conclusion that China and Germany are active in different scientific, technological and market fields and areas.

Figure 6: World trade shares in total processed goods and high-the goods



Source: UN – COMTRADE; Fraunhofer ISI calculations.

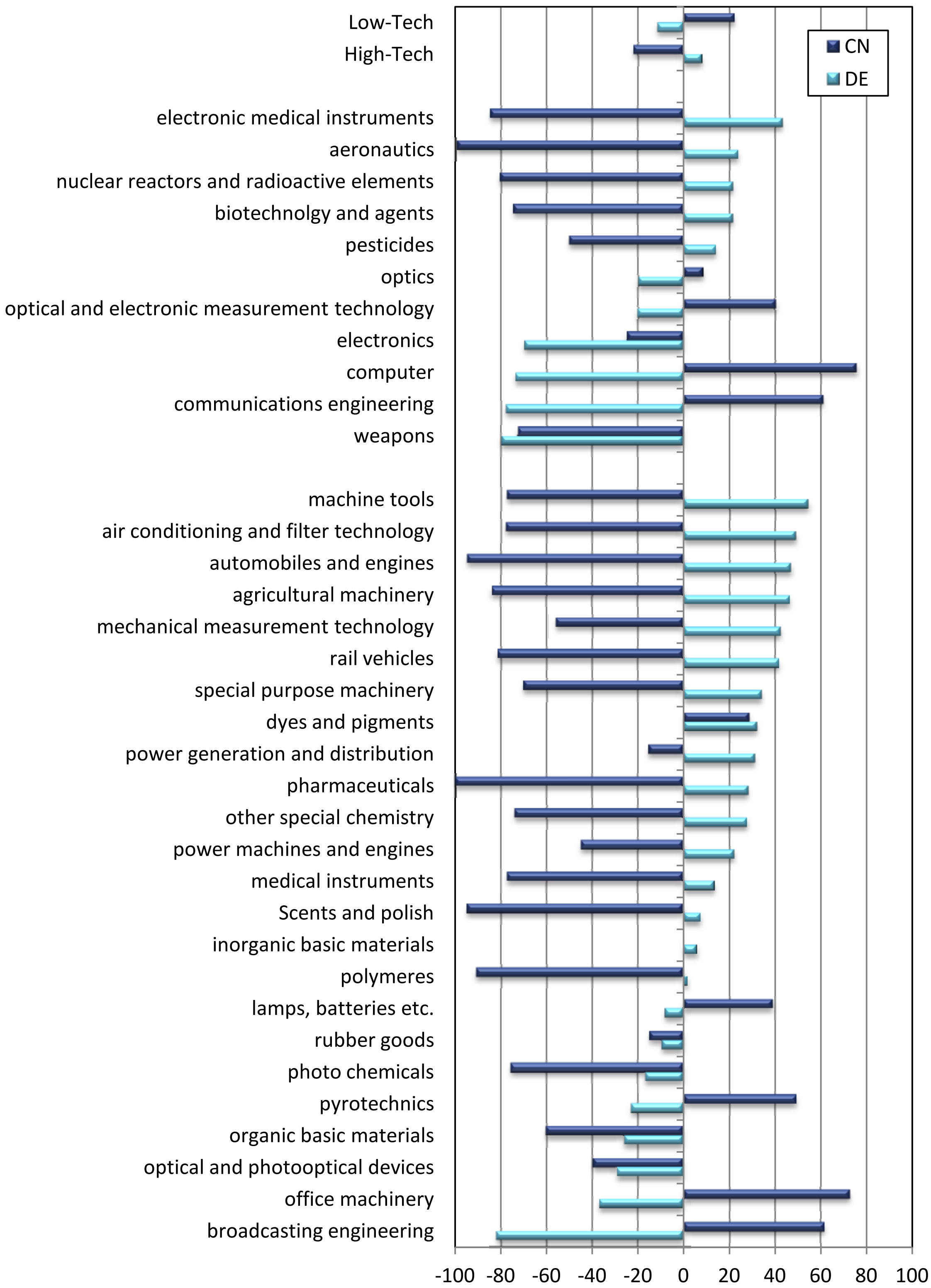
Collaboration or exchange is even more fostered by the fact that these profiles do not show an outstanding competition between China and Germany. Looking at the bilateral trade, the main findings are as follows. The exports from China to Germany as well as from Germany to China have grown considerably in the past decade – the CAGR is 22.6% and even 26.0%, respectively. However, Germany's role in total Chinese exports even declined over time from about 5% in 2000 to about 4% in 2011. Taking the German perspective, China has strictly increased its importance as a trade partner.

While in 2000 only about 1.7% of total German high-tech exports were shipped to China, this share more than quadrupled until 2011, reaching a level of 8.2% (Figure 8).

China's economy has a strong demand for German products and goods, especially machinery, machine tools, automobiles, but also medical instruments, chemistry, and pharmaceuticals. The German economy, on the other hand, also has a strong demand for and even a clear need of ICT from China, not only the consumers, but also business clients, indicating that the B2B supply chain is also a major pillar of bilateral economic activity. German machines, machines tools, or vehicles are enriched by ICT also from China.

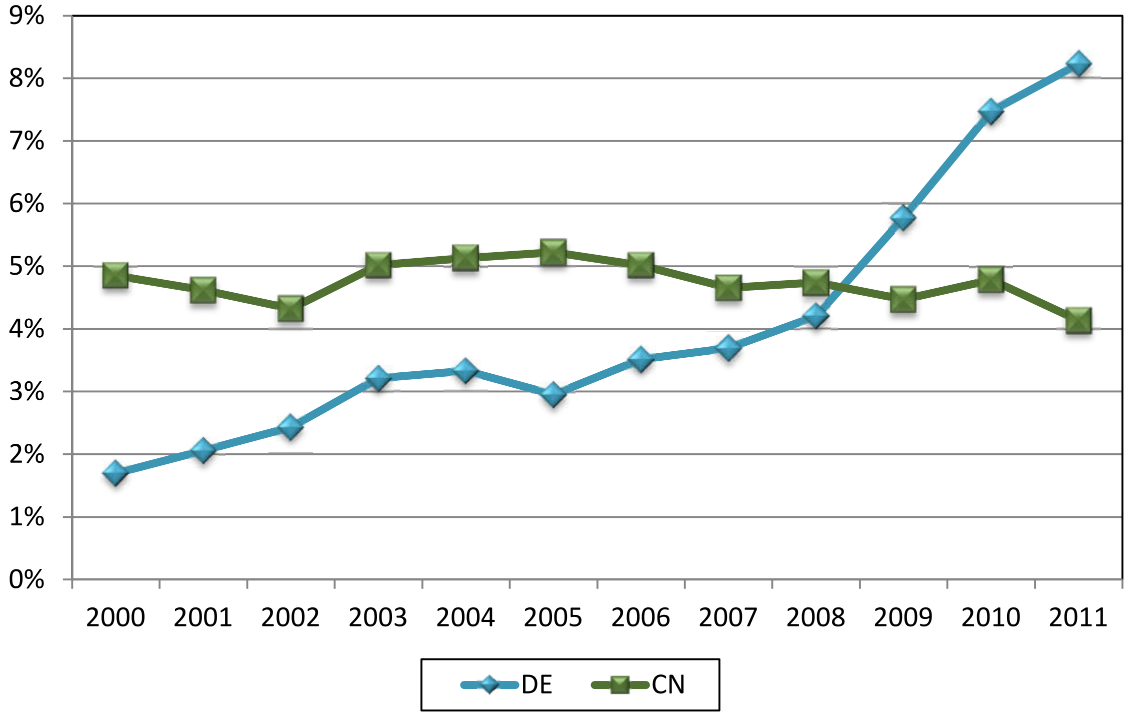
In sum, also in the case of exports the competition between China and Germany is not that fierce and obvious, as both countries – in general – are active in different fields and areas. Furthermore, the complementarities that were found in the patent portfolios were continued in the export portfolios so that the conclusion is obvious: China and Germany hardly compete, but complement each other. This, of course, is a comfortable foundation for any collaboration, be it in science, research or even development and innovation.

Figure 7: Revealed Trade Advantage (RTA) of China and Germany, 2009-2011



Source: UN – COMTRADE; Fraunhofer ISI calculations.

Figure 8: Shares of bilateral trade in total exports in high-tech fields for China and Germany, 2000-2011



Source: UN – COMTRADE; Fraunhofer ISI calculations.

4 Summarizing discussion

We have shown that China and Germany have long-lasting collaborations in science, technology and innovation, not only driven by actors from public research, but also from industry – and supported by both governments in all aspects. The science collaboration started already in the 1970s, but accelerated in the late 1990s and early 2000s, then also broadening the scope, nowadays ranging from basic to applied research. The collaboration is institutionalized in agreements that are vivid and well nourished. The Inter-governmental Agreement on Scientific and Technological Cooperation and especially the WTZ committee meetings, an institutional arrangement that Germany has with many countries in a similar way, are the basis for exchange of the two main actors in science and research on both sides, namely MOST and BMBF. More recently, the Sino-German intergovernmental consultations also addressed several STI topics, thereby boosting the political support in both countries and helping to establish a number of new collaborative activities. Germany holds similar consultations with only a limited number of countries.

The strategy for the internationalization of science and research by the German government, released in 2008, provides the framework also for the collaboration with China. From a German perspective, China's status was changed from a developing to a developed country in 2008. Since then the first two columns of the internationalization strategy are the relevant ones also for the exchange with China. These columns address the collaboration with the best scientific actors in the world and target worldwide innovation potentials. Therefore, it is not only collaboration on the level of public research, but also on the level of industry that is supported by the German government. Furthermore, this is not a one-way street. Neither knowledge nor economic flows must only head in one direction, but it is expected to have equal partners with mutual interests that join forces to achieve benefits for both sides.

The empirical evidence provided in section three meant to show this mutual interest and to stress the complementarities – both in scientific and economic terms – that prevail over the competition. The German government supports the collaboration with Chinese partners in several of these complementary fields and areas. As there are not so many competitive fields, the collaboration between China and Germany addresses a broad array of topics, both in public and private research.

Germany has an open innovation system. It nurses collaborations and exchange with many international partners, stemming from its perception of benefits and value added to the overall economic and scientific development of the country, emerging from this openness. Empirical evidence shows that nowadays rather closed systems are less successful than open innovation systems (Frietsch et al. 2012b; Weissenberger-Eibl et al. 2011).

The scientific and innovation related collaboration between China and Germany is characterized by an open approach, which is based on the political support for internationalization in both governments. Some of its success relies on the fact that neither big political nor trade related issues had the power to significantly disturb Sino-German cooperation. At the same time, economic cooperation is strong and much more complementary than competitive, strengthening the ability to collaborate in an open and trustful manner also in public research.

While basic research collaboration or pre-competitive research are often seen as harmless in terms of IPR and loss of knowledge in most cases, more applied areas of scientific collaboration are currently under discussion in Germany – not only with respect to the cooperation with China, but with any foreign country in general. The discussion follows along the line, if public research organizations publicly funded by German taxpayers' money should engage with foreign research organizations and especially with foreign industry. Furthermore, the question is also raised, if applied research organizations like Fraunhofer or Helmholtz should engage with German companies abroad, thereby maybe strengthening the foreign research and production location, while weakening the home base. This is an ongoing discussion that is not yet settled at all. Hopefully, the new internationalization strategy (or its implementation rules) of the Federal Ministry of Education and Research will provide the cornerstones for the internationalization of research. The existing strategy aims at "collaborating with the best" and "raising international innovation potentials", which give a framework also for international activities of public research. However, it is not clear or even does not mention any boundaries for such collaboration activities.

More empirical evidence is necessary especially on the home-base augmenting versus home-base harming effects of international science and especially R&D collaborations. The general openness of the German innovation system with its positive notion of collaboration seems to benefit the country instead of suffering from it, at least from an overall economic perspective.

To sum up, the Sino-German collaboration in science, technology and innovation are well established and have flourished recently. The overall pattern of collaboration is characterized by mutual benefits and complementary competences and strengths. The exchange is respectful and on an eye-level. There are clear areas of active collaboration, but also areas of non-collaboration (or low collaboration) defined by either side. For example, in ICT, genetics or biotechnology, the Chinese seem to prefer collaborations with other countries more intensively. The German side, on the other hand, (so far implicitly) also defined areas of non-collaboration – especially in areas of close or potential competition. These are to be found in LEDs or machinery.

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