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Why is Germany's Manufacturing Industry so Competitive?*

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Abstract

The German economy has been outperforming other member countries of the European Union during the recent Great Recession and the still ongoing European debt crisis. What are the determinants of this outcome? This paper sets out to empirically analyze the trade and technology specialization and the price/cost performance of the German economy over the period 1990–2011. Furthermore, we apply the unit value approach to determine whether the competitiveness of German manufacturing products is related to price or quality advantage. Also, we estimate the degree of vertical specialization characterizing the German export sector in order to assess the role global value chains play in strengthening Germany's position in manufacturing. All indicators are calculated for Germany, the Republic of Korea, the People's Republic of China, Japan and the United States. Our results confirm that Germany is specialized in medium-range technology products and show that quality is the main driver of Germany's international success, that price and cost advantage determines competitiveness in some product groups and that R&D efforts have contributed to develop and maintain German competitiveness in manufactured products.

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1. Introduction

According to standard macroeconomic indicators the German economy has been outperforming other member countries of the European Union during the recent Great Recession and the still ongoing European financial crisis.[3] The temptation to give a simple answer (i.e. good policy) to the question in the title of this paper is strong, very strong indeed. Instead of succumbing to this temptation, we enquire into the determinants of this outcome and hope to find a somewhat more sophisticated answer. There are good reasons for doing so. First, the link between 'good policy' and competitiveness has been forcefully challenged in the literature. At the end of a piece on competitiveness Paul Krugman concludes that "competitiveness is a meaningless word when applied to national economies" (Krugman, 1994: 44). Furthermore, he also qualifies the use of the word as an 'obsession' which is "both wrong and dangerous" (Krugman, 1994: 44) and argues convincingly that "the idea that a country's economic fortunes are largely determined by its success on world markets" (Krugman, 1994: 30) is just a hypothesis that not necessarily needs to be true. Second, even if nations should in fact compete with each other in the world economy, like firms do in the market, the measurement of competitiveness is not at all a straightforward matter and there is a need to assess a number of indicators for several countries before we can attempt to explain the existence of an advantage or disadvantage of a country via-à-vis other countries in selected traded goods or value chains.[4]

Third, while it remains to be seen whether the performance measured by an indicator relates directly to a policy, indicators may contribute to draw a picture of a country's economic outlook and help understand its position in the world economy. We therefore define competitiveness as a country's capacity to develop conditions that generate a sustainable level of prosperity. This definition is based on a broad set of indicators each of which represents properties of a country that are not always within the reach of the instruments of economic policy. Moreover, our analyses focus on the manufacturing sector and we are particularly interested in trade and technology. We therefore do not adhere to definitions of competitiveness related to single measures like per capita income or measures of productivity such as the concept of 'foundational competitiveness' (Delgado, Ketels, Porter and Stern, 2013). Although single measures might have their merits in a particular context, we prefer to follow the approach chosen by the authors of a recent book on competitiveness edited by Paul De Grauwe (2010). Particularly one of the authors, Sala-i-Martin (2010), gives an over-

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[3] See the recent assessments of the German economy by the International Monetary Fund (IMF, 2013) and the Organization for Economic Cooperation and Development (OECD, 2013).

[4] The early discussion of this topic addressed mainly prices and costs (Neary, 2006), whereas recent approaches (Bayoumi, Saito and Turunen, 2013; Huemer, Scheubel and Walch, 2013; Sala-i-Martin, 2010) include, among others, a long list of variables, such as institutions, infrastructure, labor, capital and goods markets, etc. While in most cases reference is made to an overall productivity measure to which all variables are assumed to contribute in some way or another, the transmission mechanism between the variables and the single measure is not generally thoroughly studied.

view of the different pillars on which competitiveness can be assumed to rest. Also, we would like to mention the European Commission's approach as deployed in its European Competitiveness Report (2013a) which assesses the competitiveness of all member countries of the European Union.

The remaining part of the paper is organized as follows: the relevant literature is reviewed in section 2, our data, methodology and research strategy are presented in section 3 and our final results are discussed in section 4.

2. Literature Review

Economic studies on Germany's international competitiveness are extremely rare, even in Germany. This may be attributed to the fact that the interest in issues in competitiveness is greatest in policy and corporate circles; economists have only recently engaged in research on the competitiveness of countries as opposed to comparative advantage in trade or technology or the competitiveness of firms. In the book by De Grauwe (2010) several multi-country studies can be found, one of them attempting to explain the productivity gap existing between the United States (US) and Europe (Cotis, de Serres and Duval, 2010). The latter concludes that heavily regulated labor markets in Europe constitute an important barrier for European countries to unleash their full economic potential and catch up with the US. Another paper in the book deals with price competitiveness among European Monetary Union countries (Fischer, 2010) and tracks the German inflation rate in order to explain the level of price and cost competitiveness achieved by this country over the past decades. The German Federal Ministry of Economics and Technology (2010) published one of the few country reports on the competitiveness of German manufacturing industry. It describes the most successful products belonging to the medium-range of technology and addresses some of the global trends expected to have a bearing on the future of the German manufacturing industry.

The only recent German academic study known to us is the one by Gehrke and Krawczyk (2012) who have been monitoring technological developments in Germany and trade in research-intensive products for many years. This study uses several methods and excellent data on R&D in Germany. It concludes that medium-range technology products are largely competitive in the world economy on the basis of their quality. The latter is related to strong R&D activity as shown by patent and industrial design data and to an economy well-endowed with researchers and private and public research institutions. Moreover, the vertical specialization of Germany has also been studied before, albeit generally on a firm level (Godart and Görg, 2011). These authors find that foreign affiliates of German companies locate mainly within the European Union and that only a relatively small number of them are present in Eastern Europe. They conclude that "increased outsourcing of goods and services permit firms to achieve gains in production efficiency and competitiveness" (Godart and Görg, 2011: 362).

3. Data, Methodology and Research Strategy

As we devote special attention to the evolution of Germany's competitiveness in manufacturing vis-à-vis other major economies, in this section we briefly present our data sources and the methodology used. Before touching upon these issues, we refer to our research strategy. In order to study the determinants of German competitiveness we first estimate the country's specialization in the product groups defined in table A1 in the Appendix. After calculating several specialization indices (trade and patents) we identify the major product groups that seem to dominate the German trade and technological position in the period under study. In a second step we ask whether this specialization is due to quality or price and calculate the corresponding revealed elasticities. In a third step we estimate the degree of vertical specialization associated with the leading German product groups. We then take a look at the basic indicators of the German innovation system as compared with those of its competitors. Finally, we discuss relevant issues in public policy related to our results for Germany and other countries.

Trade data used in this paper refers to current US$ merchandise exports and imports classified according to the Standard International Trade Classification Revision 3 (SITC) at the three-digit level for the period from 1990 to 2011.[5] We prefer Revision 3 to Revision 2, which goes further back in time, because it is more detailed and because it facilitates the matching of trade and patent data. Trade data is structured into nine sections, 68 groups and 261 subgroups and is obtained from the United Nations Commodity Trade Statistics database (UN Comtrade) covering 99 % of world merchandise trade. With respect to missing values, we note that figures for the People's Republic of China (PRC) in 1990 and 1991 as well as for Germany in 1990 are missing, as also is some data at the three-digit level for the countries studied. This also applies to product code 562 (fertilizers) reported by the US for the period 2000–2007. We classify trade data into 15 technology groups, including six main groups and nine subgroups as shown in table A1. The grouping follows the approach suggested by Lall (2000b) which is based on Pavitt (1984) and Hatzichronoglou (1996).[6] It uses the R&D intensity of industrial sectors as an indicator (instead of technological complexity) in order to group products into one of the low, medium and high technology categories. Since the original approach draws on SITC Revision 2, we extend the classification by introducing new product codes included in SITC Revision 3. Unfortunately, we face the problem that productive activities at different stages of technological complexity were classified into the same product category (Lall, 2000b: 340). For example, pharmaceuticals (SITC code 541) include innovative drug developments as well as generic drugs with an impact identical or equivalent to that of innovative drugs. It is also difficult to establish differences in quality within each product category.

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[5] More recent data is not available. With respect to 2012 data, still 14.1 % is missing (July 29, 2013).

[6] For a more comprehensive classification distinguishing between cutting-edge, high and research-intensive industries see Gehrke, Frietsch, Neuhaeusler, Rammer and Leidmann (2013).

This notwithstanding, the classification into product groups differing in their technological content applied in this paper provides useful insights into the technological dimension of international trade patterns. We complement these analyses by resorting to industrial R&D expenditures provided by the European Commission (EC, 2013b). The dataset is based on financial data of 1,500 research-intensive firms and consists of 405 EU-based and 1,095 foreign-based firms, which account for around 90 % of global business expenditures in R&D. The proposed grouping by the EC (2013) into high, medium-high, medium-low and low R&D intensity according to R&D intensity at the sectoral level is compatible with our technological classification of products as shown in tables A1 and A2 (Appendix). Available trade data is generally biased by tariff and non-tariff barriers to trade which makes the measurement a country's specialization pattern difficult. We therefore draw on Balassa (1965) who proposed to measure the revealed comparative advantage (RCA) of countries on the basis of observed trade data. Vollrath (1991) suggested to adjust Balassa's RCA index in order to obtain a symmetrical range of values. We follow him and apply his version of the above-mentioned indices[7] and calculate them for exports, imports, patents and scientific publications. The bibliographic databases Scopus and the Web of Science (WoS) differ significantly. Since Scopus covers a significant share of articles exclusively, the number of scientific publications such as articles and conference proceedings exceed that of WoS. The divergence is mainly due to the wider coverage of engineering and to its comprehensive coverage of publications of the PRC. Therefore, data for scientific publications for the period from 1996 to 2011 was obtained from SCImago Journal & Country Rank based on data provided by the Scopus database.[8] Since Greenaway and Milner (1993) argue that the outlined specialization approach for trade data is biased by the omission of domestic demand, especially when country size matters, we also calculate the RCA index dividing domestic and world export ratios by domestic and world import ratios. In doing so, we acknowledge that domestic firms compete on both global and domestic markets (see the Appendix for details).

In order to compare the specialization patterns of the countries under study, we normalize the specialization indices in the range between +100 and –100 by making use of the hyperbolic tangent and multiplying by 100. Positive values point to a specialization in the analyzed technology group vis-à-vis the world economy, negative values indicate that the country is specializing in other technology groups. In addition, we assume that values of the relative export advantage (RXA), the RCA and revealed patent advantage (RPA) indices between –100 and –60 indicate an absence of specialization, whereas values between –60 and –20 indicate a weak specialization. On the other hand, values between –20 and +20 indicate an average specialization, values between +20 and +60 an above average specialization and finally values between +60 and +100 a strong specialization.

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[7] An excellent overview of the literature on measuring international specialization is provided by Iapadre (2001).

[8] Accessible under http://www.scimagojr.com/.

Furthermore, we classify the trade data into intermediate and final (capital and consumption) goods based on Broad Economic Categories (BEC) and using a concordance table provided by the UN (2003). The BEC are divided into nine parts, 14 groups and eight subgroups. It must be noted that the concordance table does not provide a classification for BEC 321 (motor spirit), 51 (passenger motor cars) and 7 (goods not elsewhere specified). Rather, the classification is left to the user's discretion. We classify BEC 321 and BEC 51 as consumption goods. By matching the SITC with the BEC codes we obtain 454 SITC/BEC matches. In a second step we drop all duplicates, all SITC matches with BEC 7 and the match of SITC 001 (live animals) with BEC 41 (capital goods), leaving a total of 363 SITC/BEC matches. Our concordance approach provides matches for 258 or 99 % of the 261 SITC codes. The remaining 363 SITC/BEC matches define three groups. The first group provides a concordance for 173 or 66 % of all SITC codes. Since the second group includes 65 or 25 % of all SITC codes that were matched with both intermediate and final (either capital or consumption) goods, we assign 1/2 of the corresponding values to each category. Finally we assign 1/3 of the corresponding values to each category for 20 or 8 % of all SITC codes that were matched with intermediate and final (capital and consumption) goods.

In order to measure the domestic value-added embodied in export manufactures, we estimate the degree of vertical specialization (VS) following the approach of Hummels, Ishii, and Yi (2001). We define VS as the share of imported intermediate input content, namely foreign value-added, in final good (consumption or capital) exports. First, we measure the import content of a country's exports by calculating the ratio of imported intermediate inputs to gross value added, multiplied by exports. Second, we divide the ratio obtained in the first step by total exports, yielding the share of VS in total exports (see the Appendix for details). Data for gross value added at current US$ are drawn from the World Development Indicators provided by the World Bank. If a country uses no intermediate goods to produce and export goods, then VS equals zero. Basically, if the country only uses intermediate products to produce and export goods, and the whole gross value added is exported, then VS amounts to total exports. This measure does not indicate anything about the imported intermediates embodied in final goods sold within the country itself. Furthermore, the VS approach based on trade data is biased, as happens with virtually all classifications, by the grouping process itself. As mentioned before, some products do not fit uniquely into one of the BEC. Nevertheless, while 66 % of our SITC codes fit into specific product categories, our approach provides a first estimation of domestic value added within the technological groups. In order to enhance the measurement of VS, Hummels et al. (2001: 80) suggest to use input-output tables provided, for example, by the OECD Database for Structural Analysis instead of trade data. We use only trade data that cover the whole period under study, something input-output tables cannot provide. In order to analyze the geographic origin of the import content embedded in a country's exports, we use the geographic classification of the United Nations Conference on Trade and Development (UNCTAD).

In line with the empirical literature (Aiginger, 1997), we measure the Unit Value (UV) for the defined technology groups to determine the nature of competition. A UV is defined as the ratio of the value of a good in current US$ to its net weight in kilograms rather than in supplementary units. Although supplementary units are more accurate than net weights for some products, it is difficult to deal with changes in quantity units. Also, net weights are available for longer time periods than supplementary units. To determine the nature of competition, we define three groups (i) price competition, (ii) quality competition and (iii) nature of competition is ambiguous. Price competition takes place if the UV of exports is lower than the UV of imports and the amount of imports exceeds that of exports. Since consumers are not willing to pay higher prices for domestic goods than for similar goods imported, they choose to import the cheaper goods from abroad. Quality competition can be detected if the UV of exports exceeds the UV of imports and the amount of exports exceeds that of imports (see the Appendix for details). Unfortunately, theoretical predictions do not always fit the real world outcomes. Based on the information available, we are in a position to clearly define the nature of competition for 531 out of 1,177 cases (i.e. 45.1 %) and we assume that the nature of competition in the remaining cases is ambiguous.

As shown by Frietsch and Schmoch (2010: 186–187), international comparisons of patenting activity on the basis of national patent applications are highly home-biased, since domestic firms normally tend to have a strong interest in their home market. In addition, the application process at the domestic patent office is less costly, since applicants face lower admission costs and are more familiar with the administrative and legal procedures. We use international instead of domestic patent applications to avoid such a bias. To capture the international dimension of technology markets, Gerstenberger (1992) proposed to count all patent applications in at least two countries in order to achieve comparability. Since Germany, the US and Japan (hereafter referred to as the 'Triadic') achieved more than 26 % of world medium and high-technology exports in 1991, Dernis and Khan (2004) proposed to compile a synthetic patent indicator that represents patent applications in the most important patent offices, namely the US Patent and Trademark Office (USPTO), the European Patent Office (EPO) and the Japan Patent Office (JPO). But since then, the world has changed. With the emergence of the newly-industrialized countries, the share of medium and high-technology exports of the Triadic fell to around 14 % (2011). In 1987 the World Intellectual Property Organization (WIPO) introduced an international patent application process via the Patent Co-operation Treaty (PCT). Since applications filed under the PCT allow for the protection of inventions in each of its contracting states,[9] they constitute a valuable indicator of technological developments of global relevance. Therefore, we base our analysis of patent applications on those filed under PCT by the inventor's country of residence and priority date for the period from 1990 to 2010.[10] Patent data is obtained from the 8th edition of the International Patent Classification (IPC) at a four-digit level from the OECD Patent Statistics database. According to the IPC, the patent data is grouped into eight sections, 129 classes and 648 subclasses. While the original classification encompasses 664 subclasses, the database

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[9] 148 countries signed the PCT as of July 12, 2013.

[10] Unfortunately, more recent data is not yet available.

does not report values for 16 subclasses. Furthermore, we also analyze the data on total applications of utility models and industrial design provided by the WIPO Intellectual Property Statistics Data Center. The data refers to applications for utility models and industrial design filed abroad by the applicant’s country of origin.

In order to group the patent data into the same technology groups as the trade data, we use a concordance table developed by Lybbert and Zolas (2012), which assign 256 out of 261 SITC codes to 564 out of 664 IPC codes. Compared to the approach of Schmoch, Laville, Patel, and Frietsch (2003), they use a methodology that “relies on data mining the patent abstracts and titles included in the PATSTAT database using keywords from the industry classification descriptions” (Lybbert and Zolas, 2012: 8). In a first step we classify the 5455 SITC/IPC matches into the 15 technology groups. Then we merge the patent data by all pair-wise combinations within the IPC codes. As the concordance table includes a weight that is constructed as a probability distribution so that the SITC code is matched with the IPC code, we weigh the patent applications with the provided weights and then calculate the totals of each technology group. Since each patent class, as well as each subclass, is usually embedded in a different production process and therefore in a different product, the totals by technology groups tend to exceed the totals of the original dataset.

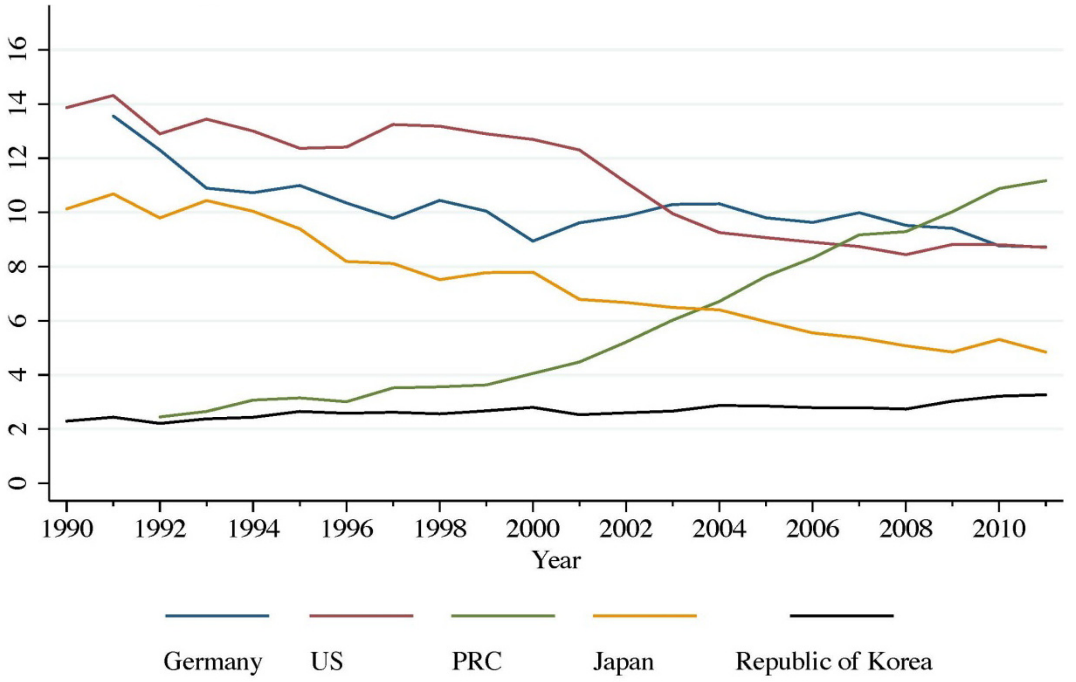
For the purpose of analyzing the dynamics of technological performance we develop a technological specialization matrix that combines the export and patent specialization in the 15 technological product groups. On the horizontal axis we plot the export specialization measured by the countries’ RXA in the period 1990–2011, on the vertical axis we plot the technological specialization measured by the countries’ RPA over the same time period. For each country the technological specialization matrix can be divided into four fields: the first quadrant shows technology groups with both export and patent specialization. Technology groups in the first quadrant indicate a strong specialization in comparison to the world average. Since firms are in a position to at least partly and temporarily exclude competitors from imitating innovative technologies by applying for national and international patents and thus securing a temporary protection of their monopoly, export specialization and patent specialization of countries constitute a possible outcome of this process. By the same token, the first quadrant represents a country‘s technological strength. The second quadrant includes technology groups that show only a patent specialization and no trade specialization. Since the analysis is based on aggregated product codes, it is possible that exports of niche-products, with significant patent specialization, do not achieve the significance needed to determine the overall pattern of the group itself. We interpret this outcome in two ways: on the one hand, the country has not been able to transform the potential associated with patent specialization into export specialization. On the other, the patent specialization might have been maintained while the corresponding export specialization has been declining. We also look at the evolution over time in order to determine the direction of the specialization. In the third quadrant we see technology groups with neither export nor technological specialization, indicating that the country does not specialize at all in the product groups under consideration. We interpret the technology groups in this quadrant to represent a country’s technological weakness.

Finally, the fourth quadrant includes technology groups with export but no patent specialization. Export specialization can be interpreted in this case as reflecting trade that results from multinational companies taking advantage of global value chains. The analysis of export and patent specialization is complemented in this paper by directly estimating the degree of vertical specialization using trade flows (Boileau and Sydor, 2011) in an attempt to determine the technological sophistication of manufactured exports in the sense suggested by Lall et al. (2006).

4. Results

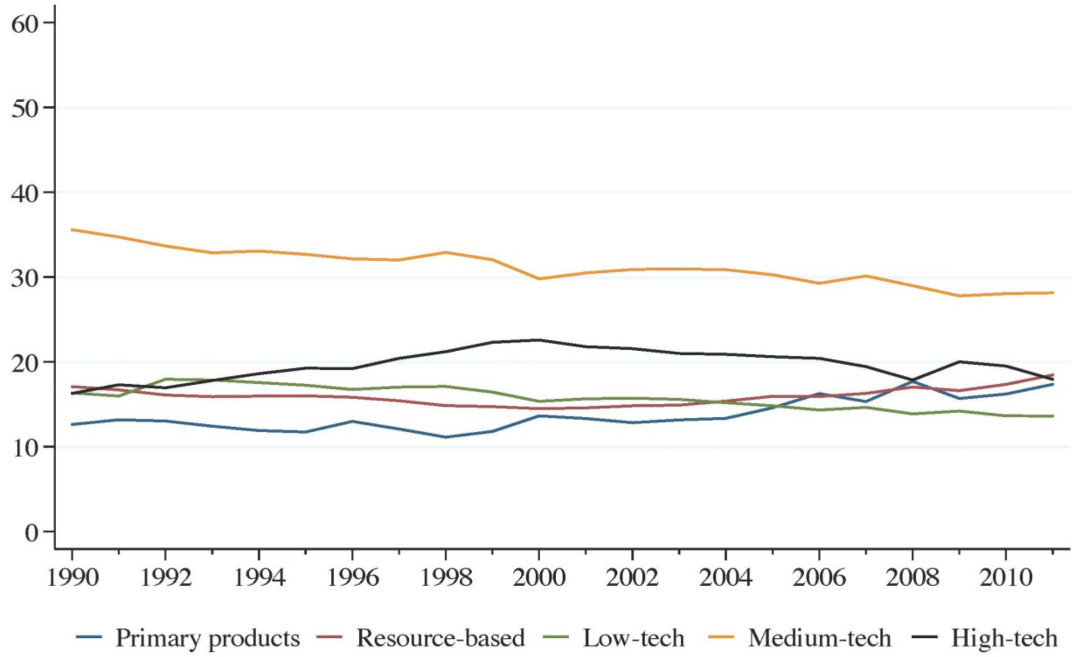
In our analysis of the determinants of Germany's competitiveness in manufactured products, trade plays a key role. We therefore present our results by giving first an overview of the position of Germany, the Republic of Korea, the US, Japan and the PRC in world trade. In recent decades, the distribution of export and import shares underwent dramatic shifts. While on average, almost 30 % of manufactured exports in the period 1990–2011 can be attributed to the Triadic, this share has been declining fast: Germany's share stagnates at around 10 %, the US's share dropped to 8.4 % in 2008 and recovered only slightly after that and Japan's share reached 4.8 % in 2011. In contrast, the Republic of Korea's share expanded from 2.3 % in 1990 to 3.3 % in 2011 and the PRC's share rose from 2.5 % (1992) to around 11 % in 2011 and thus accounts for the largest contribution in the sample (figure 1).

Figure 1:
World Export Shares



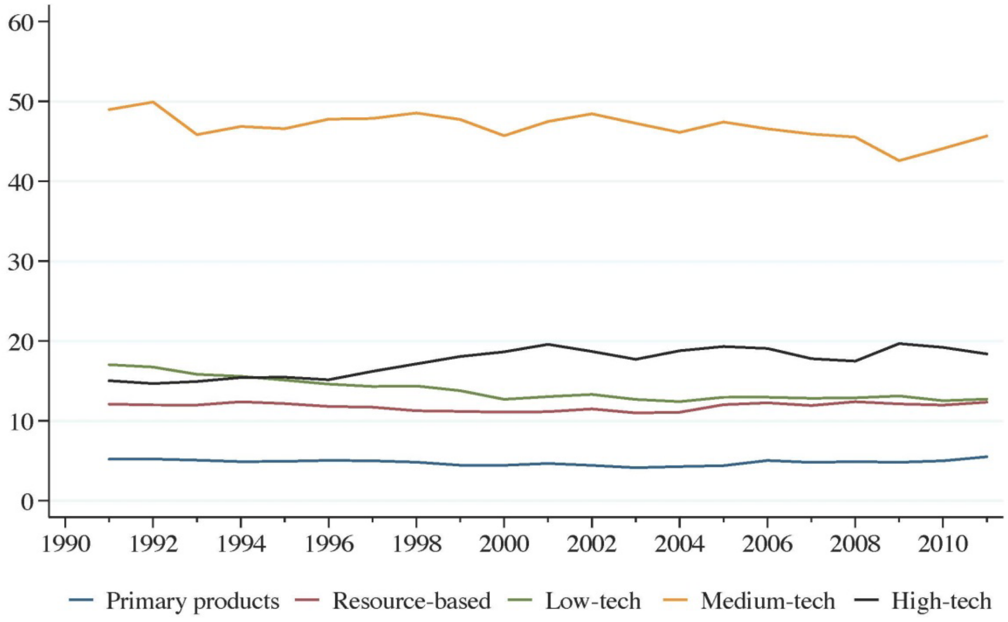
The technological composition of world trade has also changed. The share of world primary and resource-based exports fell significantly from about 43 % in 1985 to around 26 % in 1998 and increased again to 36 % in 2011, reflecting strong Asian demand, particularly in China and India (figure 2). The share of low-technology products (LT) in world exports, however, remains stable at around 14 %. Surprisingly, the share of medium-technology manufactures (MT) in world exports, perhaps the backbone of industrial production in the advanced countries, declined somewhat from 30 % in 1985 to 28 % in 2011. The latter's performance is associated with automotive and engineering products, while products from the process industries, important intermediate inputs for other production processes, experienced only a marginal change. The share of high-technology products (HT) in world exports continuously expanded from 12 % in 1985 to 20 % on average between 1998 and 2011. In our country sample, in the 1990s the US and the PRC were the most important exporters of resource-intensive products. In the case of the US, primary products (PP) and resource-based (RB) products represented some 22.9 % of total exports, with the share of RB increasing from 14.6 % to 20.3 %. Agro-based exports fell from 7.5 % to 5.8 %, while other resource-based manufactures grew from 7.1 % to 14.5 %. The PRC seems to have switched from exporting natural resources to higher value-added products. Its combined share of PP and RB in total exports fell from 25.4 % in 1992 to 12 % in 2011. PP and RB represented on average 16.6 % of German exports to the world economy, in the case of the Republic of Korea the combined share increased from 10.2 % in 1990 to 19 % in 2011. The Japanese PP and RB export share expanded from 7 % in 1990 to 11.8 % in 2011.

Figure 2:
Exportportfolio of the World – Relative Share of Total Exports



Low-technology products (LT) are mainly produced by low-skilled labor in labor-intensive industries producing mostly differentiated products by applying mature, widely diffused technologies. According to the European Commission (EC, 2013b: 52), the LT sector's R&D intensity amounts to 1–5 % of net sales. The share of LT in total exports of the US and Japan remain more or less stable at around 9–10 %. In contrast, Germany, the Republic of Korea and the PRC have been reducing their LT exports in favor of technologically more complex goods. MT can be subdivided into automotive, engineering, and process industries. The production of automotive and engineering products often requires close cooperation with supplier networks in which innovative small and medium-sized enterprises (SMEs) play a significant role. In addition, product development and design are also important. The car industry is a good example of an industry in which firms successfully outsource their assembly tasks in order to benefit from lower wages in other countries. In contrast, the process industries tend to produce mature and undifferentiated products in large-scale production facilities based on considerable R&D effort (Lall, 2000b: 342). While the share of MT exports has remained stable in the case of Germany (figure 3), the US, Japan, the Republic of Korea and the PRC have been increasing their shares. Germany faces a slight reduction from 49 % in 1991 to 45.7 % in 2011, and with approximately 5 % of world exports it currently is the major exporter of MT products. Whereas the share of automotive products remains constant at 15 %, engineering dropped from 23 % in 1991 to 20.9 % in 2011; products from the process industries fell from 10.8 % to 8.9 %. The US has managed to maintain a share of 33.8 % over time. MT products are the backbone of Japans exports accounting on average for 53.1 % of total exports. The Republic of Korea has increased its share of MT exports from 28.9 % in 1990 to 43.6 % in 2011. Significant increases were observed in the case of automotive (from 3.4 % to 12 %) and engineering products (from 15 % to 22.2 %). In the PRC, the share of MT exports rose from 15.3 % in 1992 to 24.5 % in 2011.

Figure 3:
Exportportfolio of Germany – Relative share of total exports



Finally, we turn to the smallest but most dynamic group of high-technology products (HT), including office, data and telecommunication equipment, televisions, pharmaceuticals and aircraft. HT products are based on advanced and fast-upgrading technologies, which require substantial investments in R&D and skill acquisition along with a technically sophisticated infrastructure and highly specialized researchers and engineers. According to the EC (EC, 2013: 52), the HT sector's R&D intensity exceeds 5 % of net sales. Special attention is devoted to product development and design, commonly in close cooperation with universities and R&D organizations. Since the assembly of some electronics and electrical products like televisions or cell phones occurs in technically unsophisticated, labor-intensive production processes, this activity is organized as a global value chain. As in the case of the other high-technology products, product development and design is still concentrated in advanced countries endowed with advanced levels of technology, a workforce mastering technical skills and technically sophisticated supplier networks. Therefore, comparative advantage in product development and design is largely determined by technological capabilities, whereas competitive advantage in final assembly is ruled by wage differentials (Lall, 2000b: 343).

Among the countries analyzed, Germany is the country that on average shows the lowest share of HT exports. Nevertheless, the share of HT products increased from 15 % in 1991 to 18.4 % in 2011. While in 1990 the US, Japan and the Republic of Korea showed the highest share of HT exports, in 2011 the highest shares of HT exports were registered in the Republic of Korea and the PRC. The US share of HT exports amounted to 30 % in the period between 1990 and 2004 and fell to 18.2 % in 2011. Japan managed to increase its share of HT exports from 27 % in 1990 to 31.2 % in 2000 and experienced a reduction to 18.9 % in 2011. The Republic of Korea's share went up from 20.7 % to 26.5 % and stabilized at 30 %. Between 1992 and 2011 the PRC's share of HT exports increased from 8.8 % to 32.8 %; interestingly, the share of electronic and electrical products increased from a low 5.4 % to 27.1 %.

Turning now to R&D expenditures, scientific publications and patent applications, it can be seen that the US and Japan are by far the largest R&D spenders (table A3, Appendix). While in 1996 both countries accounted for more than 80 % of world expenditures for R&D, their shares fell to some 66 % in 2010. Whereas Germany slightly reduced its share, the Republic of Korea and the PRC increased theirs from 3.1 % to 4.3 % and 2.3 % to 14.6 %, respectively. Changes in gross expenditures on R&D as a share of GDP (GERD), especially if business expenditures on R&D increase, point towards structural change in the composition of industries in the wake of a shift towards research-intensive activities. Based on the data available, the Republic of Korea and Japan show the highest research-intensity, followed by the US and Germany. Despite significant progress in GERD, the PRC still needs to catch up with the leading countries. Whereas business expenditures on R&D (BERD) represent more than 70 % of GERD in Japan, the Republic of Korea and the US, German and the PRC's firms account for more than 60 % of GERD. As in the case of Germany, in the Republic of Korea, Japan and the US, government and higher education institutions (HEI) are responsible for the rest. In the PRC the government alone accounts for nearly all of the remaining expenditures on R&D.

According to figures provided by the Institut für Mittelstandsforschung (IfM), more than 99 % of all German firms belong to the so-called ‘Mittelstand’.[11] They contribute to almost 52 % of value-added and more than 37 % of total turnover of all German firms. Almost 95 % of these SMEs are family-owned with solid financing models based on low and in some cases even no debt at all. As recent findings of the Kreditanstalt für Wiederaufbau (KfW) SME panel show, German SMEs finance their investments mostly with equity (Schwartz, 2012: 6). Figures provided by Kladroba and Hellmich (2013) indicate that the German ‘Mittelstand’ accounts for around 15 % of BERD in 2011, the remaining 85 % are attributed to large manufacturing firms. According to figures of the Stifterverband für die Deutsche Wissenschaft (2013: 8), the automotive industry accounts for around 33 %, electrical industry (16 %), engineering (9 %), pharmaceuticals (8 %) und chemicals (6.5 %) of GERD. According to EC (2013), the sample countries account for 66.5 % of global manufacturing R&D expenditures at the firm level. While 108 German firms account for 7.2 %, 502 US firms for 33.5 %, 296 Japanese firms for 19.7 %, 35 firms of the Republic of Korea for 2.3 % and 56 PRC’s firms for 3.7 %. Finally, the data on R&D personell reveals that Germany shows the lowest share of researchers working in the business sector (as compared to the US, the Republic of Korea and the PRC). This share has been declining in Germany since 2006, although Germany’s global share has increased somewhat in this period (table A4, Appendix).

With respect to scientific publications, an output measure, Germany’s share remained stable at around 6 % between 1996 and 2011. The scientific specialization of a country can be measured by calculating the revealed scientific literature advantage index (RLA). Applied to Germany, it reveals that there is a specialization particularly in physics, but also in chemistry, biochemistry, materials, and earth and planetary sciences. Surprisingly, Germany shows a weak scientific-specialization in engineering, indicating that apparently Germany does less basic research in engineering than other countries, although patenting in engineering is quite important. The share of the US dropped from 29 % in 1996 to around 23 % in 2011. The scientific focus in the US includes medicines (22.2 %), biochemistry and genetics (12.1 %), engineering (8.6 %), agricultural sciences (6.4 %) and physics (5.9 %). Japan’s share also fell, from around 8 % in 1996 to 5 % in 2011. Japanese researchers follow the German research pattern and publish mostly in medicine (18.5 %), biochemistry and genetics (12.9 %), physics (11 %), engineering (10.1 %) and chemistry (8.3 %). The RLA for Japan points to an above average specialization in biochemistry and genetics, chemicals and physics. Scientific specialization in engineering achieves world average level and medical publications show a below average specialization. The Republic of Korea increased its share from around 1 % in 1996 to nearly 3 % in 2011, whereas the focus is on engineering (15.3 %), physics (10.6 %), material sciences (10.5 %), biochemistry and genetics (10.1 %) and medicine (10.5 %). Scientific research in in the Republic of Korea shows an above average specialization in material sciences, physics and engineering, and an average specialization in biochemistry and genetics as well as no specialization in medicine. Finally, there is a significant increase in the PRC’s

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[11] Only available in German, see http://www.ifm-bonn.org/statistiken/mittelstand-im-ueberblick.

share in scientific publications. While its participation was 2 % in 1996, it reached 15 % in 2011; its scientific output mostly focuses on engineering (20.4 %), material sciences (11.7 %), physics (9.8 %), chemistry (9.5 %) and medicine (7.4 %). Furthermore, the PRC's scientific specialization index indicates an above average specialization in engineering, materials science, chemistry, but no specialization in medicine.

Patent applications vary widely across countries and industries. The five countries in our sample accounted for 65 % of world patent applications in 1990, a share that increased to 70 % in 2010. Most of the applications take place in the US, Japan and Germany. The Republic of Korea and the PRC increased their shares from 0.2 % to 5.1 % and 0 % to 6.5 %, respectively. Whereas the five countries in our sample account for around 89 % of industrial design applications worldwide, its combined share fell to 38 % in 2011. Germany is by far the largest applicant in industrial design protection, accounting for 16 % in 2011. The US accounts for 10 % and Japan for 7 %. The Republic of Korea and the PRC increased their shares over time, reaching 2.7 % and 2.4 % in 2011, respectively.

When assessing the simple trade shares above, a number of salient features of our sample countries were identified. A glance at the indices of revealed comparative advantage (RCA) and revealed export advantage (RXA) confirm most of these features: according to figures A1 and A2 in the Appendix Germany specializes strongly in MT and also shows a weak specialization in HT, while Japan and the US strongly specialize in MT and HT. The Republic of Korea shows a strong specialization in two product groups (HT and MT) and an average specialization in LT, with MT increasing over time. The PRC is revealed by the RCA to specialize strongly only in LT. The RXA confirms the results for Germany, the Republic of Korea, Japan and the US but not for the PRC. For the PRC the RXA shows a strong specialization in LT and an average specialization in HT.

The big question posed by the trade specialization patterns discussed above is whether they match the technological specialization. Figure A3 in the Appendix helps in identifying the patent specialization of our sample (not all countries are shown): the U.S. concentrates on HT and PP, Japan on MT, RB and LT, Germany (as expected) on MT and the Republic of Korea on LT and HT; the PRC's pattern is somewhat complex including several products groups and a specialization that changes over time. In order to clarify the issue it is helpful to turn to our technological specialization matrices (figures 4 to 8): in the case of Germany trade and patent specialization result in a clear specialization in MT; for the U.S. the match obtains for HT; for Japan (like for Germany) for MT. The Republic of Korea and the PRC show a multiple specialization: the Republic of Korea in LT, MT and HT and the PRC in PP, LT and HT. As the results for the latter are not that clear, we take a closer look at the evolution over time. The Republic of Korea shows an improving specialization pattern in RB, MT and HT, whereas LT specialization indicators deteriorate over time. Surprisingly, the RXA for PP deteriorates while the RPA improves. In the case of the PRC, both specialization indicators for PP, RB and LT deteriorate over time and the specialization indicators for MT improve. Regarding HT, the RXA indicator improves, while the RPA stays more or less stable.

Figure 4:
Technological Specialisation Matrix – Germany

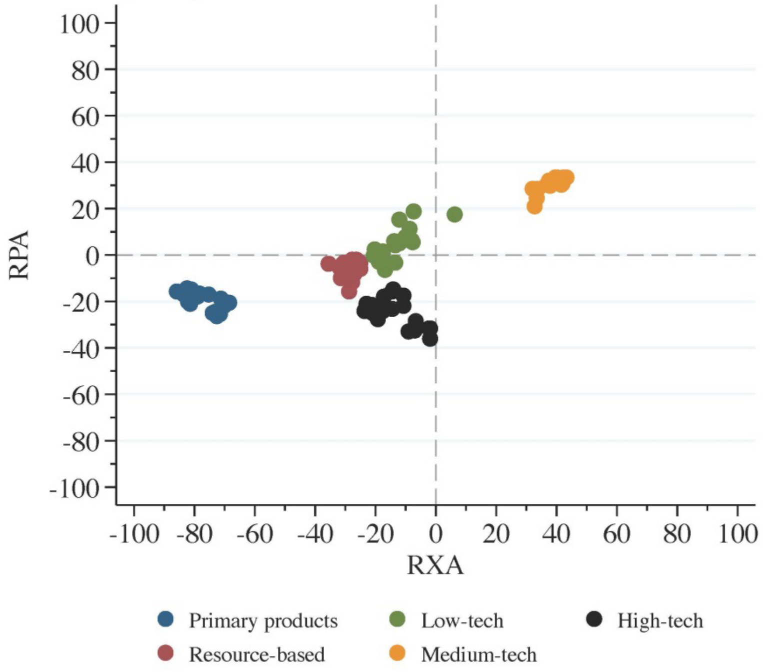


Figure 5:
Technological Specialisation Matrix – United States

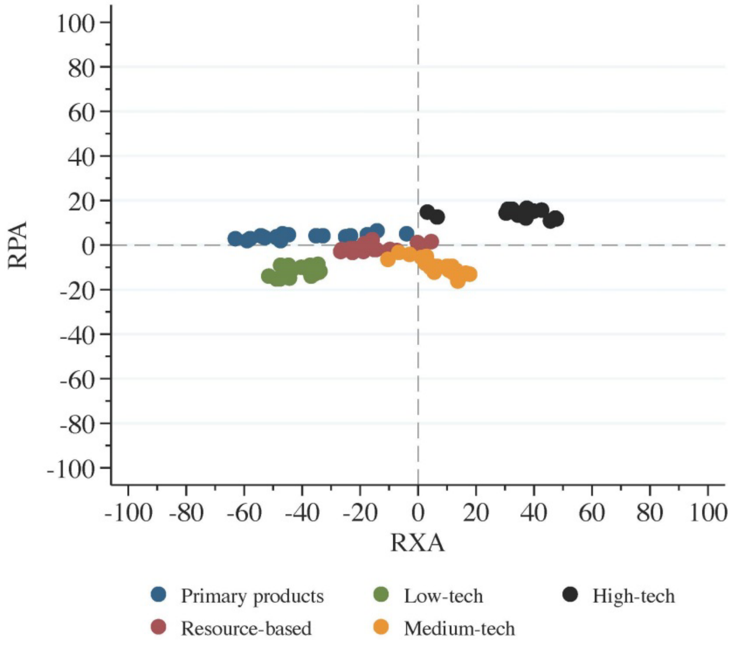


Figure 6:
Technological Specialisation Matrix – Japan

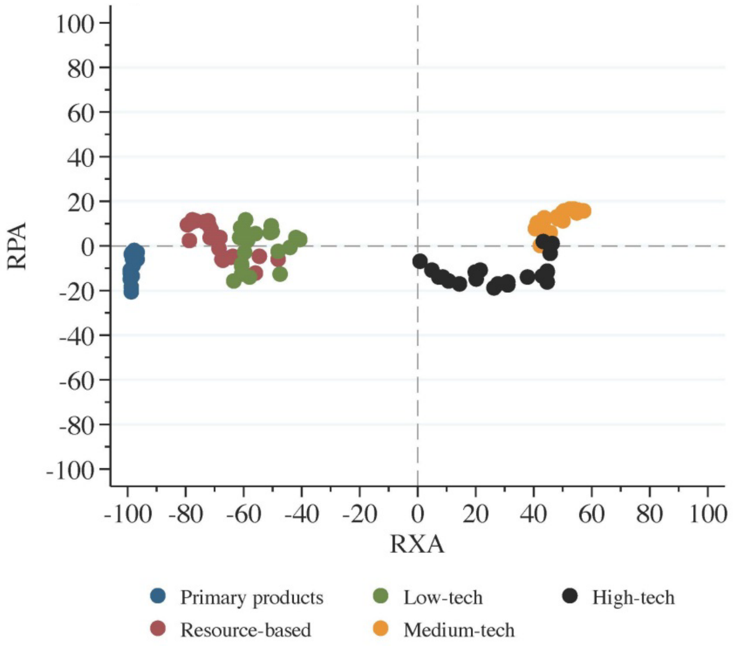


Figure 7:
Technological Specialisation Matrix – Republic of Korea

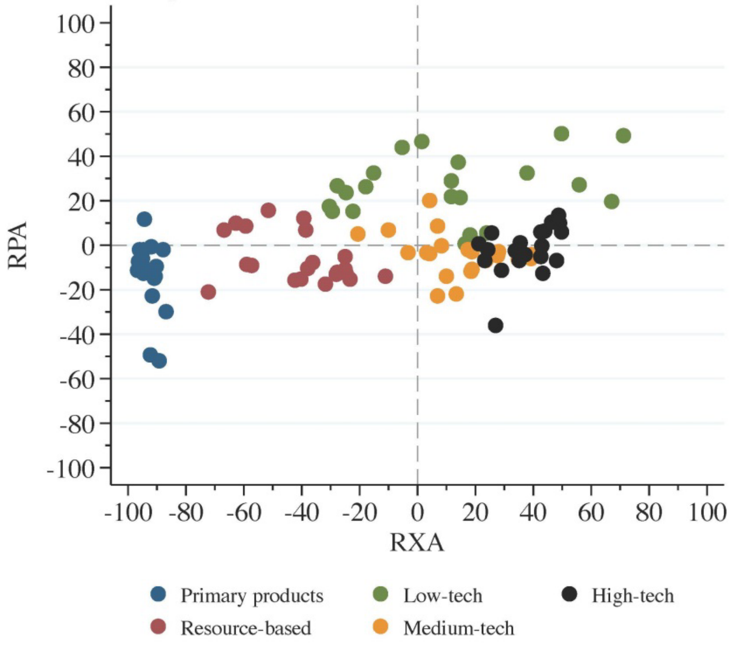
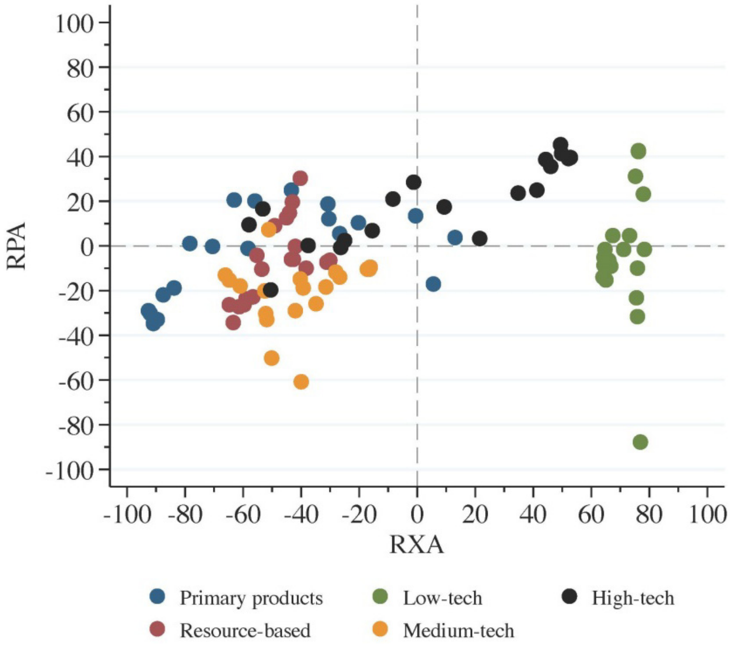


Figure 8:
Technological Specialisation Matrix – People's Republic of China



At this point we turn to the role of global value chains and present our estimates of vertical specialization (VS). Our estimates are included in table 1: the shares of VS in exports increase for all countries over time. The Republic of Korea and Germany are the countries with the highest shares, whereas Japan shows the lowest share of VS in exports. Japan and the Republic of Korea show their highest shares of VS in PP exports, whereas in RB exports the Republic of Korea, Germany and the PRC show the highest shares. Regarding LT exports, the available data indicates that Germany and the Republic of Korea use a considerable amount of foreign produced intermediate goods. In the case of MT exports, the Republic of Korea, Germany and the PRC rely strongly on VS. Finally, the latter three countries also account for the highest shares of VS in HT exports. The geographic distribution of imports of intermediate products reveals that Germany imports intermediate products mainly from other member countries of the European Union and that the US relies on Canada and Mexico for this purpose. Japan, the Republic of Korea and the PRC organize value chains with the participation of other Asian countries.

Table 1:
Vertical Specialization 1990–2010

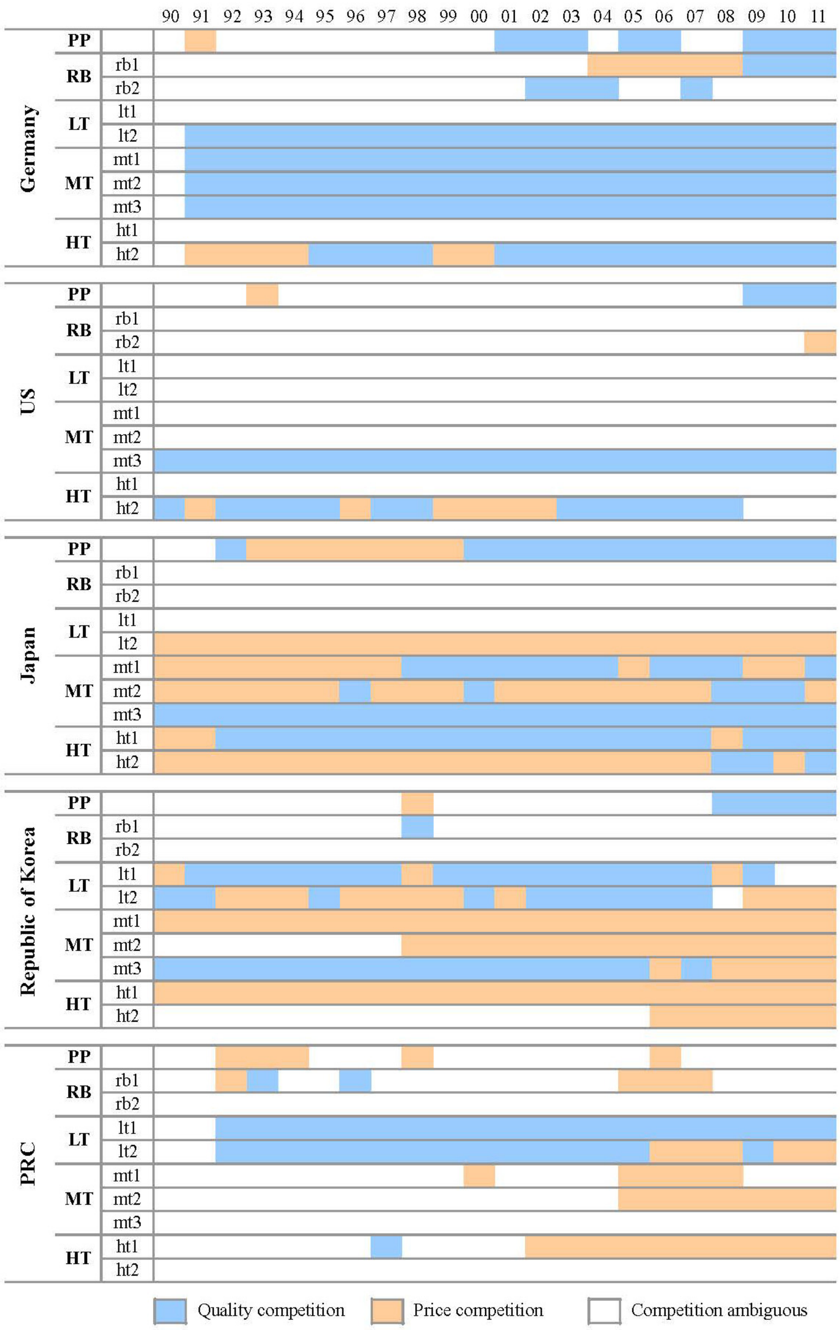
VS in % of Exports	1990	1995	2000	2005	2010
Germany	23.4	19.4	27.4	33.6	33.6
Primary products	3.5	2.9	3.8	5.9	5.7
Resource-based	4.0	3.3	4.5	5.1	5.3
Low-technologies	4.9	4.0	4.7	5.0	5.1
Medium-technologies	7.0	5.9	8.2	10.2	9.8
High-technologies	3.8	3.3	6.2	7.4	7.5
United States	9.4	11.0	13.1	14.4	14.2
Primary products	1.5	1.4	1.8	2.6	2.8
Resource-based	1.4	1.4	1.7	2.1	1.9
Low-technologies	1.8	2.1	2.4	2.6	2.4
Medium-technologies	3.1	3.6	4.0	4.2	3.7
High-technologies	1.5	2.5	3.1	2.9	3.3
Japan	7.5	6.2	8.0	11.2	12.5
Primary products	2.8	1.9	2.4	3.6	4.4
Resource-based	1.8	1.3	1.4	2.0	2.3
Low-technologies	1.0	1.0	1.2	1.5	1.6
Medium-technologies	1.0	0.9	1.2	1.8	1.9
High-technologies	0.8	1.1	1.8	2.1	2.3
Republic of Korea	29.4	29.0	33.7	34.5	46.6
Primary products	7.0	6.1	9.4	10.1	14.4
Resource-based	5.7	4.8	4.7	5.2	8.2
Low-technologies	2.9	3.0	2.7	3.5	4.7
Medium-technologies	8.4	8.5	6.7	7.6	10.8
High-technologies	5.2	6.0	9.6	8.0	8.4
People’s Republic of China	20.2	19.2	20.4	32.7	26.3
Primary products	2.2	2.1	3.1	4.8	5.2
Resource-based	2.5	2.6	2.9	4.8	5.0
Low-technologies	3.4	3.0	2.5	2.9	1.4
Medium-technologies	8.8	8.0	6.2	8.6	6.6
High-technologies	3.3	3.4	5.8	11.7	8.0

Note: Figures for Germany in 1990 were not available, therefore we report figures for 1991, the same is in the case of PRC, where figures reported refer to 1992. Furthermore, other-technologies were excluded.

Source: Own calculations based on data from UN Comtrade and the World Bank.

Concerning the nature of competition we present our estimates calculated with the unit value method (UV) mentioned in the last section. Based on the results of UV outlined in table 2, we attempt to establish whether the product groups our sample countries are specialized in are subject to price or quality competition on the world market. Price competition seems to prevail for LT (Japan), MT (PRC and the Republic of Korea) and HT (PRC, Japan, the Republic of Korea and the US). Quality competition obtains for PP (Japan), LT (PRC, Germany and the Republic of Korea), MT (Germany, Japan, the Republic of Korea and the US) and HT (Germany, Japan and the US). Quality competition seems to be particularly relevant for Germany’s specialization.

Table 2:
Unit Values 1990–2011



			90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11
Germany	PP		☐	🟧	☐	☐	☐	☐	☐	☐	☐	☐	☐	🟦	🟦	🟦	☐	🟦	🟦	☐	☐	🟦	🟦	🟦
	RB	rb1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	🟧	🟧	🟧	🟧	🟧	🟦	🟦	🟦
		rb2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	🟦	🟦	🟦	☐	☐	🟦	☐	☐	☐	☐
	LT	lt1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		lt2	☐	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	MT	mt1	☐	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
		mt2	☐	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
		mt3	☐	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	HT	ht1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		ht2	☐	🟧	🟧	🟧	🟧	🟦	🟦	🟦	🟦	🟧	🟧	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
US	PP		☐	☐	☐	🟧	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	🟦	🟦	🟦
	RB	rb1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		rb2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	🟧
	LT	lt1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		lt2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	MT	mt1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		mt2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		mt3	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	HT	ht1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		ht2	🟦	🟧	🟦	🟦	🟦	🟦	🟧	🟦	🟦	🟧	🟧	🟧	🟧	🟦	🟦	🟦	🟦	🟦	🟦	☐	☐	☐
Japan	PP		☐	☐	🟦	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	RB	rb1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		rb2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	LT	lt1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		lt2	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
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		ht2	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟦	🟦	🟧	🟦
Republic of Korea	PP		☐	☐	☐	☐	☐	☐	☐	☐	🟧	☐	☐	☐	☐	☐	☐	☐	☐	☐	🟦	🟦	🟦	🟦
	RB	rb1	☐	☐	☐	☐	☐	☐	☐	☐	🟦	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		rb2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	LT	lt1	🟧	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟧	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟧	🟦	☐	☐
		lt2	🟦	🟦	🟧	🟧	🟧	🟦	🟧	🟧	🟧	🟧	🟦	🟧	🟦	🟦	🟦	🟦	🟦	🟦	☐	🟧	🟧	🟧
	MT	mt1	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
		mt2	☐	☐	☐	☐	☐	☐	☐	☐	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
		mt3	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟧	🟦	🟧	🟧	🟧	🟧
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		ht2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	🟧	🟧	🟧	🟧	🟧	🟧
PRC	PP		☐	☐	🟧	🟧	🟧	☐	☐	☐	🟧	☐	☐	☐	☐	☐	☐	☐	🟧	☐	☐	☐	☐	☐
	RB	rb1	☐	☐	🟧	🟦	☐	☐	🟦	☐	☐	☐	☐	☐	☐	☐	☐	🟧	🟧	🟧	☐	☐	☐	☐
		rb2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	LT	lt1	☐	☐	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
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	MT	mt1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	🟧	☐	☐	☐	☐	🟧	🟧	🟧	🟧	☐	☐	☐
		mt2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	🟧	🟧	🟧	🟧	🟧	🟧	🟧
		mt3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	HT	ht1	☐	☐	☐	☐	☐	☐	☐	🟦	☐	☐	☐	☐	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
		ht2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

🟦 Quality competition 🟧 Price competition ☐ Competition ambiguous

Due to the fact that price competition also plays a role in explaining specialization patterns, we will now take a look at price and cost indicators (figures A4, A5, A6, Appendix). Real effective exchange rates (REER) are traditionally used to determine the price competitiveness of countries. We use data from a database supplied by the Bruegel Institute in Brussels (Darvas 2012) which includes a REER on the basis of the consumer price index. As may be seen from figure A4, the Republic of Korea is the only country experiencing a strong depreciation since 2007; all other countries see their REER appreciate, especially

Japan. This indicator puts the Republic of Korea at the top. Turning to figure A5 we see the nominal unit labor costs (data from the OECD), excluding the PRC. From this indicator we may conclude that Japan occupies the best position and that (nominal) costs are increasing in Germany and in the Republic of Korea as well as in the US; in fact the US shows the weakest performance in this respect. Finally, we take a look at labor productivity (figure A6; data from the OECD, Appendix): the Republic of Korea features productivity increasing at a high rate, while the other countries (again excluding the PRC) show only very slowly increasing labor productivities.[12]

5. Conclusions

Germany is one of the few advanced countries in the world economy with a share of manufacturing industry in gross value added of around 20 %. As most indicators show, Germany's manufacturing sector is particularly strong in the field of middle-range technologies and earned the country important market shares in world trade. German trade specialization matches technological specialization well and largely emerges as a result of product quality and vertical specialization in the relevant product group. The latter consists of automotive and engineering products as well as products derived from the process industries. Although this pattern of specialization is shared in part with Japan and the US, the Republic of Korea and the PRC also have developed strong positions in medium-technology products. The quality of German products is characterized by relatively high research intensity and is closely related to R&D effort and industrial design and patenting activity. German trade specialization, however, also includes products that are subject to price competition the international success of which depends on the evolution of price and cost indicators vis-à-vis Germany's major trade partners.

As world trade expands, Germany's share has been declining in line with that of Japan and the US. In contrast, the shares of the Republic of Korea and the PRC have been increasing. In the wake of globalization, global value chains account for an increasing share of world trade. In our sample, the Republic of Korea shows the highest share of intermediate imports in its exports, followed by Germany; the PRC also relies to a larger extent on vertical specialization than Japan and the US. Germany's future performance will be influenced by current and future challenges and its ability to respond technologically to them by adjusting its R&D, industrial design and patenting activity. Compared with the sample countries, Germany has the lowest share of researchers working in the private sector and at the same time the highest share of researchers working for the government and in higher education. This poses a problem of sustainability. More worrying than structural issues seems to be the stagnation in German patenting activity over the last decade.

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[12] For reasons of space we do not include all tables and figures in the Appendix. The authors will be pleased to provide the data to interested readers.

Future challenges faced by Germany and other open economies include the consequences of climate change and of population ageing for the composition of GDP and particularly the manufacturing sector. Technologies aiming at a mitigation of climate change and enabling economies to adapt to climate change are expected to play a leading role over the next decades. Also, the need to substitute scarce natural resources for new materials and capital will have to be addressed by R&D and process and product innovations. Furthermore, to the extent that the bottlenecks existing in the supply of qualified labor (including researchers) are not overcome, structural change in Germany could slow down.

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APPENDIX

I. Methods

We use the standard formula for the **Relative Export Advantage (RXA)** index which assumes that domestic firms compete with other firms on a global level. Hence, the indicator is defined as the ratio of exports *x* in technology group *j* and the sum of exports by country *i* to the ratio of the sum of world exports *x* in technology group *j* and the overall sum of world exports:

$$RXA_{ij} = 100 * \tanh \ln \left[\frac{\left(x_{ij} / \sum_{i} x_{ij} \right)}{\sum_{j} x_{ij} / \sum_{ij} x_{ij}} \right]$$

The **Revealed Comparative Advantage (RCA)** index is calculated as the ratio of exports *x* and imports *m* of country *i* in technology group *j* over the ratio of the sum of exports to the sum of imports of the country taken into consideration:

$$RCA_{ij} = 100 * \tanh \ln \left[\frac{\left(x_{ij} / m_{ij} \right)}{\sum_{j} x_{ij} / \sum_{j} m_{ij}} \right]$$

In order to measure domestic value-added in export manufactures, we focus on input-output relationships. Following the seminal work by Hummels et al. (2001: 78–79) we define **Vertical Specialisation (VS)** as the ratio of imported intermediate inputs *M* to gross value added *Y* , multiplied by exports *X* of country *i* in technology group *j*:

$$VS_{ij} = \frac{M_{ij}}{Y_i} * X_{ij}$$

Finally, in order to determine whether quality or price determines export advantage, we follow Aiginger (1997) and estimate the **Unit Values** (UV) of traded goods (a type of elasticity). A UV is defined as the ratio of the value of a export good *x* or import good *m* of country *i* in technology group *j* in current US$ to its quantities:

$$UV_{ij} = \frac{x_{ij}}{net\ weight\ of\ x_{ij}}$$

In doing so, we recommend to use the net weight in kilograms instead of supplementary units. Although supplementary units a more accurate than net weights for some products, it is rather difficult to deal with changes in those units. Furthermore net weights are available for a longer time period than supplementary units.

II. Tables and Figures

Table A1: Technological Classification of Trade Data at a Glance

Classification	Product examples	SITC codes	
1. Primary products	Fruits, meat, rice, cocoa, tea, coffee, wood, crude petroleum, natural gas	52	19.9 %
2. Resource-based manufactures		68	26.1 %
Agro-based products	Processed meats and fruits, beverages, wood products, vegetable oils	37	14.2 %
Other resource-based products	Petroleum and rubber products, ore concentrates, cement, glass	31	11.9 %
3. Low-technology manufactures		47	18.0 %
Textile and footwear	Textile fabrics, clothing, headgear, footwear, leather	20	7.7 %
Other low-technology products	Pottery, furniture, jewellery, toys, consumer goods, plastic products	27	10.3 %
4. Medium-technology manufactures		71	27.2 %
Automotive	Passenger vehicles, commercial vehicles, motorcycles and parts	5	1.9 %
Engineering	Engines, motors, industrial machinery, pumps, switchgear, ships, watches	37	14.2 %
Process industries	Synthetic fibres, chemicals and paints, fertilisers, plastics, iron, pipes and tubes	29	11.1 %
5. High-technology manufactures		19	7.3 %
Electronics and electrical	Office, data and telecommunication equipment, televisions, transistors, turbines	10	3.8 %
Other high-technology products	Aerospace, pharmaceuticals, optical and measurement instruments, cameras	9	3.4 %
6. Others	Electricity, cinema film, printed matter, gold, art	4	1.5 %
		261	100 %

Source: Own elaboration with data from UN COMTRADE.

Table A2: Sector Classification Regarding R&D Intensities

Classification	Industries
Low R&D intensity with R&D expenditure less than 1 % of net sales	Oil and gas producers, industrial metals, construction and materials, food and drug retailers, transportation, mining, tobacco, multi-utilities
Medium-low R&D intensity with R&D expenditure between 1 % and 2 % of net sales	Food producers, beverages, travel and leisure, media, oil equipment, electricity, fixed line telecommunications
Medium-high R&D intensity with R&D expenditure between 2 % and 5 % of net sales	Electronics and electrical equipment, automobiles & parts, aerospace and defence, industrial engineering and machineries, chemicals, personal goods, household goods, general industrials, support services
High R&D intensity with R&D expenditure above 5 % of net sales	Pharmaceuticals and biotechnology, health care equipment and services, technology hardware and equipment, software and computer services

Source: Own elaboration based on the EU Industrial R&D Scoreboard (2013).

Table A3:
Expenditures on R&D 1996–2010

Share in World R&D expenditure	1996	1998	2000	2002	2004	2006	2008	2010
Germany	8.6	8.2	8.0	7.7	7.3	7.0	7.1	7.1
GERD	2.2	2.3	2.5	2.5	2.5	2.5	2.7	2.8
BERD	1.5	1.5	1.7	1.7	1.7	1.8	1.9	1.9
United States	41.0	40.9	40.8	37.8	35.9	35.2	35.1	33.6
GERD	2.6	2.6	2.7	2.6	2.5	2.7	2.9	2.8
BERD	1.8	1.9	2.0	1.8	1.8	1.9	2.0	1.9
Japan	41.0	40.9	40.8	37.8	35.9	35.2	35.1	33.6
GERD	2.8	3.0	3.0	3.1	3.1	3.4	3.5	3.3
BERD	2.0	2.1	2.1	2.3	2.4	2.6	2.7	2.5
Republic of Korea	3.1	2.6	2.8	3.1	3.3	3.5	3.8	4.3
GERD	2.4	2.3	2.3	2.4	2.7	3.0	3.4	3.7
BERD	1.8	1.6	1.7	1.8	2.1	2.3	2.5	2.8
People's Republic of China	2.3	2.8	4.1	5.4	6.9	8.6	10.4	14.6
GERD	0.6	0.6	0.9	1.1	1.2	1.4	1.5	1.8
BERD	0.2	0.3	0.5	0.7	0.8	1.0	1.1	1.3

Note: World shares are calculated in current international US$, Gross Domestic Expenditures on R&D (GERD) and Gross Business Expenditures on R&D (BERD) as a percentage of GDP.

Source: Own calculations with data provided by the UNESCO Institute for Statistics.

Table A4:
Country Shares in World Researchers 1996–2010

Share of World Researchers	1996	1998	2000	2002	2004	2006	2008	2010
Germany	9.6	9.5	9.1	8.8	8.2	7.6	7.5	8.8
Government	16.4	16.1	14.6	14.7	15.6	14.8	15.0	15.8
Higher education	28.7	27.8	26.0	26.8	24.3	24.0	25.4	27.6
Business sector	54.9	56.2	59.4	58.5	60.0	61.1	59.6	56.7
United States	45.3	49.3	44.9	43.3	40.9	37.2	33.8	36.5
Government	4.8	3.9	3.7	3.7	3.6	3.5	3.5	3.5
Higher education	16.4	14.4	14.6	14.2	13.8	13.6	13.6	13.6
Business sector	78.8	80.6	81.7	82.1	82.6	82.9	82.9	82.9
Japan	25.7	26.0	22.8	20.6	19.9	18.6	16.3	17.6
Government	4.9	4.7	4.8	5.4	5.2	4.9	4.9	4.9
Higher education	27.5	27.1	27.7	23.6	23.6	23.3	18.8	19.1
Business sector	64.8	64.9	66.3	73.4	74.2	77.8	77.5	76.5
Republic of Korea	4.1	3.7	3.8	4.7	4.8	5.4	5.8	7.1
Government	12.4	10.9	10.7	8.0	7.8	7.0	6.6	7.5
Higher education	19.6	23.3	21.8	17.6	17.1	14.2	14.7	14.9
Business sector	66.6	64.9	66.3	73.4	74.2	77.8	77.5	76.5
People's Republic of China	22.2	18.8	24.5	26.8	28.2	33.2	39.4	32.4
Government	33.6	34.3	27.8	23.3	20.6	17.2	15.0	19.1
Higher education	24.6	34.1	21.3	22.0	22.3	19.3	16.4	19.8
Business sector	41.8	31.6	50.9	54.7	57.1	63.5	68.6	61.1

Note: Since some values for USA are missing, we extra/interpolate values for researchers working in government from 2003–2010, for higher education for 1996, 1998 and the period 2000 to 2010 and for business sector from 2008 to 2010. Figures for private non-profit and not specified are nor reported here.

Source: Own calculations with data provided by the UNESCO Institute for Statistics.

Figure A1:
Revealed Comparative Advantage (RCA) of Germany

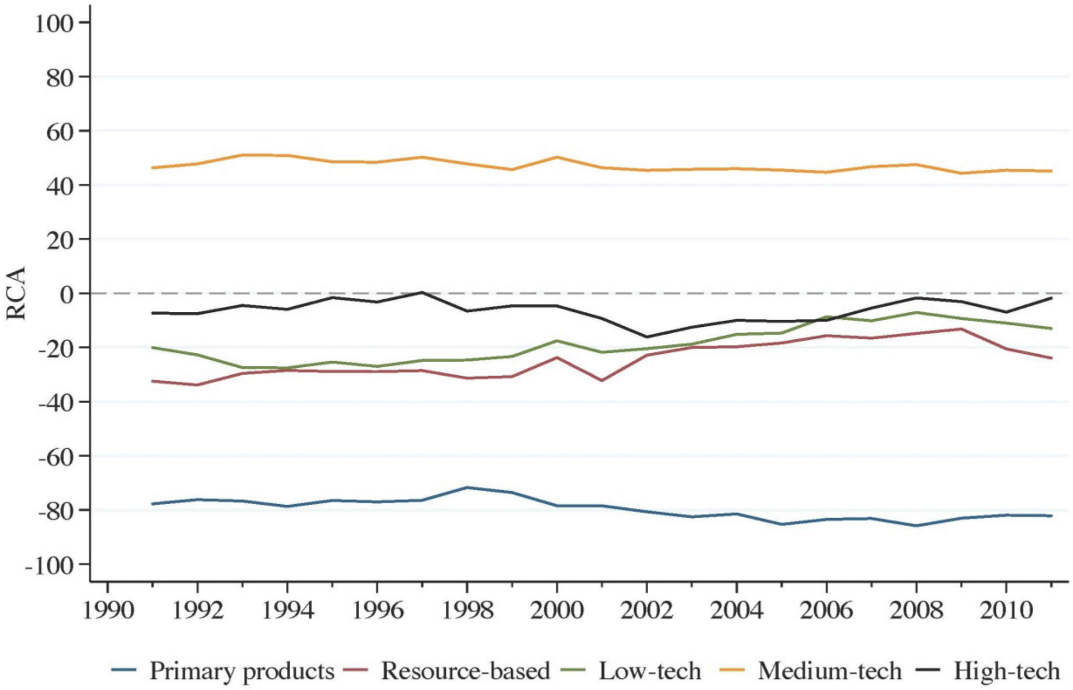


Figure A2:
Relative Export Advantage (RXA) of Germany

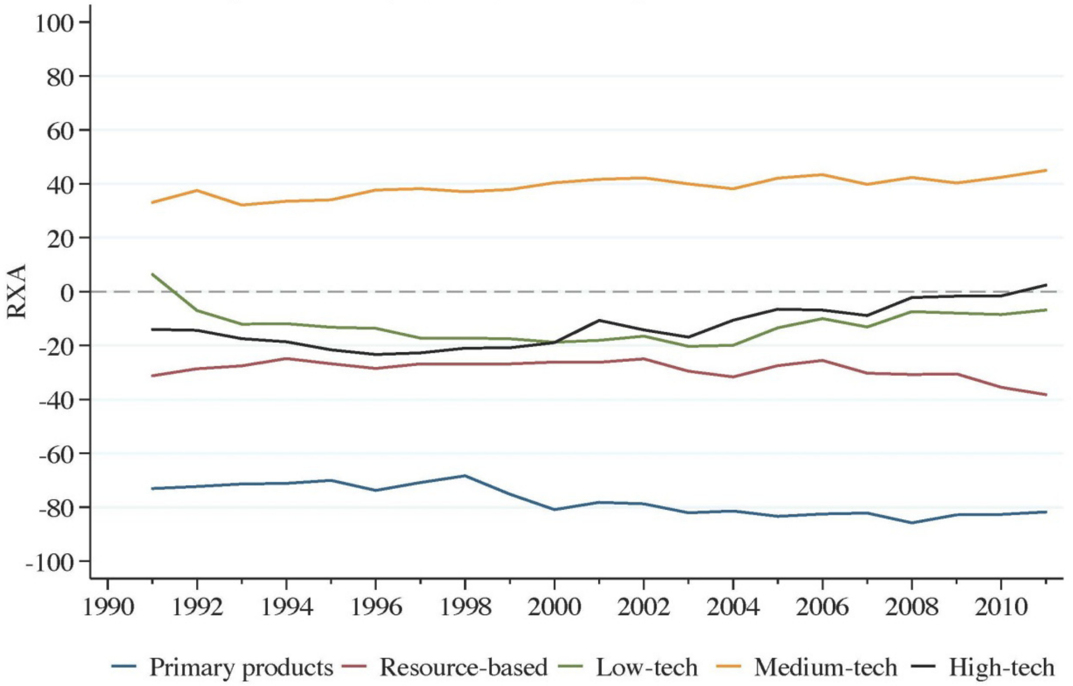


Figure A3:
Relative Patent Advantage (RPA) of Germany

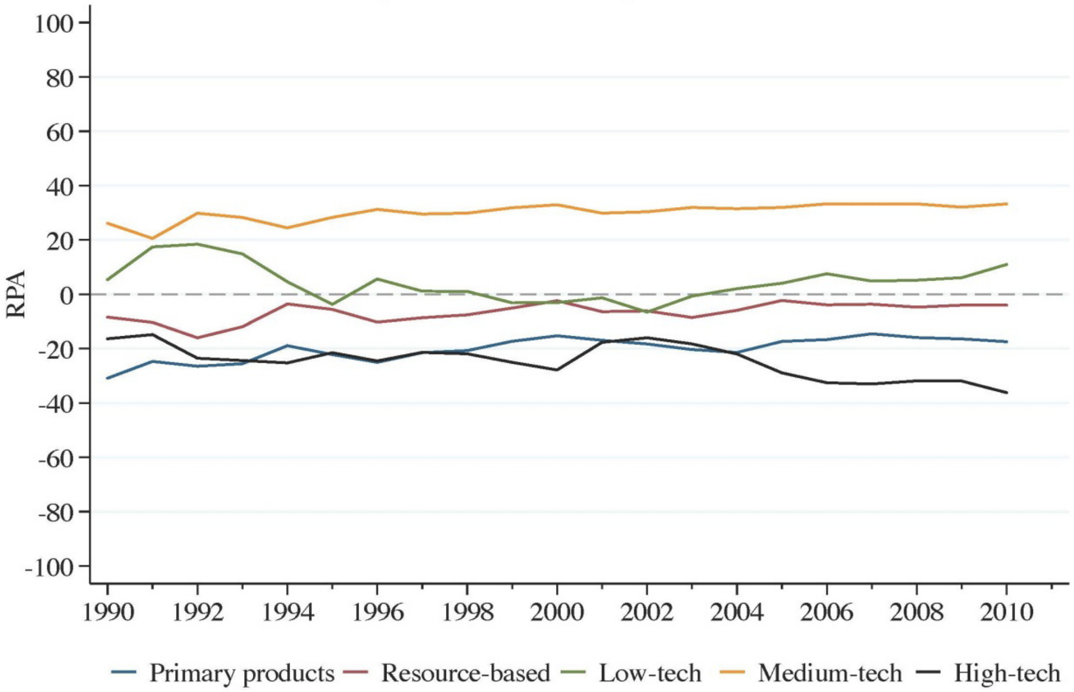


Figure A4:
Real Effective Exchange Rate (REER) – Based on Consumer Price Index (2007=100)

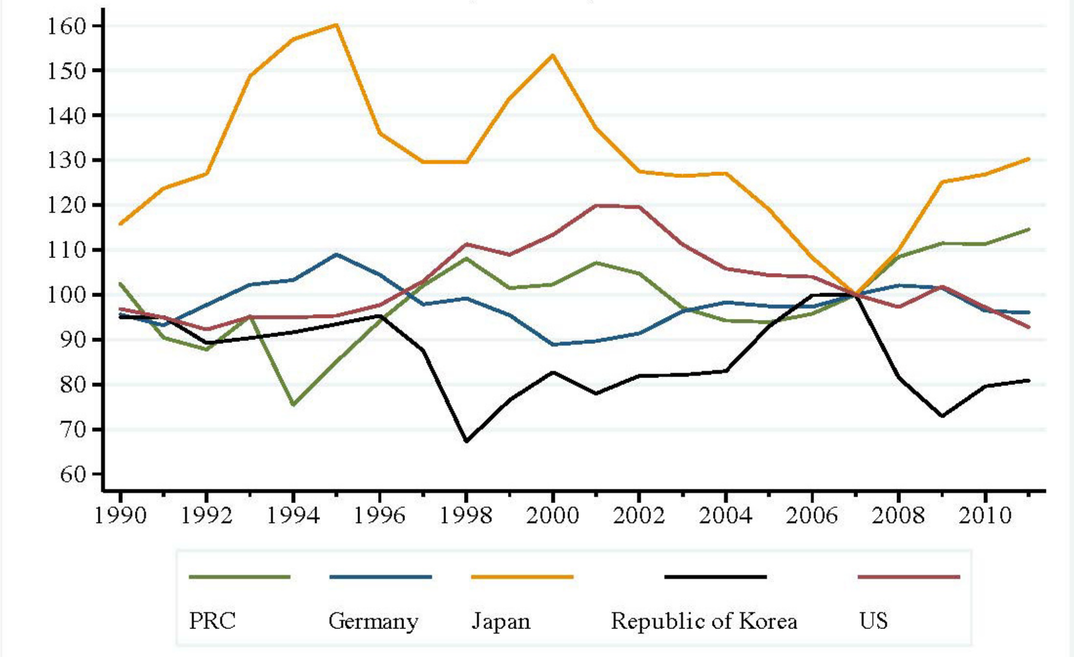


Figure A5:
Nominal Unit Labour Costs – Index OECD Base Year 2005=100

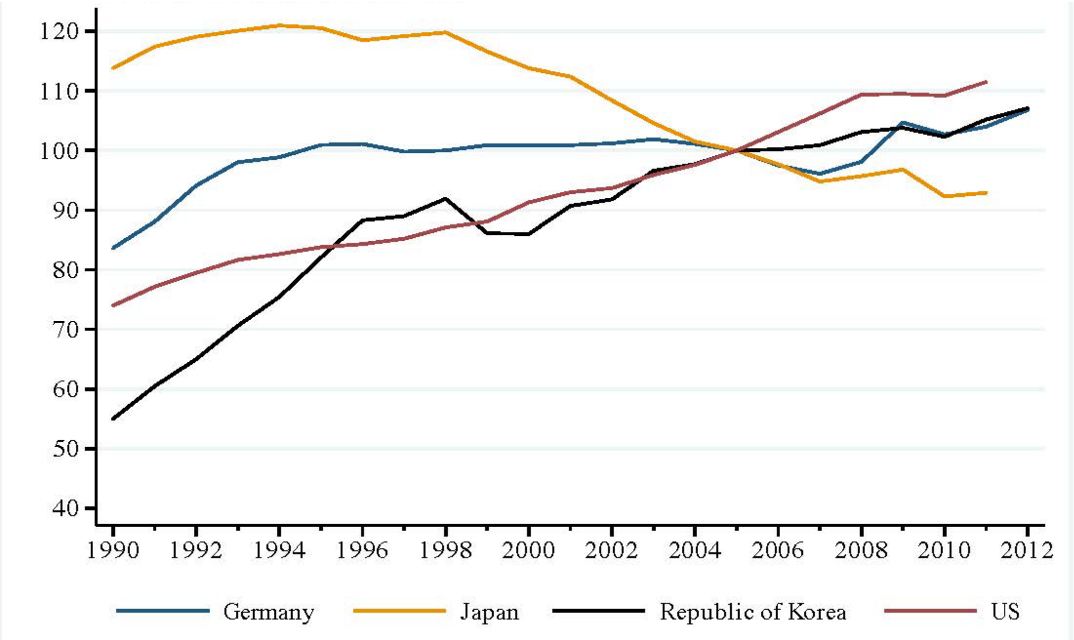
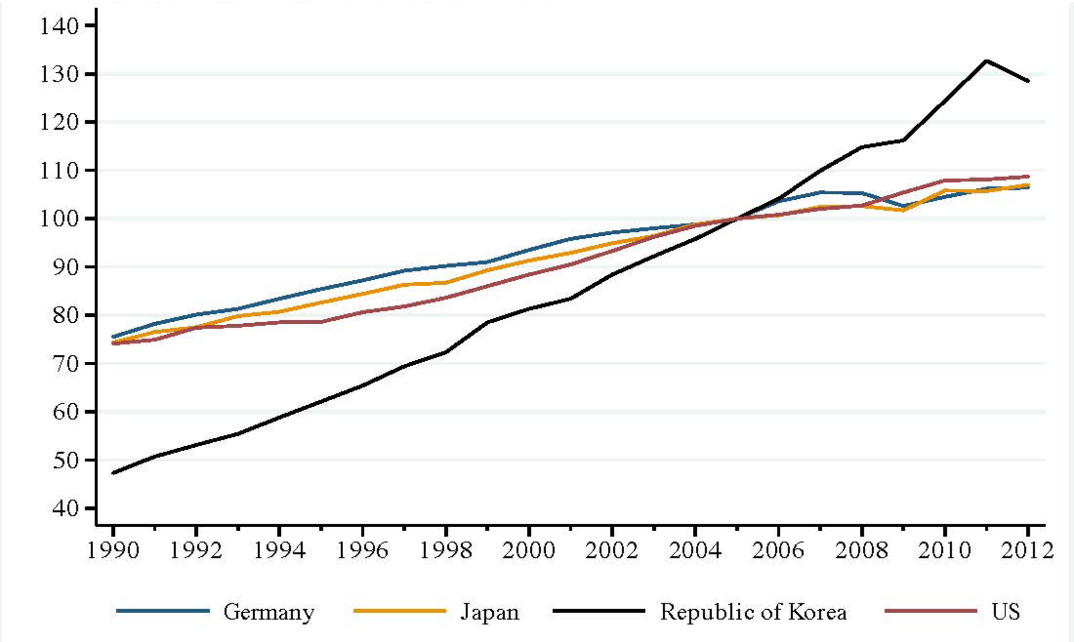


Figure A6:
Labour Productivity of the Total Economy – GDP per Hour Worked Index (2005=100)



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