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Performance and Structures of the German Science System in an International Comparison 2008

Analyses carried out for the annual report of the
Expert Commission on Research and Innovation

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Studien zum deutschen Innovationssystem Nr. 6-2009

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1. Introduction to the Issue

The scientific capability of a country is an essential basis for its technological performance, which is why this topic has been regularly analyzed for many years in the context of reports on technological performance. The crucial contribution of science to technology development consists in educating highly skilled personnel whose quality depends to a considerable extent on the research capability. It goes without saying that the results of scientific research are also an essential foundation for technical development, whereby the connections between science and industry are frequently of an indirect nature and less obvious, particularly because in many cases a distinct time lag can be observed between activities in science and their impact on technology.

Scientific performance is difficult to measure, especially as the structures in the individual disciplines frequently vary distinctly. Statistical analyses of publications by experts have proved to be meaningful, inasmuch as they are conducted with a meticulous regard for methodology. The analyses presented here refer not only to science areas with a close link to technology, but to the natural, life and engineering sciences as a whole. In this context, the number of publications and citations is analyzed as a performance indicator in an international comparison. Furthermore, publications of German enterprises, in particular small and medium-sized enterprises, are analysed in more detail. A special chapter is devoted to scientific publications of catching-up countries.

The data for the analysis of scientific performance of Germany in an international comparison were provided in August 2008, the analysis of enterprises and catching-up countries were performed in October 2008.

2. Scientific Performance Mirrored by Bibliometric Indicators

2.1 Methodological Basis

The bibliometric analyses were carried out utilizing the Science Citation Index (SCI), a multidisciplinary database covering a broad spectrum of disciplines. The searches cover the natural and engineering sciences as well as medicine and life sciences. The database deals above all with English language journals, which is unproblematic for most fields. The German engineering sciences which mainly publish in the German language, however, are inadequately recorded. Generally, journals are reviewed in the SCI which are frequently cited, i.e. with high visibility, so that primarily higher quality publications are taken into consideration. Thus the fact alone that a paper is recorded in the SCI, respectively, that it appears in journals covered by the SCI, can be considered a first quality indicator.

Besides the absolute number of publications which are available up to the year 2007, citations in particular will be utilized as performance indicators. To estimate the citation rates, citations from the actual year of publication and the two following years are considered, so that a standard time window of three years forms the basis for all years considered. For this reason, citation rates can only be calculated up to the year of publication 2005. As this type of analysis is quite complex, a special preparation of the SCU is necessary; the data for this report were provided by the Centre of Science and Technology Studies (CWTS) at the University of Leiden, the Netherlands.

For a more exact analysis of the citation quotas, the calculation of two additional indicators is meaningful, the "Zeitschriftenspezifischen Beachtung" (journal-specific Scientific Regard (SR Index)) and the "Internationalen Ausrichtung (IA Index)" (International Alignment). The indicator "Scientific Regard" states whether the articles of a country /a region are cited on average more frequently or more seldom than the articles in the journals in which they appeared. Positive indices point to an above-average citation rate; values of zero correspond to the world average. Through reference to the journal in question the disadvantages of countries which have less than optimum access to big English-language journals are compensated for. Furthermore, the different citation behaviour between disciplines is compensated. The indicator is calculated as follows:

$$SR_k = 100 \tanh \ln (OBS_k/EXP_k)$$

In this equation, OBS_k means the actually observed citation frequency of publications from country k. EXP_k is the expected citation rate which results from the average citation frequency of the journals in which the authors of this country have published their articles.

In addition to this, the indicator "International Alignment" shows whether the authors of a country publish in internationally visible or in less visible journals, judged against the world average. Through a high quota of publications in internationally visible journals an intensive participation in the international scientific discussion is documented. Similar to the SR Index, positive values in the IA Index signify an above-average international orientation. The IA Index is calculated as follows:

$IA_k = 100 \tanh \ln (EXP_k/OBS_w)$

The same conventions apply as for the SR index. The index w stands for the world as a whole.

In order to compensate for possible distortions through database coverage in the analysis of absolute publication numbers, the specialization index RLA (Relative Literature Advantage) is calculated. The corresponding equation is:

$RLA_{ij} = 100 \tanh \ln [(Publ_{ij} / \sum_i Publ_{ij}) / (\sum_j Publ_{ij} / \sum_{ij} Publ_{ij})]$

Here i stands for the country and j for the field. The RLA Index is so constructed that its scale of values encompasses ± 100 with the neutral value 0. Positive values indicate an above-average specialization, negative values a below-average one, whereby the world average serves as a reference.

2.2 Scientific Publications from Germany in an International Comparison

Due to the changes in the journals recorded in the SCI it is not meaningful to consider absolute numbers. It is better to consider the shares of selected countries in all SCI publications (Table 2-1). For Germany, a gradually decreasing share since the year 2001 emerges hereby, which was however also similarly observed for other large industrialized countries such as the USA, Japan, Great Britain or France. This phenomenon is explained by the increase of publications from catching-up countries like China, India, South Korea or Brazil.[1] As the number of journals in the SCI is limited and thus also the number of the publications it contains, the growing strength of the catching-up countries leads to visible displacement effects at the expense of established actors.

Table 2-1: Shares of Selected Countries and Regions in all Publications in the SCI

Country/ Region	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
USA	36.5	36.7	35.7	36.0	35.1	35.1	34.3	33.7	32.9	32.3	31.9	32.1	31.9	31.7	31.4	30.8	30.5	29.9
JPN	8.1	8.3	8.7	8.8	9.0	9.1	9.5	9.5	10.0	10.2	10.2	10.2	10.1	10.0	9.4	9.0	8.5	8.2
GER	6.4	7.3	7.5	7.4	7.8	7.9	8.2	8.6	9.0	9.0	9.0	9.0	8.8	8.7	8.4	8.4	8.2	8.0
GBR	8.9	9.1	9.1	9.3	9.5	9.5	9.6	9.3	9.4	9.3	9.4	9.1	8.8	8.6	8.4	8.2	8.1	8.1
FRA	5.4	5.5	5.9	6.0	6.1	6.3	6.4	6.6	6.7	6.7	6.6	6.6	6.4	6.4	6.1	6.0	5.9	5.8
SUI	1.5	1.6	1.6	1.7	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0
CAN	4.7	4.8	4.8	4.8	4.8	4.7	4.7	4.4	4.3	4.3	4.3	4.1	4.2	4.3	4.3	4.4	4.5	4.6
SWE	1.9	1.9	1.8	1.9	1.9	2.0	2.1	2.1	2.1	2.1	2.0	2.1	2.1	2.0	1.9	1.9	1.8	1.8
ITA	3.1	3.2	3.5	3.5	3.7	3.9	4.2	4.2	4.3	4.4	4.4	4.6	4.7	4.8	4.8	4.7	4.7	4.9
NED	2.3	2.3	2.3	2.5	2.5	2.6	2.6	2.7	2.6	2.5	2.5	2.5	2.5	2.5	2.6	2.6	2.6	2.5
FIN	-	-	-	-	-	-	-	-	-	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9
KOR	-	-	-	-	-	-	-	-	-	1.7	1.9	2.1	2.3	2.6	2.8	3.0	3.1	2.9
CHN	-	-	-	-	-	-	-	-	-	-	-	-	5.2	5.8	6.5	7.6	8.6	9.3
EU 15	-	-	-	-	-	-	-	-	-	40.9	40.7	40.6	39.9	39.4	39.4	38.8	38.4	38.0
EU 12*	-	-	-	-	-	-	-	-	-	-	-	-	3.4	3.4	3.5	3.5	3.5	3.5
EU 27*	-	-	-	-	-	-	-	-	-	-	-	-	42.4	41.9	42.0	41.3	40.9	40.4
World	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

*Data till 2005 refer to the EU10, from 2006 to EU12; **Data till 2005 refer to EU25, from 2006 to EU27.

Sources: SCI, searches by University of Leiden (CWTS), calculations by Fraunhofer ISI.

[1] Cf. section 4 for further details.

The displacement effect has different impacts in the various industrialized countries: if the publication share of the year 2000 is indexed to the level 100, then the index for Germany in the year 2007 lies at 88.5 (Table 2-2). In the USA with an index of 94.0 in 2007 the decrease was clearly less, in Japan with 80.8 on the contrary considerably larger. It is remarkable that the publications in Canada, Italy and the Netherlands have further risen in the past years, while the share has decreased in Great Britain, Japan, Sweden and Finland. On the contrary, South Korea with an index of 157.0 in 2007 showed a very strong increase. A time series for China, which was only included in this reporting process recently, is only available from the year 2002. However, even in this short time span a growth of the Chinese publication share by 80 per cent was observed.

Table 2-2: Shares of Selected Countries and Regions in all Publications in the SCI in the Period 2000 to 2006 indicated to the Year 2000 (Index = 100)

Country/ Region	2000	2001	2002	2003	2004	2005	2006	2007
USA	100	100.7	100.2	99.5	98.5	96.7	95.7	94.0
JPN	100	100.6	99.1	98.7	92.4	88.2	83.5	80.8
GER	100	99.6	97.6	95.7	93.3	92.9	90.4	88.5
GBR	100	96.4	93.3	91.0	89.5	87.0	86.0	86.2
FRA	100	99.8	97.2	96.8	92.2	91.9	89.6	87.5
SUI	100	96.7	95.8	99.0	99.3	98.3	99.2	100.8
CAN	100	96.4	98.2	99.7	100.7	104.2	106.0	106.8
SWE	100	103.7	101.4	97.6	94.4	93.5	90.1	90.8
ITA	100	104.0	105.7	108.2	109.5	107.6	107.5	111.2
NED	100	99.7	100.8	101.0	101.3	102.8	102.2	101.0
FIN	100	100.0	96.7	96.8	94.5	90.4	91.4	89.7
KOR	100	113.6	123.2	137.6	150.0	159.9	162.5	157.0
CHN	-	-	100.0	111.4	125.8	146.8	166.0	179.7
World	100	100	100	100	100	100	100.0	100.0

Sources: SCI, searches by University of Leiden (CWTS), calculations by Fraunhofer ISI.

Relatively new, incidentally, is the separate presentation of the new EU Member States[2], in which an increase in the share of the worldwide publications can also be observed, however on a much more modest scale than in South Korea or China.

When the citation rates are scrutinized (Table 2-3), the particularly good positions of Switzerland, the United States and the Netherlands emerge. All three countries were able to strengthen their already good position further, whereby Switzerland succeeded in taking over the leading position. It exhibits in 2005 better indicator values than the United States. Germany too was able to continue the positive trend of the past years, which however had no impacts on its relative positioning in comparison with the other actors, as in recent years the cita-

2 The addition of the shares of the EU15 and EU12 countries in Table 2-1 leads to a somewhat higher value than is given for the EU27 countries together, as there are co-publications of the old and new member countries and sometimes double counting took place.

tion quotas improved in almost all investigated countries. Also, the worldwide average citation numbers rose slightly. This could point to a general structural change in the database, for example, an increase in the number of journals covered which leads to an increase in the number of possible citations.[3]

Table 2-3: Citation Rates (3 year window) of Selected Countries and Regions in Publications in the Science Citation Index (without self-citations)

Country/ Region	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
USA	4.4	4.5	4.5	4.8	4.8	4.8	4.8	5.0	4.7	5.1	4.9	4.9	5.1	5.2	5.4	5.3
JPN	2.4	2.4	2.4	2.5	2.5	2.5	2.4	2.6	2.5	2.6	2.4	2.6	2.8	2.8	3.1	3.0
GER	3.2	2.9	3.1	3.4	3.4	3.4	3.5	3.6	3.3	3.6	3.6	3.6	3.9	4.0	4.3	4.4
GBR	3.3	3.2	3.4	3.6	3.5	3.6	3.5	3.9	3.6	3.7	3.6	3.8	4.4	4.5	4.8	4.8
FRA	2.9	3.0	3.0	3.2	3.1	3.2	3.2	3.3	3.1	3.2	3.2	3.4	3.5	3.6	3.8	3.9
SUI	4.7	4.7	4.7	5.0	5.2	5.0	5.1	5.4	4.7	5.1	5.0	5.0	5.2	5.2	5.6	5.7
CAN	3.0	3.0	3.2	3.3	3.5	3.4	3.6	3.8	3.6	3.8	3.4	3.8	4.0	4.2	4.3	4.3
SWE	3.2	3.2	3.4	3.5	3.6	3.6	3.5	3.7	3.4	3.7	3.8	3.9	4.0	4.5	4.5	4.6
ITA	2.4	2.6	2.6	2.8	2.9	2.9	2.9	3.1	2.9	3.2	2.7	3.0	3.3	3.4	3.6	3.8
NED	3.5	3.6	3.7	3.8	3.9	4.0	3.8	4.2	3.9	4.4	4.1	4.3	4.4	5.0	5.2	5.2
FIN	-	-	-	-	-	-	-	-	-	3.2	3.7	3.6	3.9	3.8	4.0	4.1
KOR	-	-	-	-	-	-	-	-	-	1.7	1.9	1.9	2.1	2.3	2.5	2.5
CHN	-	-	-	-	-	-	-	-	-	-	-	-	1.6	2.0	2.2	2.3
EU 15	-	-	-	-	-	-	-	-	-	3.3	3.3	3.3	3.5	3.7	3.8	3.9
EU 12*	-	-	-	-	-	-	-	-	-	-	-	-	1.9	2.1	2.1	2.2
EU 27**	-	-	-	-	-	-	-	-	-	-	-	-	3.4	3.5	3.7	3.8
World	2.8	2.9	2.9	3.1	3.0	3.0	3.0	3.2	2.9	3.1	3.0	3.2	3.3	3.4	3.6	3.6

Sources: SCI, searches and calculations by University of Leiden (CWTS), calculations by Fraunhofer ISI.

Whilst China demonstrates the greatest development dynamic with regard to the number of annual publications, China's citation quota is still relatively low, despite continual increases. However, the value is in the meantime slightly above that which was calculated for the new EU Member States (EU12) and which almost stagnated in 2004. The new Member States are thus the only countries in which the values for the citation rate are not rising, against the otherwise prevalent trend. As the new EU Member States are of lesser importance on the whole, their low indicator value hardly influences the total value for the EU27; this is primarily defined by the old Member States.

Table 2-4 reports the results for the indicator "journal-specific consideration" (SR Index). For Germany, this index has been slightly declining since the mid 1990s and at present remains relatively constant. On the whole, the value is comparable with that of the other leading industrialized countries like the USA, Great Britain or Canada. After an increase in the indicator values was noted especially for Sweden and the Netherlands in 2003, in the last two years it appeared that this positive trend was reversed again. Then as now leading with regard to the SR Index is Switzerland, but here too the values are slightly declining. Positive trends, how-

3 Actually, the research group CWTS of Leiden University, that supplied the data for this study, used a somewhat extended dataset as the basis in this year.

ever, begin to emerge for the investigated threshold countries, just the opposite of the developments in the leading industrialized countries. Not only South Korea, but also China were able to distinctly improve their indicator statistics since 2002 and in the meantime are achieving values which are even a little bit higher than the international norm. They are thus clearly ahead of the new EU12 Member States. China in particular has meanwhile reached the level of France and Finland, respectively, and the average value of the old EU Member States.

Table 2-4: Scientific Regard (SR Index) of Selected Countries and Regions in Publication in the Science Citation Index (without own citations)

Country/ Region	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
USA	9	9	10	10	10	10	11	11	11	9	9	9	10	9	9	8
JPN	-7	-7	-7	-9	-7	-7	-8	-7	-4	-7	-6	-7	-7	-10	-9	-10
GER	11	6	8	10	10	9	9	7	8	7	7	8	8	7	7	7
GBR	10	8	9	10	10	9	5	4	3	8	9	9	10	7	8	8
FRA	2	1	2	3	2	4	4	3	2	1	3	2	1	2	2	1
SUI	20	17	19	18	24	20	23	22	17	15	17	17	16	17	15	15
CAN	0	-1	2	1	5	5	6	5	9	5	9	3	4	6	5	4
SWE	10	10	12	12	15	12	13	14	12	15	9	8	9	11	9	8
ITA	-10	-8	-7	-8	-4	-4	-5	-5	-4	-3	-2	-4	0	-5	-2	-1
NED	12	11	13	11	12	13	10	15	14	10	7	11	8	13	11	9
FIN	-	-	-	-	-	-	-	-	-	2	7	8	8	3	2	4
KOR	-	-	-	-	-	-	-	-	-	-16	-11	-11	-9	-5	-2	4
CHN	-	-	-	-	-	-	-	-	-	-	-	-	-11	-1	1	3
EU 15	-	-	-	-	-	-	-	-	-	2	2	2	2	2	2	2
EU 10	-	-	-	-	-	-	-	-	-	-	-	-	-15	-13	-11	-12
EU 25	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
World	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Sources: SCI, searches and calculations by Leiden University (CWTS), calculations by Fraunhofer ISI.

From the German perspective, the development of the international orientation (IA Index) (Table 2-5) is positive. Here the on the whole positive trend observed since the beginning of the 1990s continues, i. e. the efforts towards a broad integration in the international scientific discussion are being successfully continued. On the whole, German authors are increasingly successful in placing their articles in reputed international journals. Switzerland too is particularly successful in this respect. In 2005, Switzerland reached the same value as the world leader in the IA Index, the USA, whose values are slightly declining. The Netherlands' values also develop positively, whereas the values for Canada and Sweden stagnate.

As far as international orientation is concerned, the South East Asian countries Japan, South Korea and China still do badly. The same applies for the new member states of the European Union (EU12). Whereas slight improvements are becoming visible for the former, the indicator value of the EU12 stagnate on a low level.

Generally, it can be assessed that due to the database structure and the still existing bias in favour of English-language and in particular US American journals, it is easier for these countries to achieve good indicator values, but the fact that non-English-speaking, European countries can also successfully break into internationally visible scientific journals, is seen in the

good position of Switzerland, but also of the Netherlands. Both these countries are ahead of Great Britain.

Table 2-5: International Orientation (IA Index) of Selected Countries and Regions in Publications in the Science Citation Index (without own citations)[4]

Country/ Region	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
USA	35	35	35	34	35	35	35	34	36	36	34	33	33	32	32	31
JPN	-10	-11	-11	-13	-13	-15	-17	-14	-14	-14	-18	-11	-11	-10	-6	-7
GER	3	-3	-2	0	0	3	4	3	3	5	7	6	8	9	11	13
GBR	7	4	7	5	5	7	6	11	10	12	15	15	19	19	20	21
FRA	1	4	1	1	0	-1	0	2	2	0	3	4	5	3	5	7
SUI	31	32	29	30	29	29	29	30	29	30	29	28	28	27	30	31
CAN	5	5	7	7	8	7	10	11	11	13	11	16	14	15	15	14
SWE	8	5	8	6	8	8	7	6	8	8	11	12	11	15	15	16
ITA	-3	-3	-2	-1	0	0	0	2	1	2	1	-1	-1	3	3	7
NED	11	12	12	11	12	14	13	13	14	21	20	19	21	24	26	27
FIN	-	-	-	-	-	-	-	-	-	8	10	6	8	9	8	9
KOR	-	-	-	-	-	-	-	-	-	-45	-38	-38	-37	-34	-32	-30
CHN	-	-	-	-	-	-	-	-	-	-	-	-	-56	-47	-45	-42
EU-15	-	-	-	-	-	-	-	-	-	1	3	2	4	5	6	8
EU-10	-	-	-	-	-	-	-	-	-	-	-	-	-38	-36	-38	-36
EU-25	-	-	-	-	-	-	-	-	-	-	-	-	1	2	3	4
World	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Sources: SCI, searches and calculations by University of Leiden (CWTS), calculations by Fraunhofer ISI.

2.3 Germany's Scientific Profile

In order to arrive at a more disaggregated consideration of Germany, a differentiation of the publication activities according to 26 sub-fields was undertaken. 18 of these sub-fields demonstrate clear relations to technology, the remaining 8 have a rather general character. This division[5] was made in order to more clearly emphasize the relationships between science and technology in the context of the process of reporting on Germany's technological performance (Schmoch 2000). Based on the indices of Scientific Regard (SR Index) and International Alignment (IA Index) for the individual fields, country-specific profiles of strengths and weaknesses in scientific performance can be drawn up. It proved meaningful to compare the German profiles with those of Switzerland, in order to illustrate how a western European country can achieve very high values in both categories.

Additionally, it is important that both indicators, the SR and the IA Index, are regarded in context, as they provide complementary information about the performance of a country, respectively its positioning. Thus the IA Index expresses whether a country/region has been successful in appearing in internationally particularly visible journals, the SR Index reflects in

4 For Finland, Korea, EU15 and the new candidate countries no data are available for 1993 and 1997.

5 In the figures (Figure 2-1 to Figure 2-3) this is made apparent by a separating line.

complementary fashion whether they were cited more frequently or less frequently than expected within the journal set in which the publications appeared.

Generally, it can be stated that the German actors are successful in placing their publications in very reputed journals (Figure 2-2, Table 2-5), simultaneously they succeed in these journals in attracting great attention to these articles, which is expressed in good citation quotas, which are higher than the typical average values for the journals. The distribution of the SR Index for Germany thus shows that in the great majority of the fields an above-average level was attained compared to the world average (Figure 2-1, Table 2-4).

With regard to the Scientific Regard (SR Index), the fields "civil engineering", "thermal processes", "process engineering", and "mechanical engineering" are especially well positioned in the German profile. Due to the limited coverage of German authors in these fields in the SCI (cf. Schmoch 2004 on this problem), the distinctly positive indices here could, however, be exaggerated with regard to the overall activities in these fields. However, the positive SR Indices in "measuring/control", "nuclear technology", "physics" "medicine" and "geosciences" can be considered as statistically meaningful in any way.

When the indicator values for International Alignment are simultaneously considered, Germany is well positioned in the fields "basic chemistry", "physics" "biology", "geosciences" as well as "multi-disciplinary journals". The good values of the previous year are confirmed in these fields.

Comparing the profile of SR Indices with Switzerland, it is particularly striking that Switzerland has succeeded in achieving positive indicator values for all sub-fields, except thermal processes (a quite small field) and that it achieves a higher level than Germany in the vast majority of the sub-fields. Whereby the reservations made for Germany with regard to coverage in the engineering science fields with the mentioned consequences surely also apply to Switzerland. On the whole, the comparison shows that Switzerland's scientific performance exhibits a remarkable level in almost all fields, not only in a selected number of fields, which explains the high average rating for Switzerland on the whole.

For the IA Index Switzerland achieved very high scores in almost all fields and above all is very well positioned in the broad range of fields. Only on this basis is an average value possible which lies clearly above that of Germany. A significant reason for this striking difference could be the high share of foreigners in Swiss science, which inevitably leads to a stronger orientation towards the international discussion.

Up to now the scientific sub-fields were analyzed with regard to performance indices. A further aspect is the question, which fields are indeed the focus of a country's research efforts. For these observations we use the specialization index RLA, which is defined in Section 2.1. Figure 2-3 reflects Germany's specialization profile from 2003 until 2007. It becomes clear primarily that the direction of German scientific research is characterized by a high degree of stability. The fluctuations in the indicator values are relatively low on the whole. Strengths of German science, in the sense of positive specialization in these fields, lie in "medical technology", "nuclear technology" and "physics". Here too hardly any changes have taken place in

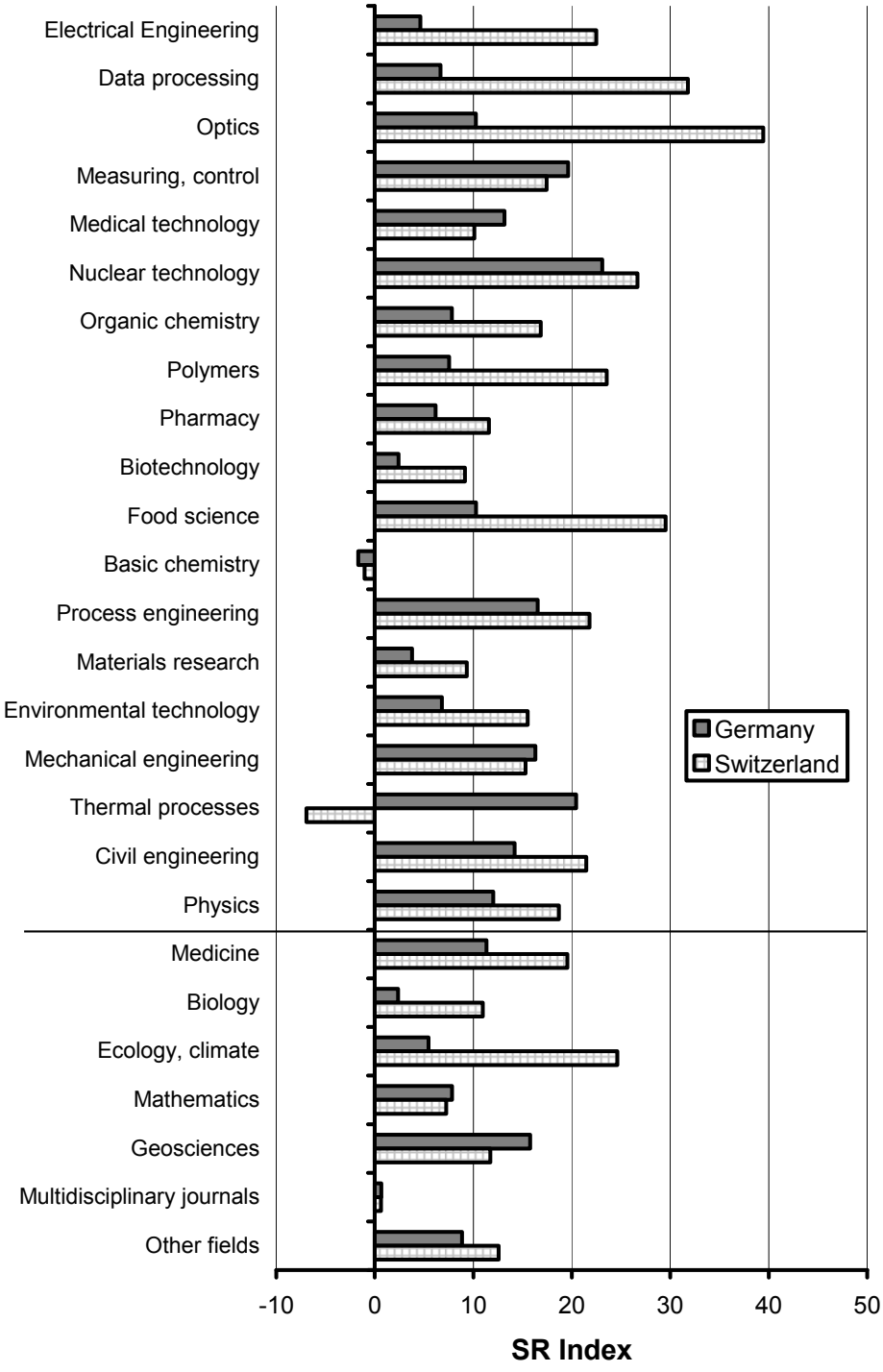
the course of time. The major sub-fields with a revent negative trend are "data processing" and "measuring/control"

As already briefly mentioned above, the negative indices in the engineering science fields like "process technology", "environmental technology", "mechanical engineering", "thermal processes" and "civil engineering" can be explained by the choice of journals in the SCI database which is inappropriate for German authors (Schmoch 2004). In these fields, a strong orientation towards national journals is necessary, in order to maintain contact with domestic enterprises. Only a small part of the publications by German authors appears in these fields in internationally famed journals, so that the statements to the citation indices in Figure 2-1 and Figure 2-2 refer only to a small share of the German publications and thus can in no way be representative for German engineering sciences as a whole.

The changes in the course of time are also relatively small within the single fields of engineering, on the whole.

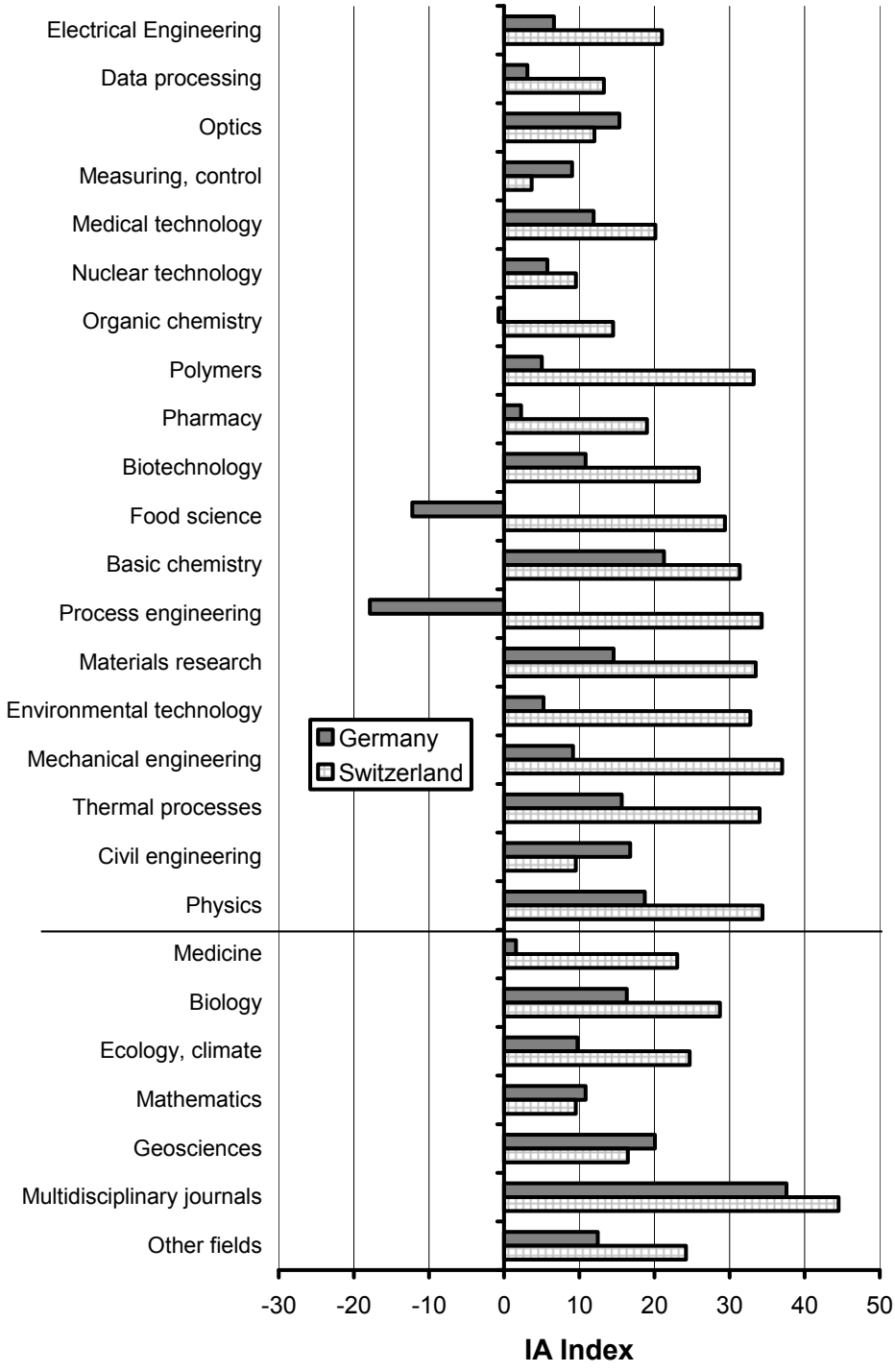
It has to be underlined again that the specialization in a sub-field, measured by the RLA, the Scientific Regard (SR), and the International Alignment (IA) indices are different dimensions of scientific performance. A computation of the correlation between the RPA and the SR or the IA shows no positive result, as in most cases the orientation of the different indices does not correspond. Furthermore, there is no correlation between the SR and IA indices. However, it is possible to determine fields where all three indices are positive. These fields can be considered as fields of specific scientific performance. As illustrated in Figure 2-4, German authors show these specific patterns in "optics", "medical technology" "nuclear technology", "physics" and "geosciences".

Figure 2-1: Scientific Regard (SR Index) of Germany and Switzerland of Publications in the Science Citation Index (without own citations) differentiated acc. to Science Fields, 2005



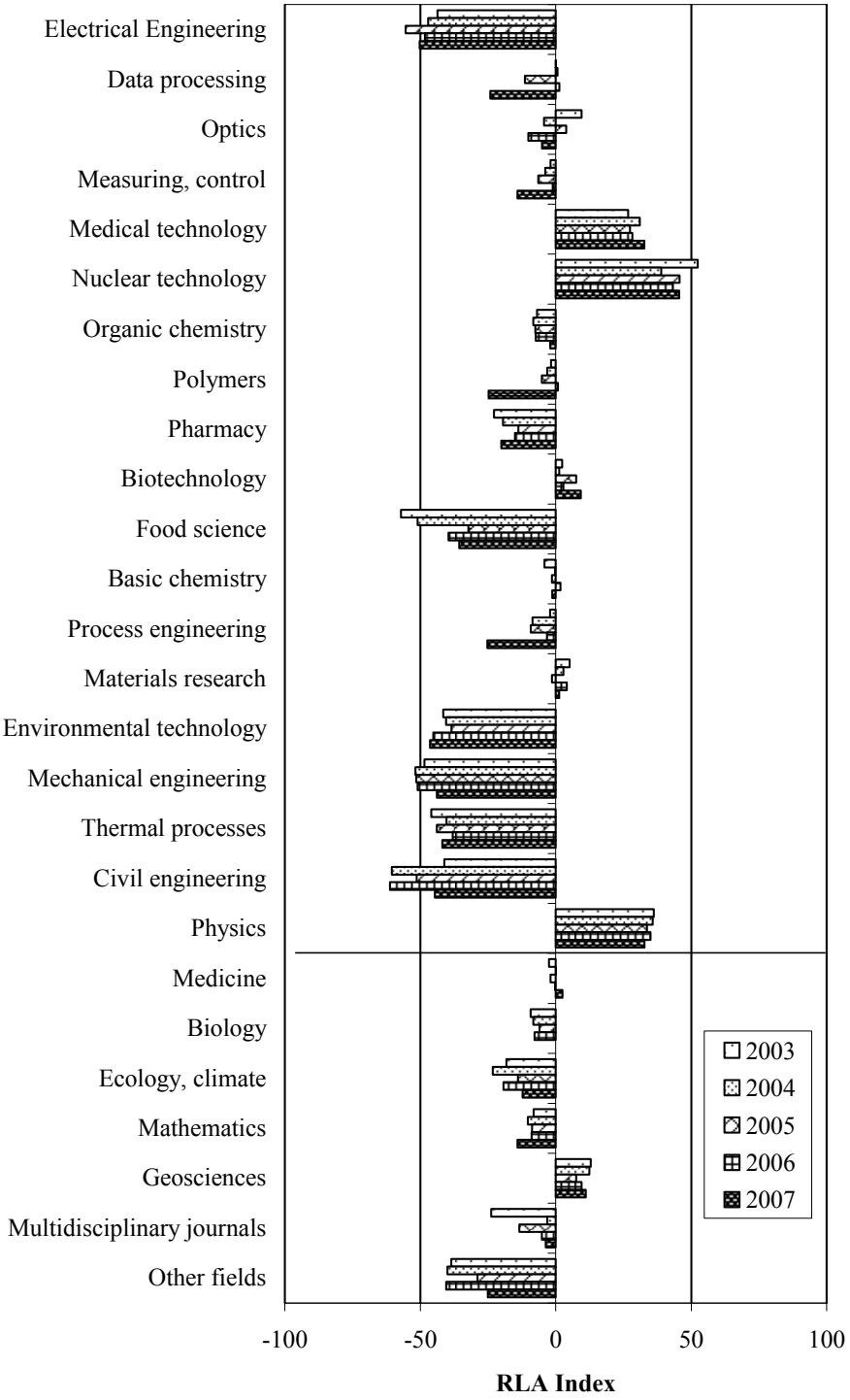
Sources: SCI, searches and calculations by University of Leiden (CWTS), calculations by Fraunhofer ISI.

Figure 2-2: International Alignment (IA Index) of Germany and Switzerland in Publications in the Science Citation Index (without own citations) differentiated acc. to Science Fields, 2005



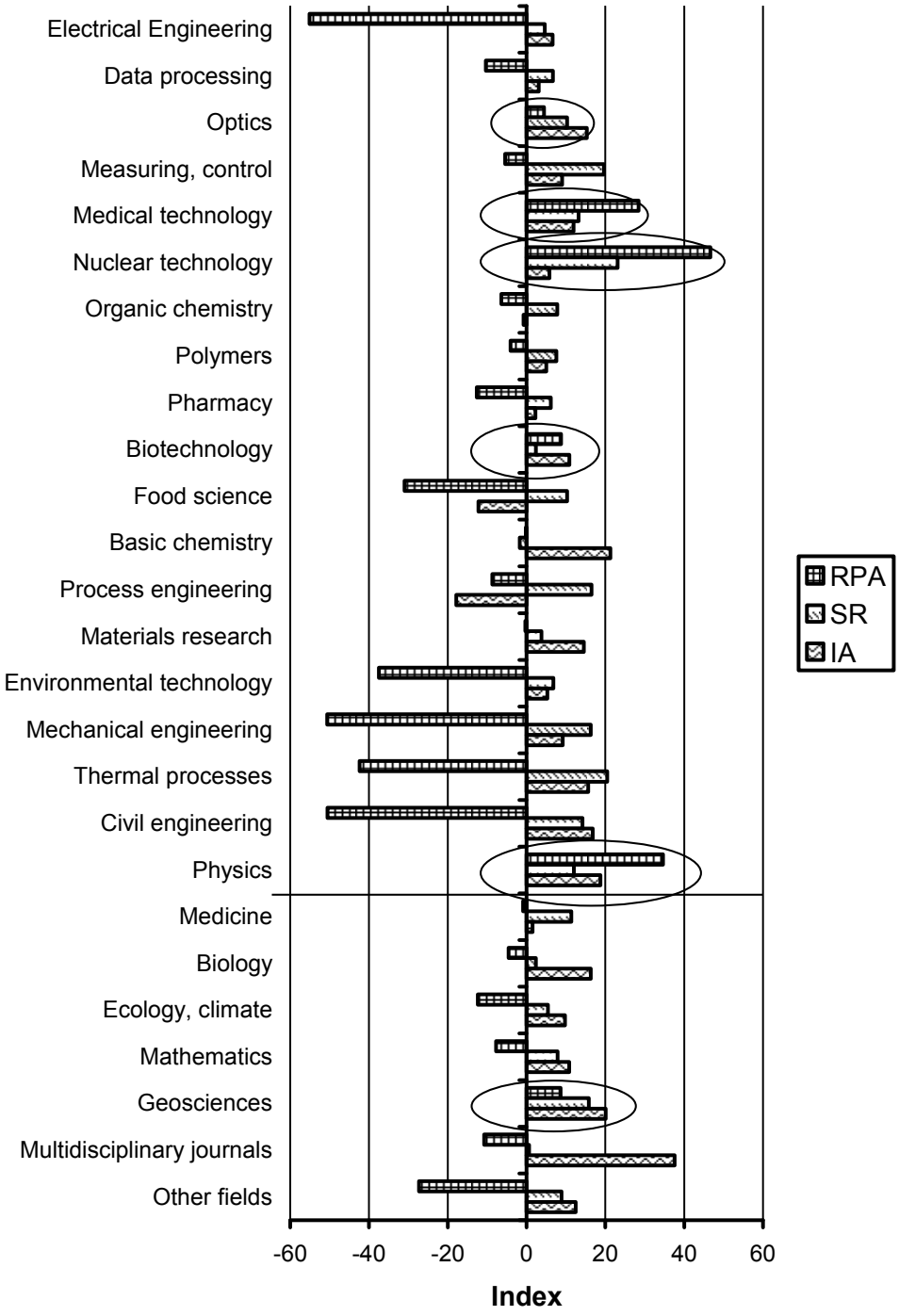
Sources: SCI, searches and calculations by University of Leiden (CWTS), calculations by Fraunhofer ISI.

Figure 2-3: Specialization of Germany in Publications in the Science Citation Index differentiated acc. to Science Fields, 2002-2007



Sources: SCI, searches and calculations by Leiden University (CWTS), calculations by Fraunhofer ISI.

Figure 2-4: Relative Literature Specialisation (RLA) Scientific Regard (SR), and International Alignment (IA) of Germany in Publications in the Science Citation Index (without own citations) differentiated acc. to Science Fields, 2005



Sources: SCI, searches and calculations by Leiden University (CWTS), calculations by Fraunhofer ISI.

3. Publications of Small and Medium-Sized Enterprises

The following section deals with publications of German enterprises with a focus on small and medium-sized ones. In this context, the reader may wonder why enterprises publish at all, as by this activity they disclose research results to their competitors. At first sight, publications do not support the market interest of enterprises and even seem to harm them. Nevertheless, a considerable number of publications by firms can be observed. In analyzing the various motives of corporate publishing, Hicks (1995) shows the close link of publications to results of basic research and identifies as the major motive the interest in signalling research competencies to potential partners in scientific institutions. In publications, it is possible to hold off results which are relevant for specific product features by employing appropriate strategies. These results have to be protected by patents before publishing.

3.1 Methodology

The searches for enterprise publications were performed in the online version of the Science Citation Index (database SCISEARCH of the host STN). In this context, it is important to indicate that the SCI primarily covers journals with a focus on basic research, so the search focuses on activities with this specific orientation.

In order to identify firms, we looked for typical abbreviations referring to legal forms of enterprises. In Germany these are in particular the codes AG, GmbH, mbH, OHG, KG or KGAA. As some of these legal forms are also used in other countries such as Switzerland or Austria, exclusively German institutions were considered.

To distinguish large versus small and medium-sized enterprises (SME), the optimal approach is to compare firm names in the publication database with those in company databases recording other data such as turnover or number of employees for identifying SMEs. On this basis the criteria for small and medium-sized enterprises can be correctly fulfilled, according to the present definition of the European Commission up to 50 employees or € 7 million Euro for small enterprises, up to 250 employees or € 40 million turnover for medium ones. However, this requires substantial efforts which could not be realized in the present context.

Therefore we started with a search for the abbreviation AG (Aktiengesellschaft, public company, corporation, stock corporation) as a crude delineation, as in the German context AGs are generally large companies. By listing large samples of institutions defined by this approach, in the majority of cases we could verify that this assumption is correct. The major exception is the use of AG with reference to universities where it refers to "Arbeitsgemeinschaft" (working group). Furthermore, some start-up companies have the status of AG, but are still SMEs, such as Micromet or Vermicon.

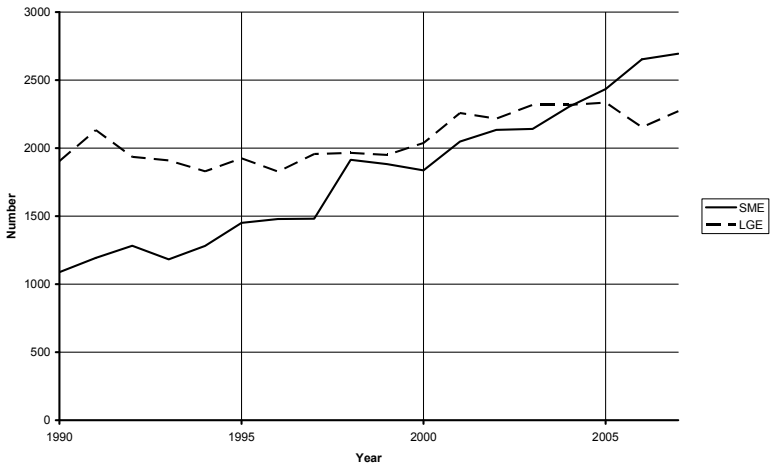
A closer look at the institutions, identified by the search for "GmbH, mbH, OHG, KG or KGAA" reveals that many larger companies have these legal forms, for instance, the large company Robert Bosch is a GmbH. In these cases, the companies were included in the search for large companies. Furthermore, various non-university research centres and some hospitals have the legal form of a GmbH, for instance most Helmholtz centres are GmbHs. These types of institutions were excluded from the SME search.

All in all, it cannot be guaranteed that in each case the association of an enterprise to large enterprises or SMEs is correct. However, the most relevant cases in terms of publications were associated correctly and the general trends and structures are correct.

3.2 Results

The searches reveal that the absolute number of publications by enterprises is modest, with almost 5,000 SCI articles in 2007 equivalent to about 6 percent of all articles of German origin. As the majority of industrial R&D is spent by large enterprises, it can be assumed that the number of their publications is largely above that of the SMEs. Instead, in 1990, the SME share was at a level of 37 percent, increased steadily and reached 57 per cent in 2007, thus the number of publications by SMEs was even higher than that of the large enterprises (LGE) (cf. Figure 3-1).

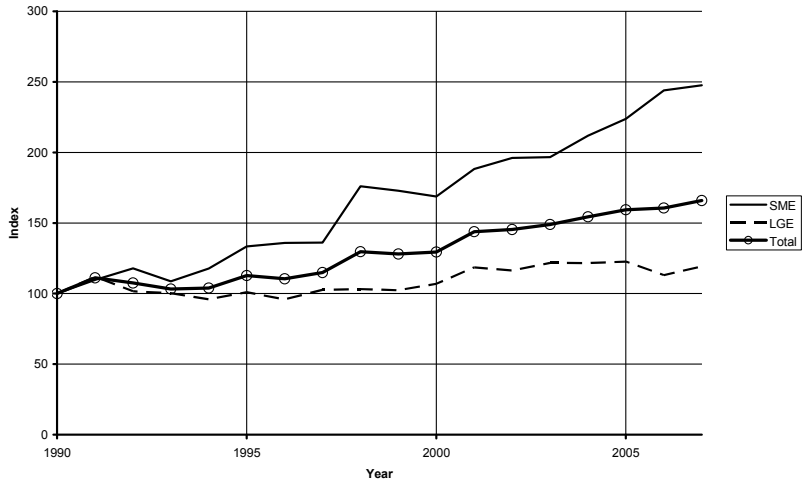
Figure 3-1: Publications of German Enterprises in SCI Journals



Source: SCISEARCH (STN), computation by Fraunhofer ISI.

Looking at the increase since 1990, the number of the publications by SMEs grew by 148 percent, those by LGEs grew moderately by 19 per cent (Figure 3-2). However, the total number of German publications grew by 76 per cent, so the growth of the LGE publications is largely below average. Assuming that about 50 per cent of the growth of the publication numbers in the SCI is due to the growth of science and further 50 per cent to a broader inclusion of journals, and thus to a change in the database policy, the publications of the LGEs even decreased by 11 percent with reference to the German average growth. With this corrected growth rate, the number of publications by SMEs still grew by 110 per cent between 1990 and 2007.

Figure 3-2: Trend of SCI Publication Numbers of German Enterprises (index 1990 = 100)

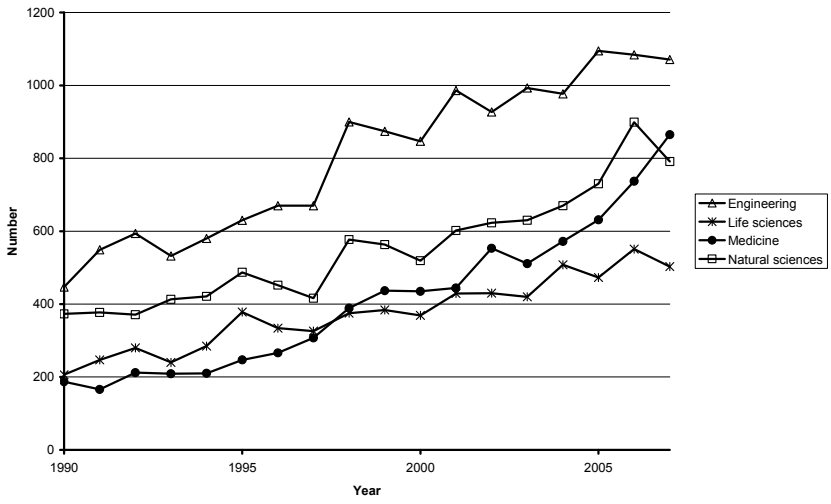


Source: SCISEARCH (STN), computation by Fraunhofer ISI.

In 1990, 25 per cent of the SME publications were written in cooperation with universities, thereof 78 per cent with German universities. In 2007, the share of co-publications with universities was at a level of 63 per cent, 73 per cent thereof with German universities. These structures for LGEs are similar.

Differentiated by major fields of science, the SME publications are focussed on engineering, the natural sciences, and medicine with a considerable growth of medicine in recent years (cf. Figure 3-3). The absolute numbers in life sciences are growing as well and have reached since the beginning of the 1990ies a substantial level. At first sight, it may be surprising that the number of publications in engineering is such high, as in this field less basic research might be expected. However, engineering includes fields such as material research, microelectronics, surface technology, telecommunications, or sensors which still have a relevant focus on basic research.

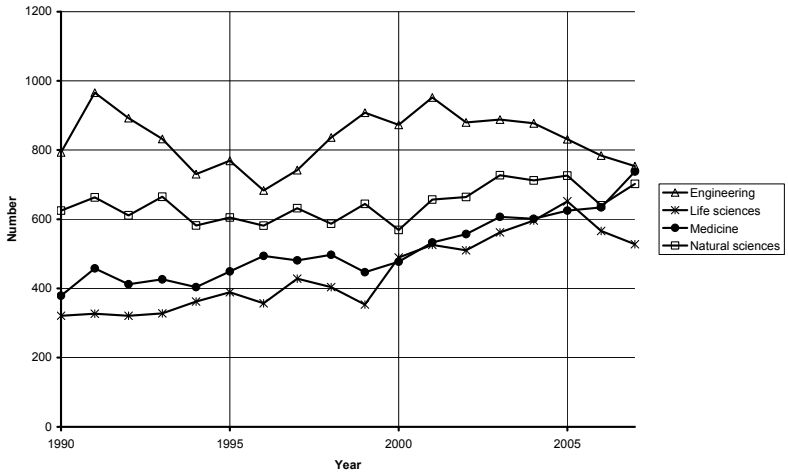
Figure 3-3: SCI Publications of German SMEs by Major Scientific Fields



Source: SCISEARCH (STN), computation by Fraunhofer ISI.

A similar picture for LGEs reveals that the overall stagnation of their publications can be observed in all scientific fields. In particular, the publications in medicine grow as well, but less strongly than for the SMEs. The publications of the LGEs in engineering and life sciences have even decreased in recent years.

Figure 3-4: SCI Publications of German LGEs by Major Scientific Fields



Source: SCISEARCH (STN), computation by Fraunhofer ISI.

3.3 Assessment

The findings for SMEs in the context of publications cannot be interpreted as a generally higher R&D activity in comparison to LGEs. The R&D share of LGEs is at a level of about 90 per cent of all industrial R&D in Germany, and between 1995 and 2003 the share of the SMEs even decreased. In a similar way, Legler et al. (2007) state that the share of SMEs active in R&D has been steadily decreasing since 10 years. However, the share of R&D of SMEs (< 250 employees) increased from 7.9 to 9.2 per cent between 2003 and 2005 (BMBF 2008). But this recent growth cannot explain the growth of SME publications since 1990.

The only convincing explanation of the considerable dynamics of SCI publications of German SMEs is their engagement in basic research. A closer look at the major contributing enterprises reveals that most of them are science-oriented new enterprises, many of them spin-out enterprises from scientific institutions. The general statistics show that the R&D intensity of enterprises active in research with less than 100 employees is higher than the average for all enterprises and similar to that of enterprises above 1,000 employees (Legler et al. 2007). However, the relative share of basic research compared to applied research and development is obviously quite high in new enterprises and leads to a high level of scientific publications. These findings support the thesis that science-oriented new enterprises trigger the change of economic structures more effectively than R&D in long-established enterprises, as basic research primarily supports radical innovation, whereas applied research and development favours incremental innovation (Achleitner et al. 2008; Henderson/Clark 1990; Rosenberg 1990). The unexpected result of the publication analysis is that the contribution of SMEs in Germany to these basic activities is already quite substantial compared with LGEs and is growing with a considerable dynamic.

These findings reflect the change of structures in the last 15 years where LGEs reduced the activities of their central R&D departments and linked to that shifted towards applied R&D and development and put less emphasis on basic research with a long-term strategic perspective. They rather observe the activities of start-up enterprises and buy those which prove to be successful in the marketplace. So in principle, the LGEs outsourced their strategic R&D activities to start-up enterprises in order to reduce their risk. Furthermore, the start-ups seem to be more flexible and dynamic than the central R&D department of LGEs.

A further remarkable result is that the medical and life science are major fields in this dynamic and not the traditional fields of German industrial strength. This finding supports, in a different perspective, the contribution of SMEs to the long-term change of industrial structures.

It is not surprising that a large share of the publications of enterprises is realized in cooperation with universities. But it is remarkable that about a quarter of these co-operations is performed with foreign universities. This observation applies to LGEs as well as SMEs and highlights a specific aspect of globalization.

All in all, the findings of this chapter show the crucial role of science-oriented new enterprises for innovation.

4. Publications of Catching-up Countries

The analysis in chapter 2 revealed that catching-up countries play an increasing role in scientific publications. In this chapter a set of typical catching-up countries is analyzed in more detail, in order to assess their dynamics and specific orientation. For this purpose the following countries were selected: Brazil and Mexico for South and Middle America; Korea, China, and India for Asia; Poland, the Czech Republic, Slovakia, Hungary and Romania for Eastern Europe; Russia may be associated with this group. Further examples are South Africa, Turkey and Israel.

The experiences with many cases show that publications can be considered as an early indicator for economic activities. A growth in publications documents increasing scientific activities and, linked to that, an increasing number of highly qualified people who are able to engage in more complex industries and services. About ten to fifteen years after the start of growth of publications, a growth of patent activities can generally be observed, documenting a switch from copying technology to the generation of own new technology.

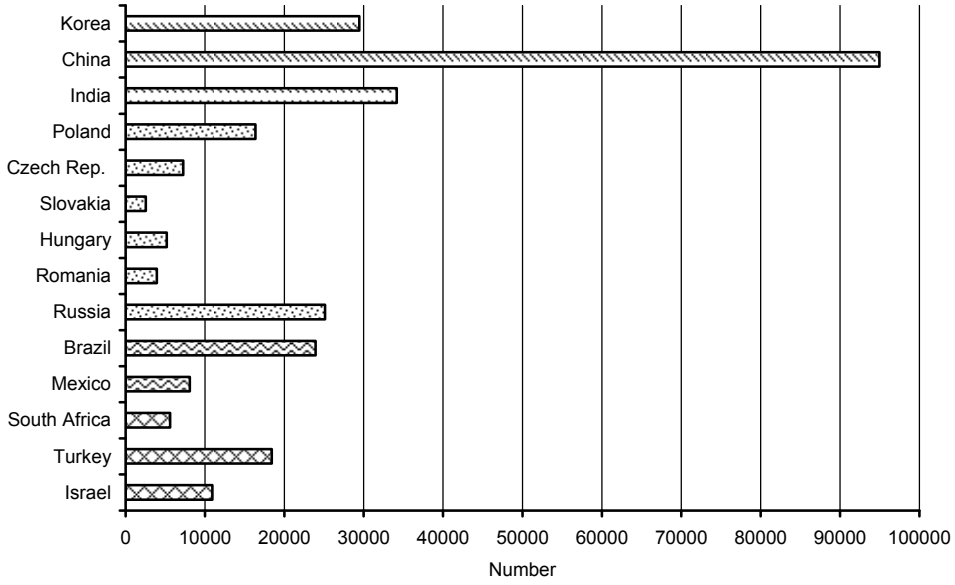
4.1 Size and Growth

As a first step, the absolute number of publications in the Science Citation Index (SCI) without conference proceedings was considered for the period 1980 to 2007. All countries mentioned above were included except Russia, the Czech Republic and Slovakia, as the latter countries changed their national status at the beginning of the 1990s, that is, in the middle of the observation period. In 1980, the catching-up countries had a share of 7.4 per cent of all SCI publications; until 1990 this share moderately increased to 8.5 per cent. Then in 2000, it was much higher at 14.9 per cent, and in 2007, a share of 25.1 per cent was reached. This dramatic increase in the last years explains why the analysis in chapter 1 stated a relative crowding out of most advanced industrialized countries.

The publications of start-up countries primarily stem from China, India, and Korea (Figure 4-1). Furthermore, relevant contributions come from Poland, Russia, Brazil, and Turkey. So the South East Asian countries have the major impact, but the general dynamics of the start-up countries is also based on various other ones.

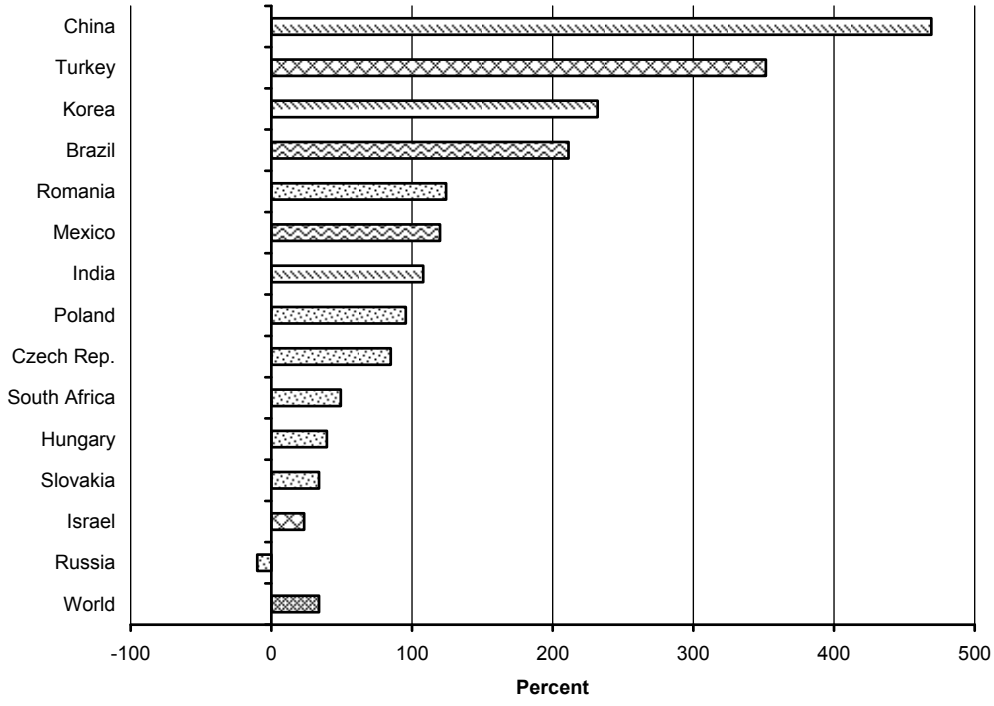
China also had the highest growth in the last ten years (Figure 4-2). Further countries with very high growth rates are Turkey, Korea, and Brazil. Romania, Mexico, India, Poland, and the Czech Republic display medium growth rates, still distinctly above the world average. However, South Africa, Hungary, Slovakia, and Israel are near the world average; the growth of Russia is even negative. The low recent growth of Israel has to be seen in the context that research activities have been established there for many years, so that in absolute terms a quite high absolute level was already achieved in 1997. All in all, the highest growth can be observed in Asia and is linked to high absolute numbers as well. In Eastern Europe, the absolute level and the growth rate is generally medium. Turkey and Brazil appear to be highly relevant in terms of size and growth.

Figure 4-1: SCI Publications of Selected Catching-up Countries in 2007



Source: SCISEARCH (STN), computation by Fraunhofer ISI.

Figure 4-2: Growth of SCI Publications between 1997 and 2007 for Selected Catching-up Countries



Source: SCISEARCH (STN), computation by Fraunhofer ISI.

4.2 Orientation to Scientific Fields

The total numbers of publications may be linked to quite different scientific orientations. Therefore the data were differentiated by the five major scientific fields agriculture, engineering, life sciences, medicine and natural sciences, based on category codes in the SCI. Then

specialization indexes with reference to the world-wide averages were calculated as defined in chapter 2.1. By this way, the profiles of the countries are analyzed. The high specialization in a field does not necessarily imply a high international competitiveness in this field, as the absolute values are not considered.

Based on these country profiles, it is possible to determine similar ones and calculate clusters or MDS graphs. In the MDS graph in Figure 4-3, the profile of each country is represented by a five-dimensional vector which is projected on a two-dimensional plane. The two dimensions of the plane have no specific meaning, but the local proximity indicates a similarity of profiles. This representation was confirmed by a cluster analysis, and the clusters were marked by areas and numbers. The typical profiles in the different clusters are documented in Table 4-1.

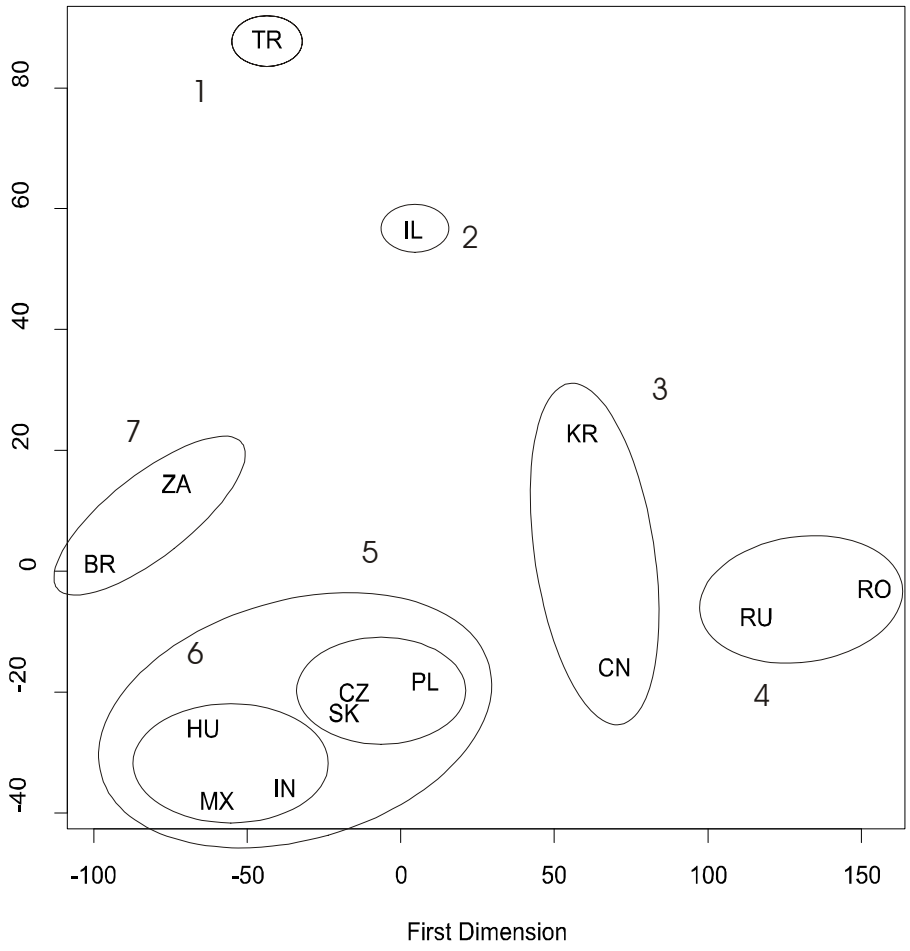
Table 4-1: Orientation of Countries to Scientific Fields in Different Clusters, 2005 to 2007

Field	Cluster						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Agriculture	+	--	--	--	+	++	++
Engineering	--	+	++	+	-	-	--
Life sciences	--	0	--	--	+	+	+
Medicine	++	+	--	--	--	--	-
Natural sciences	--	o	+	++	++	++	0

0 = average specialization, + = high specialization, ++ = very high specialization, - = low specialization, -- = very low specialization
Source: SCISEARCH (STN); computation by Fraunhofer ISI.

Turkey has a profile which significantly differs from all other countries and thus represents one cluster on its own (cluster 1); it has a strong focus on medicine, an above average activity in agriculture, but all other fields the specialisation is distinctly below average. Israel has a very specific profile, too, and represents Cluster 2 where all fields are quite balanced on an average level. Only engineering and medicine are above average. Cluster 3 comprises Korea and China, two Asian countries. The cluster is characterized by a strong orientation on the natural sciences and in particular engineering. The features of cluster 4 with Romania, and Russia, two East European countries, are a very strong focus on the natural sciences and activities above average in engineering. Cluster 3 and 4 are quite similar and in the MDS graph they are located close to each other. Cluster 5 and 6 are very similar as well and contain a broader set of countries with Poland, the Czech Republic, Slovakia and India, Mexico, Hungary. The specific features of these clusters are above average specializations in agriculture, engineering, and in particular natural sciences. The major difference between the fifth and the sixth cluster is the stronger specialization of the sixth one in agriculture. The seventh cluster brings in South Africa and Brazil close to each other; they have specific strengths in agriculture combined with a relevant focus on life sciences.

Figure 4-3: MDS Graph for Selected Countries based on the Specialization on Scientific Fields in SCI Publications, 2005-2007



Source: SCISEARCH (STN), computation by Fraunhofer ISI.

To summarize, the profiles of the catching-up countries are not identical, and only in some cases does a regional similarity of the specialization profiles emerge, in particular for Korea and China (Cluster 3) as well as Poland, Czech Republic, Slovakia Cluster 5) and Hungary; Russia (Cluster 4).

A final question refers to the long-term change of profiles. There it may be assumed that catching-up countries have a clear focus on agriculture and medicine in the early stage of development and on engineering in later ones. Table 4-2 shows the major changes for selected countries, again without Russia, the Czech Republic and Slovakia due to the intermediate change of the national status. Korea as first case meets these expectations with a change of focus from agriculture to engineering. However, such a pattern cannot be found in any other case. In China, Romania, or Israel a move towards engineering can be observed at least, but from different basic orientations. In the cases of Brazil, Mexico, South Africa, and Turkey a clear focus on agriculture can be stated also for the present situation, a statement which also applies to India and Hungary. So beyond industrialization, these countries have to care for basic needs as well.

Table 4-2: Major Change of Scientific Specialization between the early 1980s and the mid 2010s for Selected Countries

Country	High specialization
Korea	Agriculture, engineering → engineering
China	Natural sciences → natural sciences, engineering
India	No major change: natural sciences, agriculture → natural sciences, agriculture
Poland	No major change: natural sciences → natural sciences
Hungary	No major change: natural sciences, agriculture → natural sciences, agriculture
Romania	Natural sciences → natural sciences, engineering
Brazil	Agriculture → agriculture, life sciences
Mexico	Life sciences, medicine → life sciences, agriculture, natural sciences
South Africa	Medicine → life sciences, agriculture
Turkey	Engineering → agriculture, medicine
Israel	Life sciences, medicine → engineering, medicine

Source: SCISEARCH (STN), computation by Fraunhofer ISI.

To summarize, there is no clear pattern of development for catching-up countries. Compared to advanced industrial countries, a strong orientation towards agriculture can be observed even in recent years.

5. Summary

The overall analysis in the Science Citation Index shows a gradual decline in recent years in the German share of worldwide publications, an observation which also applies to many other large industrialized countries. This development can be attributed to a strong growth in the activities of threshold countries in South East Asia and East Europe, but also in South America and Central Asia, which have received perceptible weight since the year 2000. After German publication shares remained constant between the years 2004 and 2005, Germany's share is declining to an extent comparable with those of Great Britain and France. The share of Japanese publications is declining even more, for instance. The USA is still clearly the unchallenged strongest nation, but here too the share is falling to a comparable extent.

For the number of citations and the indicators of Scientific Regard and International Alignment derived here from, in recent years a stabilization of the SR Index and in the meantime a very distinct upward trend of the IA Index can be determined. Hence a stronger orientation towards internationally visible journals and thus a closer connection to the international discussion was noted on the part of German authors. It is to be assumed that this tendency, visible at the macro level, can be attributed at least partly to the gradual shift towards considering publication- and citation-based indicators not only in the evaluation of scientific institutions, but also in professorship appointment decisions, i. e. at the level of individual scientists. This better integration in the international scientific community must certainly to be judged positive on the whole, but at the same time it should be carefully observed whether the consideration of corresponding indicators and procedures leads, in the mid term, to unintentional effects, e. g. to thematic restrictions, such as an orientation towards the American main stream discussion. Compared with Switzerland, which exhibits very high indices in both citation dimensions, it is apparent that the scientific performance here extends over nearly all scientific areas, while this is not the case in Germany to a comparable breadth.

The analysis of scientific publications of enterprises primarily reflects their engagement in basic research with a mid- and long-term orientation with high risk, on the one hand, but with the high potential to achieve radical innovations, on the other hand. For German enterprises, a stagnation of the publication numbers since the beginning of the 1990s can be observed, whereas the publications of small and medium-sized enterprises steadily increase and meanwhile even outperform the large enterprises in absolute numbers. The dynamics of the small and medium-sized enterprises are particularly strong in the life and medical sciences. This development can be seen as a structural change where the large enterprises reduced their activities in basic research and an increasing number of start-up enterprises engages in mid- and long-term research. Then successful start-ups are likely to be bought by large enterprises which thus factually outsource these activities to the small and medium-sized enterprises.

A more detailed analysis of the publications activities of catching-up countries reveals a very strong relative and absolute dynamics in South East Asian countries as well as in Turkey and Brazil. The publications of East European countries increase too, but less dynamically than in Asia. The orientation towards scientific fields is not uniform and it is even difficult to identify typical regional patterns. Each country is embedded in specific structures and has a specific industrial and scientific history, so that each country follows a specific path, its development is path-dependant. Although a certain trend towards engineering can be stated, agriculture and health generally remain important for the scientific activities of theses countries.

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