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Techno-Globalization: Theory and Empirical Analysis for OECD Countries

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Summary:

Parallel to the globalization of production and sales, multinational firms have partly also internationalized their research and development (R&D). In both the media and modern research on innovation, the increase in terms of the international generation, transfer and diffusion of new technologies has been described as technological globalization and techno-globalization; research has picked up the topic in scientific analysis. Based on the patent indicators suggested by Guellec and Pottelsberghe de la Potterie (2001), this contribution gives a consistent analysis of global technological cooperation as well as of the global sourcing of innovations as key elements of techno-globalization. In addition to taking stock for a cross-section of OECD countries and a time series examination for the whole of the OECD, and Germany and the Netherlands in particular, the significant drivers of techno-globalization are determined by simple correlation and regression analyses. Furthermore, simple tests for beta convergence show that there is an international convergence of the patent shares with domestic inventors and foreign applicants and also a convergence of the countries' patent shares with an international cooperation of inventors. The analysis is completed by a view on the sectoral differences with regard to the internationalization of innovations as well as by some considerations with regard to the links between the internationalization of enterprises' innovations and domestic employment.

Zusammenfassung:

Parallel zur Globalisierung von Produktion und Vertrieb haben multinationale Unternehmen teilweise auch ihre Forschung und Entwicklung (F&E) internationalisiert. Sowohl in den Medien als auch in der modernen Innovationsforschung wird die Zunahme der internationalen Generierung, des Transfers und der Verbreitung neuer Technologien als technologische Globalisierung bzw. Techno-Globalisierung bezeichnet; die Forschung hat das Thema in der wissenschaftlichen Analyse aufgegriffen. Auf der Grundlage der von Guellec und Pottelsberghe de la Potterie (2001) vorgeschlagenen Patentindikatoren wird in diesem Beitrag eine konsistente Analyse der globalen technologischen Zusammenarbeit sowie der globalen Beschaffung von Innovationen als Schlüsselelemente der Techno-Globalisierung vorgenommen. Neben einer Bestandsaufnahme für einen Querschnitt der OECD-Länder und einer Zeitreihenbetrachtung für die gesamte OECD, insbesondere aber für Deutschland und die Niederlande, werden die wesentlichen Treiber der Techno-Globalisierung durch einfache Korrelations- und Regressionsanalysen ermittelt. Darüber hinaus zeigen einfache Tests auf Beta-Konvergenz, dass es eine internationale Konvergenz der Patentanteile mit inländischen Erfindern und ausländischen Anmeldern sowie eine Konvergenz der Patentanteile der Länder mit einer internationalen Kooperation von Erfindern gibt. Abgerundet wird die Analyse durch einen Blick auf die sektoralen Unterschiede bei der Internationalisierung von Innovationen sowie durch einige Überlegungen zu den Zusammenhängen zwischen der Internationalisierung von Unternehmensinnovationen und der inländischen Beschäftigung.

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1. Introduction

Parallel to the introduction of globalization of production, the traditional approaches of research & development (R&D) have also changed over time – generating new technological innovations is increasingly shaped by the general trend towards globalization. This means that multinational companies increasingly are internationalizing their R&D efforts. What has been picked up in the media under the heading of techno-globalization – the creation, transfer and diffusion of technologies in an international context – has also been picked up by advanced innovation research and economic analysis.

Compared with the degree of globalization of the markets for goods and services, however, technology production is often described as "far from globalized" (Patel and Pavitt 1991); rather, it is still concentrated in the firms' home countries (Belderbos, Leten and Suzuki, 2011). However, many international organizations are finding that R&D activities are increasingly carried out across national borders (e.g., UNCTAD 2005; OECD 2008; UNESCO 2010). Additionally, there is empirical evidence for a correlation between an increase in an industry's knowledge base complexity and higher concentrations of innovation at the national level, but at the same time, this increase is accompanied by a rising share of non-country of origin inventions owned by multinational companies (Maleki and Rosiello 2019).

In the literature, which attempts to classify the internationalization of innovation activities of companies theoretically, two strategies can essentially be identified (cf. Danguy 2017, p. 76). First, companies set up foreign R&D facilities to exploit technologies that have already been developed. Such foreign R&D activities mainly support entry into new foreign markets by adapting products or processes to local conditions. The main objective of the internationalization of innovation activities is therefore to exploit the technological advantages created in the home country. This type of internationalization strategy is referred to as an 'asset exploiting' (Dunning and Narula 1995) or 'home base exploiting' (Kuemmerle 1997) strategy.

Secondly, the internationalization of R&D may be motivated by innovative companies' desire to track down or have access to foreign technological developments. In doing so, they want to improve their own existing technological capabilities or reduce their own technological weaknesses and tap into global knowledge. The main objective of this strategy is therefore to expand the company's knowledge base by combining its own skills with new foreign resources (Cantwell 2017; Lin, Liu and Chen 2018). Ultimately, the aim is to strengthen the companies' own technological competence and innovative performance. This type of internationalization strategy is referred to as "asset-seeking motive" (Dunning and Narula 1995) or "home-base augmenting" (Kuemmerle 1997). Taking this one step further, Cantwell (2017) concludes that the increasing relevance of the knowledge-seeking motive for international business networks and of competence-creating subsidiary activities at a local level have linked localized innovation systems to international business and to international knowledge exchange. According to his analysis, from a locational perspective, international knowledge connectivity has become crucial for sustainable innovation and growth. Indirectly, these results are also supported by the empirical findings of de Rassenfosse and Thomson (2019), which show that R&D offshoring contributes positively to productivity in the home country, irrespective of the host country destination. However, on the other hand, Tabrizy (2017) found that those firms that offshore their innovative activities tend to be more productive than domestic firms, exporters, and other multinational corporations. He argues that his findings imply that firms with superior productivity are more likely to exploit the global task distribution in innovative activities, which may provide an explanation for why such low participation is observed in the data.

At the same time, securing access to lead markets is seen in the current literature as a major driving force behind the globalization of innovation activities, as lead markets are seen as "early indicators" of emerging consumer needs (Tiwari and Herstatt 2011). Thus, such markets offer an opportunity to reduce the uncertainty inherent in innovation processes. Yip (1992) already concluded that companies should locate at least an observation function in leading countries in order to gather information about developments there. The importance of the role of demand-driven, lead market-oriented factors in the establishment of R&D institutions abroad is also supported by empirical studies. Hakanson and Nobel (1993), for example, in an empirical analysis of the foreign R&D activities of Swedish multinational companies, show that proximity to markets and customers is the most common reason for the internationalization of R&D. Proximity to the market is not necessarily linked to the aforementioned reason for adapting products and processes to local conditions, but rather to the search for cooperation with technologically challenging customers. In this respect, such motives for the internationalization of R&D can also be seen as a step towards gaining access to lead markets. In the same way, Beise and Belitz (1999) argue that in most cases it is not the technological superiority of the target country per se that constitutes the decisive locational advantage for attracting the R&D activities of multinational companies, but the lead market function of a country or a region.

In addition, the more recent literature discusses a further strategy with regard to the internationalization of R&D activities. According to Levin, Massini and Peeters (2009), new foreign R&D institutions are increasingly "replacing home bases". Similarly, Branstetter, Lee and Veloso (2015) find evidence of an increasing trend of an international division of R&D labor, especially a vertical disintegration of R&D, with various stages of the R&D process now being conducted in different locations around the world. The authors argue that with the innovation networks of multinational firms spanning the globe, emerging economies like India and China that possess both a huge scientific and engineering talent pool and large markets have become an important part of these global innovation networks. They show empirically that the rapid growth in US patents awarded to private sector inventors based in India and China is driven largely by multinational corporations from advanced industrial economies and that these patents are highly dependent on collaborations between local inventors and other inventors in advanced economies. Some authors recognize in these network-like characteristics of international R&D activities the emergence of international or global innovation networks (Nepelski and De Prato 2018; Papanastassiou, Pearce and Zanfei 2020).[1]

In the following, the internationalization of innovation activities and techno-globalization will first be clarified conceptually. Concepts for measuring this development through appropriate indicators will then be presented. Then empirical findings are presented on the extent of techno-globalization and the main determinants. On the one hand, the cross-section of OECD countries

[1] Papanastassiou, Pearce and Zanfei (2020) provide a recent review of the literature on the internationalization of R&D and innovation by multinational enterprises and their changing perspectives.

for the sub-periods of 1991-2000 and 2001-2010 is considered *(thus the post-2009/2010 decade is left out which is characterized by critical changes in the real adjustment of OECD countries)*, on the other hand a more detailed analysis of the temporal development of techno-globalization for selected countries is carried out. Furthermore, the indicators of the internationalization of innovation activities previously used at country level are then presented and interpreted at the level of individual branches of the economy. This is followed by an examination of the links between the internationalization of innovation activities and employment. The contribution concludes with a number of final policy options and ideas for future research.

2. Techno-Globalization: Definition and measurement

In order for the initially confusing concept of techno-globalization to actually acquire meaning beyond that of a general buzzword and to make a meaningful contribution to the description of the globalization of R&D and technology markets, it must be defined more precisely. Such a definition (or taxonomy) should distinguish at least three processes (Archibugi and Michie 1995 and Jungmittag 2000):

- The *international (global) exploitation* of technologies developed at national level: Companies try to exploit their technologies internationally, whether through exports, foreign production or licensing. This is certainly not a new development, but its importance continues to grow.

- The *international (global) technological cooperation* of partners in more than one country in developing know-how and innovations, whereby each partner retains their own respective institutional identity and ownership: This cooperation can take place both between companies (e.g., through joint R&D projects, the exchange of technical information, joint ventures or strategic alliances) and through joint scientific projects and the exchange of scientists or students. Typical actors here are national and multinational companies as well as universities and public R&D institutions. Forms of international technological cooperation continue to gain in importance and are also - promoted by politicians through appropriate programs.

- The *international (global) generation of technologies* is carried out by multinational companies that develop R&D strategies across national borders to create innovations - through the establishment of research networks. These include R&D and innovation activities taking place simultaneously in the home and host countries, the acquisition of foreign R&D institutions and the establishment of new R&D institutions in the host countries. There is a range of empirical evidence that these activities are gaining importance at least for large enterprises in a number of industries.

Another possibility is the *global sourcing* of technologies via foreign trade (and the import of high-technology and high-tech goods). It is certainly an expression of the internationalization of technology markets, but not of the internationalization of R&D.

The three different processes outlined above also contribute to analytical clarity, because the extent of their impact can be described by different indicators. Archibugi and Michie (1995) propose the following indicators:

- The economic equivalent to the global exploitation of technologies developed at the national level is first and foremost foreign trade flows. Likewise, they are associated with patent applications on foreign markets. In addition, direct investments are made to set up foreign branches that serve exclusively downstream stages of the value chain.

- Global technological cooperation is reflected in the corporate sector by international joint ventures, which in turn can be represented by the number of corresponding cooperation agreements. For academic and public research institutions, international scientific exchange can be measured by the number of transnational co-authorships.

- The approximate measurement of the global generation of technologies is somewhat more difficult due to the data situation. First of all, they require direct investment in R&D institutions either in the form of the acquisition of existing foreign R&D institutions or the establishment of new ones in the host countries. R&D output can then be approximated by the patent applications of foreign-controlled enterprises.

In the indicators proposed by Archibugi and Mitchie (1995), which were taken up by Jungmittag (2000), the three facets of techno-globalization are represented at different levels by a "bouquet" of differentiated indicators. Especially in the last mentioned process of the global generation of technologies, the analysis is limited to the use of company data. The following studies are to be mentioned here briefly: Kuemmerle (1999) examined the foreign direct investment in R&D facilities of 32 multinational companies in the pharmaceutical and electronics industries and found that home-base broadening motives played a major role. Patel and Vega (1999) looked at the US patent activities of 220 companies and compared them with the technological profiles of the countries of origin, suggesting that the adaptation of products to foreign markets and the support of long-term manufacturing were the main determinants of the internationalization of technology. Le Bas and Sierra (2002), who analyzed the patent activities of 245 multinational companies in Europe, confirmed this finding. Cantwell and Piscitello (2005) examined patents granted to large US industrial companies for regional inventions in four European countries. According to their results, the choice of location for R&D activities abroad is driven by the potential to exploit spillover effects, which may be intra-industrial, inter-industrial or scientific-technological spillover effects. Additionally, Kerr and Kerr (2018) investigated the prevalence and characteristics of global collaborative patents for US public companies, where the inventor team is located both within and outside of the US. They found that collaborative patents are frequently observed when a corporation is entering into a new foreign region for innovative work, especially in environments with weak intellectual property protection.

ISI, DIW and ZEW (1997) have also examined different models of internationalization for three technology areas - pharmaceuticals, semiconductor technology, and telecommunications technology. In these fields of technology, it turned out that the internationalization of R&D is mainly influenced by three factors (cf. Jungmittag, Meyer-Krahmer and Reger 1999, p. 54):

- An early connection of R&D activities to leading, innovative customers ("lead users") or to the lead market;
- early coordination of a company's own R&D with scientific excellence and the research system;
- a close link between production and R&D.

A central finding of this study is that the determinants of the internationalization of R&D in the three fields of technology are quite different. The innovation dynamics in product development in the areas of semiconductor technology and software in telecommunications technology are very strongly driven by lead markets. In the case of process engineering in semiconductor technology and hardware in telecommunications, the link between production and R&D is also an important factor. In the pharmaceutical industry, a clear distinction must be made between preclinical and clinical research. Innovation dynamics in preclinical research are driven by scientific excellence, while lead markets in clinical research are the driving forces. However, the link between R&D and production is very loose in the pharmaceutical industry.

Company data can thus provide a number of insights into the extent and motives of the internationalization of R&D and innovation, but it is difficult to derive an overall picture. In order to overcome this limitation of studies based on company data, Guellec and van Pottelsberghe de la Potterie (2001) propose three patent-based indicators for the internationalization of technology that reflect international cooperation and the location of research facilities of multinational companies. The starting point is a simple definition of an international patent for a country *i*, namely as a patent with at least one inhabitant from country *i* and one inhabitant from another country.

Table 1: Four types of international patents

		Foreign countries	
		Inventors	Applicants
Domestic	Inventors	EE	EA
	Applicants	AE	AA

Then there may be four types of international patents, summarized in Table 1, where the inventors are designated by E and the applicants by A. Two types reflect international technological cooperation. On the one hand, there may be co-inventions (EE), which is a patent with inventors from different countries. On the other hand, it can be co-ownership (AA) of a patent, namely if the applicants for a patent come from different countries. The other two types of international patents cover the global procurement of innovations. This may be the case if a domestic invention is in foreign ownership (EA), i.e., a patent with a domestic inventor and a foreign applicant. On the other hand, a foreign invention may have a foreign owner (AE), namely a patent with a domestic applicant and foreign inventor.

Based on this definition, three indicators will be analyzed below:

A-EA: The share of patents with a domestic inventor and a foreign applicant in the total number of patents with domestic inventors.

A-AE: The share of patents with a domestic applicant and a foreign inventor in the total number of patents with domestic applicants.

A-EE: The share of patents with a foreign co-inventor in the total number of patents with a domestic inventor.

In the following, the extent of techno-globalization and internationalization of innovation activities will be analyzed with the help of these indicators. The patent applications at the European Patent Office for the priority years 1991-2010 are used for this purpose. The OECD has now divided the international patents into the three types required for this purpose and published them in its data offer. The Statistical Office of the European Union (Eurostat) also takes over these data.

3. Empirical findings for the cross-section of OECD countries

In a first step, the OECD countries are considered as a cross-section for the two periods from 1991 to 2000 and 2001 to 2010. Table 2 shows the three patent indicators as percentages. Of course, the two indicators A-EA and A-AE are the same worldwide, but there may be large differences between them at country level. Firstly, it is striking that with a worldwide and OECD-wide increase in all three indicators, there is a very high degree of heterogeneity between the individual countries. The countries with the most patents in absolute terms are not the most internationalized in terms of innovation activities. In the US, for example, only 13.5 % of patents were co-invented between 2001 and 2010, and in the co-ownership of innovations, with 18.4 %, the US are directly equivalent to the global value. Rather, it is often smaller countries, such as Austria, Belgium and the Netherlands, or countries with weak patents in absolute terms that are strongly internationalized. These circumstances will be examined in more detail below. The two Asian countries, namely Japan and the Republic of Korea, are the least internationalized in terms of innovation activities. With regard to co-ownership, Germany lies slightly below the worldwide value for both indicators, while it is above the worldwide value for co-inventions, i.e. inventions in which German inventors as well as inventors in other countries were involved.

Secondly, for all countries with the exception of Finland, Iceland, Luxembourg and Switzerland, the share of international co-inventions (A-EE) is smaller than the share of foreign ownership and domestic inventors (A-EA).

Table 2: Three patent indicators for techno-globalization, EPO, for the sub-periods of 1991-2000 and 2001-2010

Country	Share EA		Share AE		Share EE	
	1991-2000	2001-2010	1991-2000	2001-2010	1991-2000	2001-2010
Australia	26.6	30.4	13.1	14.4	17.7	22.6
Austria	32.9	37.1	22.4	25.4	21.1	26.6
Belgium	45.9	45.9	27.1	39.3	31.0	37.6
Canada	34.2	38.8	30.7	25.1	28.4	30.7
Chile	55.6	45.7	20.5	12.2	37.5	31.4
Czech Republic	49.8	47.6	15.4	17.7	36.2	37.8
Denmark	21.1	25.1	18.5	23.9	17.9	20.8
Estonia	73.1	50.9	36.4	27.6	42.3	39.3
Finland	11.8	14.7	19.4	31.7	11.4	17.4
France	17.5	24.9	14.6	21.9	11.7	18.3
Germany	12.5	16.9	10.5	15.6	9.4	13.9
Greece	33.1	38.3	11.8	11.1	30.6	30.3
Hungary	43.3	59.5	12.8	18.7	28.7	39.2
Iceland	49.7	21.8	20.6	50.0	34.4	37.6
Ireland	40.2	40.7	49.2	59.6	33.4	34.5
Israel	32.3	29.1	11.5	11.0	18.2	16.2
Italy	17.8	20.4	5.9	6.0	8.3	10.6
Japan	4.2	3.7	3.7	4.8	2.9	3.0
Korea	8.0	4.2	8.5	5.6	7.8	4.4
Luxembourg	54.9	51.7	82.7	89.0	52.3	55.4
Mexico	63.9	59.0	16.8	39.3	47.9	42.4
Netherlands	23.0	26.1	36.3	39.2	15.4	18.6
New Zealand	27.8	31.0	13.0	15.2	19.9	26.8
Norway	22.3	31.0	21.7	21.9	18.8	24.4
Poland	65.7	45.0	22.8	14.0	55.4	33.1
Portugal	41.7	43.2	40.4	25.1	35.5	31.9
Slovak Republic	54.5	63.4	22.7	28.2	49.6	54.8
Slovenia	35.3	29.1	16.5	12.0	27.7	17.4
Spain	29.0	30.1	8.6	9.2	17.9	21.3
Sweden	16.6	22.4	22.8	34.2	13.5	19.3
Switzerland	23.0	26.1	43.9	56.2	26.2	35.7
Turkey	46.9	17.0	17.1	4.5	45.5	13.9
United Kingdom	35.7	41.8	20.0	20.5	17.9	25.1
United States	10.5	15.3	15.3	18.4	9.4	13.5
OECD - Total	13.8	17.4	13.8	17.8	5.7	8.1
World	14.3	18.2	14.3	18.3	5.7	7.9

Source: Own calculations based on OECD data

In addition, for the majority of countries, the share of patents with domestic inventors and foreign applicants (A-EA) is higher than the share of patents with foreign inventors and domestic applicants (A-AE) (see Table 3). These countries are therefore net exporters of innovations. Only ten countries do not. These are either very large countries, such as the US, or smaller countries with very strong multinationals, such as the Netherlands and Sweden.

Table 3: Net importers and net exporters of innovations

Share EA > Share AE	Share EA < Share AE
Australia	Finland
Austria	Iceland
Belgium	Ireland
Canada	Japan
Chile	Korea
Czech Republic	Luxembourg
Denmark	Netherlands
Estonia	Sweden
France	Switzerland
Germany	United States
Greece	
Hungary	
Israel	
Italy	
Mexico	
New Zealand	
Norway	
Poland	
Portugal	
Slovak Republic	
Slovenia	
Spain	
Turkey	
United Kingdom	

Source: Own representation

By construction, the various patent indicators are not independent of each other. All patents, which have joint inventors in different countries, also have a foreign applicant for at least one of the countries concerned. Consequently, each patent application that is included in the A-EE indicator (i.e., share of patents with inventors at home and abroad) for a country will also be included in either the A-EA or the A-AE indicator. This interdependence of the indicators is also evident when looking at the correlations between the indicators (cf. Fig. 1). With a correlation coefficient of 0.876 and a significance level far below one percent, the linear dependency between the shares of co-inventions (A-EE) and the shares of patents with domestic and foreign applicants is most pronounced. The correlation between A-EE and A-AE (share of patents with foreign inventors and domestic applicants) is also significant below one percent. In contrast, the correlation between the two indicators for the global acquisition of innovations (A-EA and A-AE) is, as expected, smaller, but still statistically significant at a significance level of five percent.

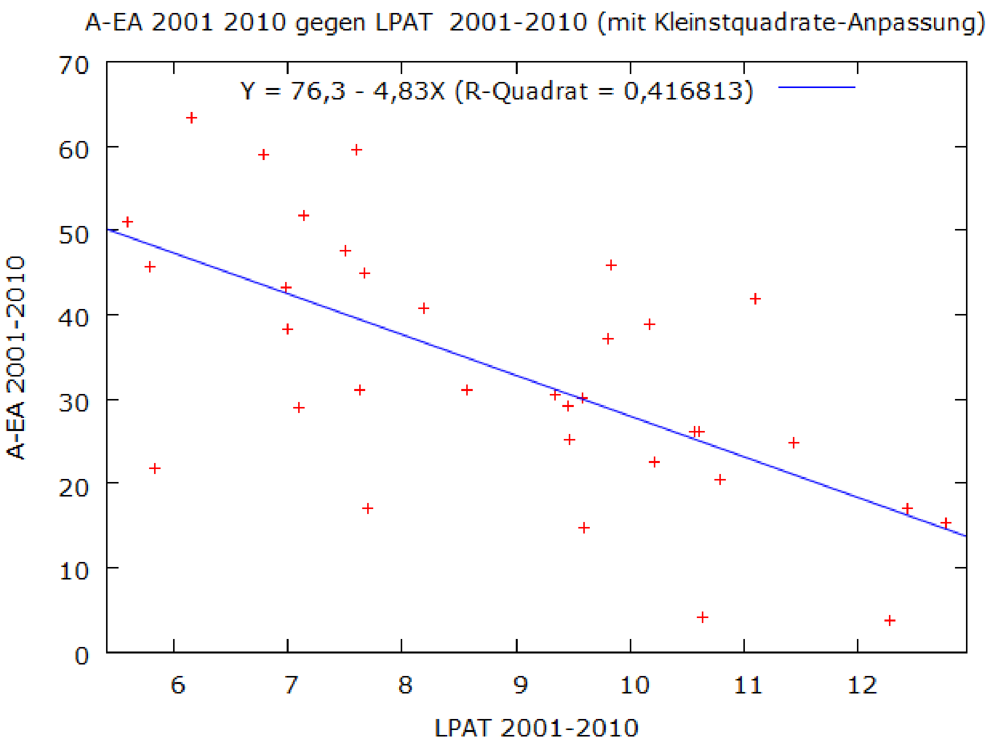
Figure 1: Correlations between patent indicators

Covariance Analysis: Ordinary
Correlation coefficients and t-values
Sample: 1 34
Included observations: 34

Correlation t-Statistic	A-EA 2001-2010	A-AE 2001-2010	A-EE 2001-2010
A-EA 2001-2010	1.000000 -----		
A-AE 2001-2010	0.322523 1.927464	1.000000 -----	
A-EE 2001-2010	0.876445 10.29677	0.630467 4.594674	1.000000 -----

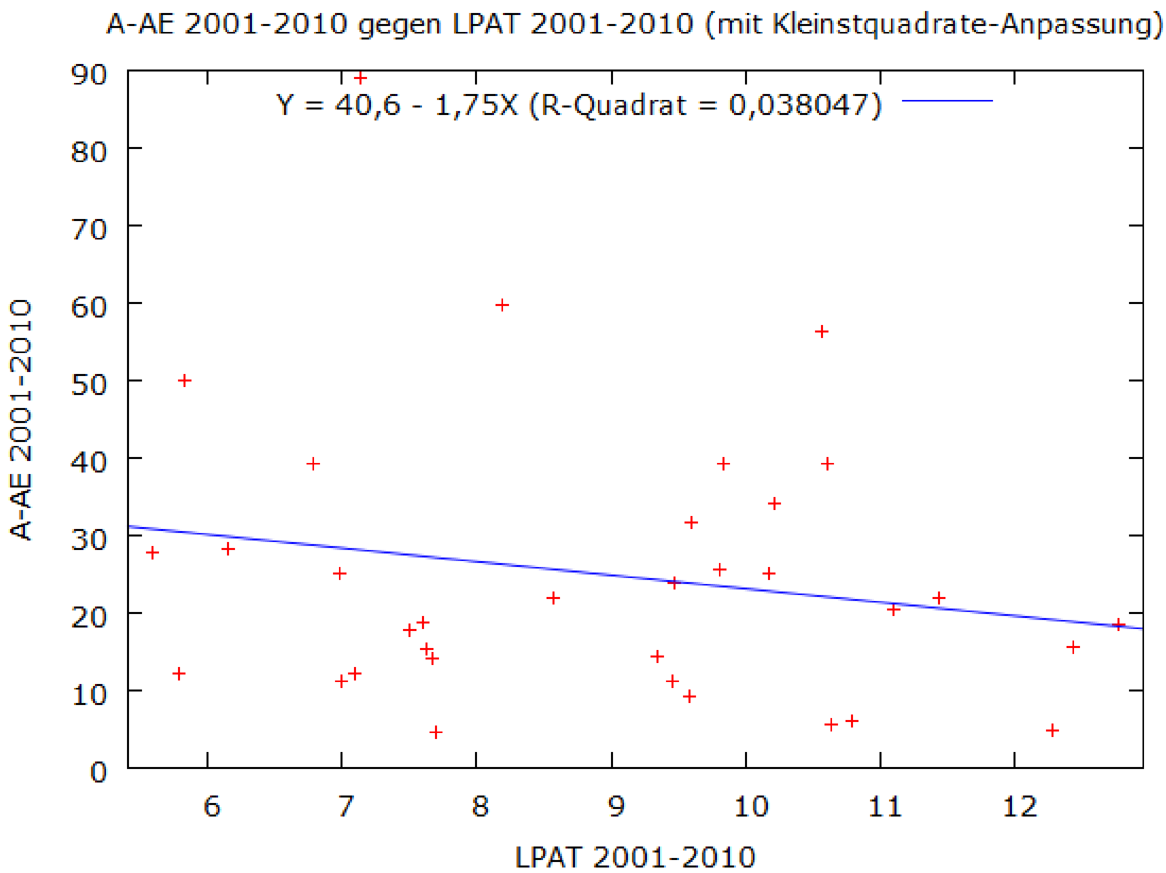
Already during the first inspection of the patent indicators it became apparent that small and/or patent-weak countries (in absolute terms) seem to be more internationalized in their innovation activities. In order to subject this observation to statistical verification, linear simple regressions were calculated for the relationship between the patent indicators and the logarithmic absolute numbers of patent applications for the period 2001 to 2010.

Figure 2: Regression between the shares of patents with domestic inventors and foreign owners and the total number of patents



In fact, there is a significant negative correlation between the shares of patents with domestic inventors and foreign owners (A-EA) and the total number of patents in a cross-sectional view (cf. Figure 2). Approximately 42 % of the dispersion of indicator values can be explained by the dispersion of absolute patent numbers. Patents with inventors in small and/or, in absolute terms, patent-weak countries thus appear to have more foreign applicants.

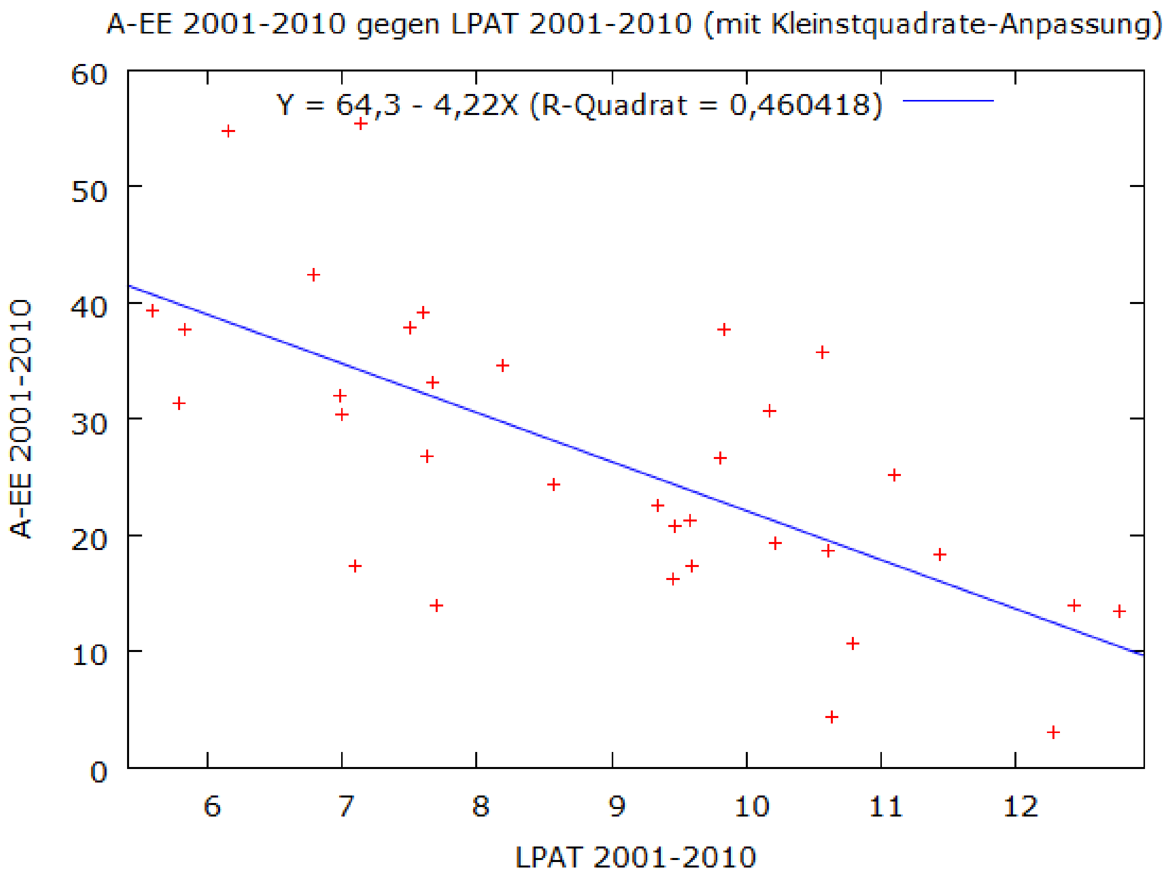
Figure 3: Regression between shares of patents with foreign inventor and domestic owner and total number of patents



The situation is different for the shares of patents with foreign inventors and domestic owners (A-AE) and the total number of patents. As can be seen from Fig. 3, there is no significant correlation here. Statistically significant, however, is again the negative correlation between the shares of patents with domestic and foreign inventors (A-EE) and the total number of patents (cf. Fig. 4). Here the linear coefficient of determination shows that 46 % of the dispersion of co-inventions can be explained by the total number of patents in the country cross-section.

Overall, these findings suggest that the smaller the "technological base" of a country, the greater the proportion of that base controlled by foreign applicants is and the more domestic inventors cooperate with foreign inventors. The more recent figures thus confirm the findings already made in Guellec and van Pottelsberghe de la Potterie (2001).

Figure 4: Regression between the shares of patents with domestic and foreign inventors and the total number of patents



If one compares the proportional values for the two sub-periods, i.e. 1991-2000 and 2001-2010 in Table 2, it becomes apparent that for patents with domestic inventors and foreign applicants (A-EA) and for patents (A-EE) based on co-inventions, countries with relatively high proportional values in the first period show stagnating or declining proportional values in the second period. Conversely, countries that are less internationalized with regard to these indicators in the first period usually show higher values in the second period. If this trend were general, it would mean that there would be a tendency towards convergence between countries in terms of share values. This does not seem to be the case for the shares of patents with a domestic applicant and a foreign inventor.

Whether there is actually a statistically significant convergence of the proportions between the OECD countries can be checked by simple regression estimates in which the rates of change of the two periods are explained by the logarithmic levels of the shares in the first period. If the slope coefficient has a significant negative sign, a convergence of the shares between the countries can be assumed.[2]

[2] This approach, which is common in empirical growth research, is therefore also referred to as a test on β convergence.

Figure 5: Test for beta-convergence for the shares of patents with domestic inventors and foreign applicants

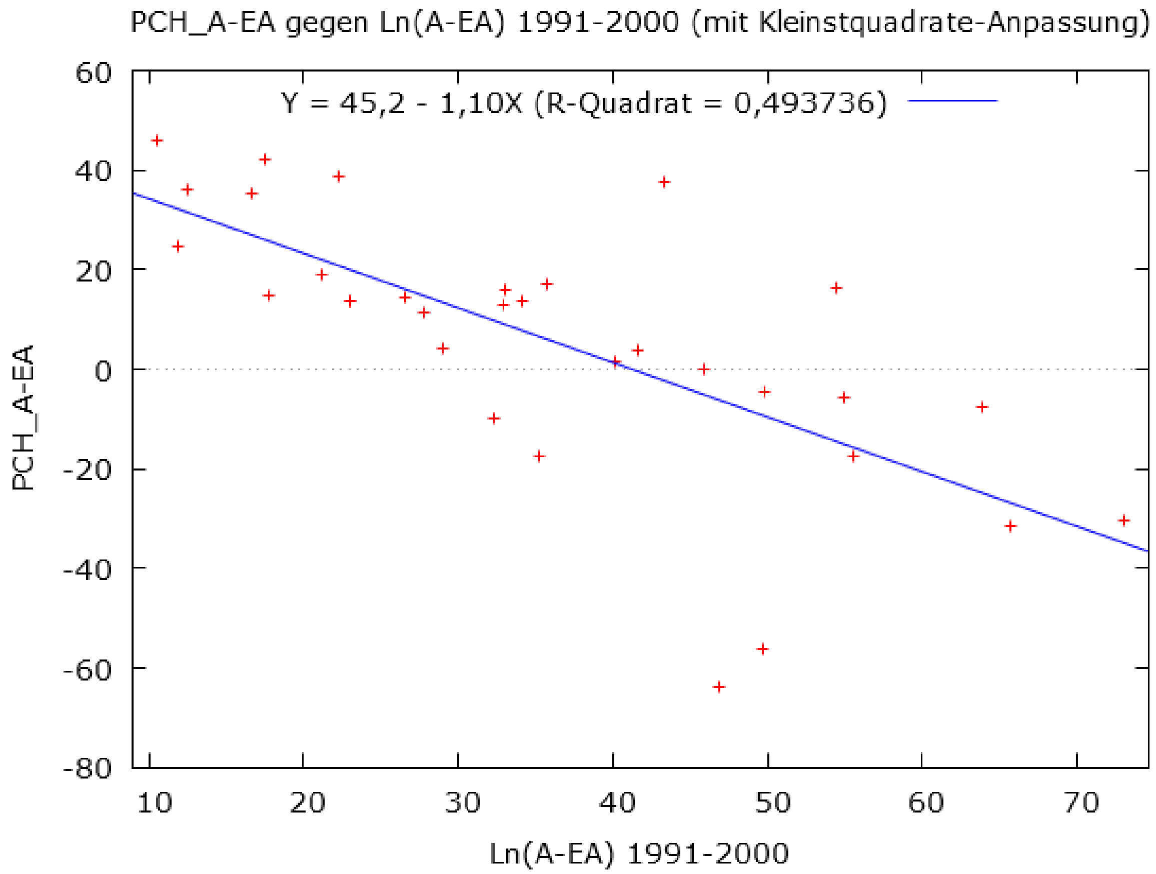
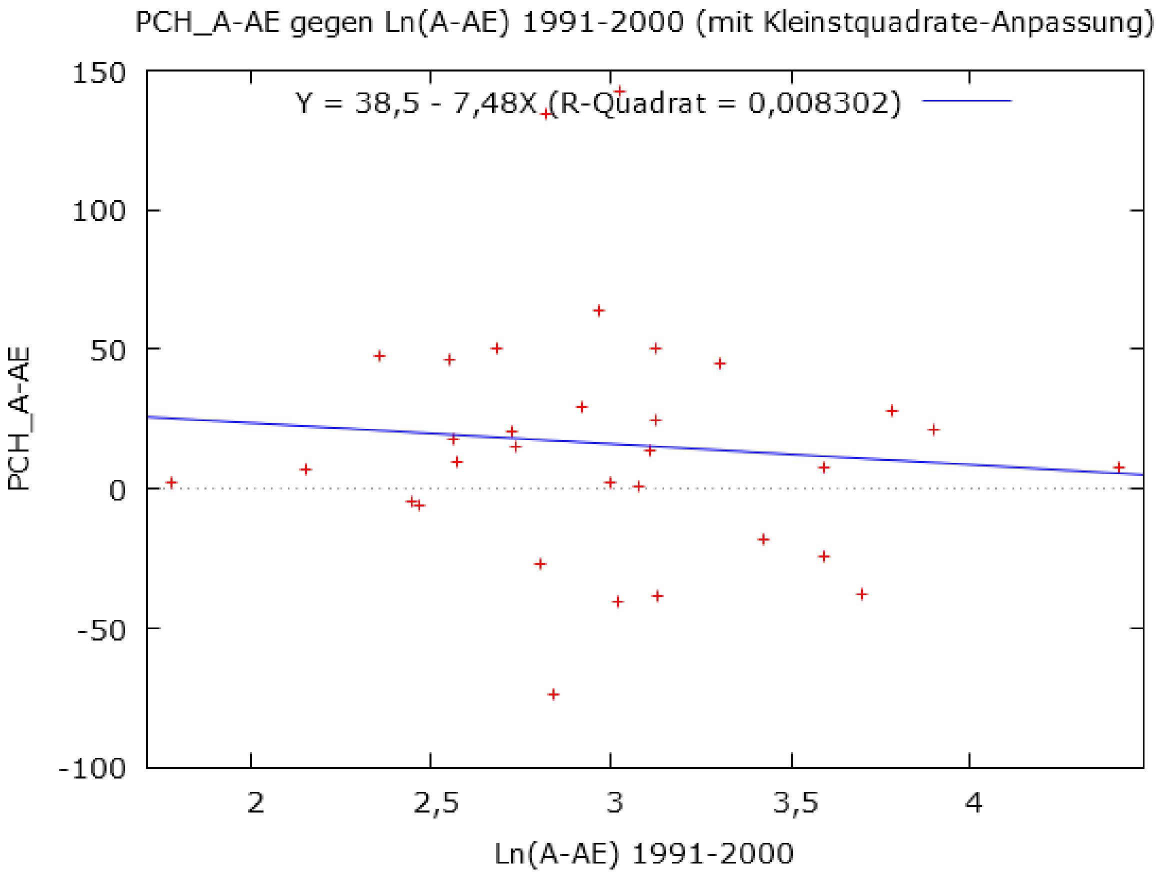


Figure 5 shows the estimate of the convergence equation for the shares of patents with domestic inventors and foreign applicants. In this estimate, neither Japan nor South Korea was included, since statistically they are outliers with their very low internationalization of innovation activities. The regression line shows a highly significant negative slope, so that countries with a high degree of internationalization of their innovation activities in the first sub-period from 1991 to 2000 reduced or only slightly increased their share of patents with domestic inventors and foreign applicants in the second sub-period from 2001 to 2010, while countries that showed a relatively lower degree of internationalization for this indicator in the first sub-period significantly increased it in the second sub-period. It can therefore be assumed that the internationalization intensities will converge for the cross-section of countries considered.

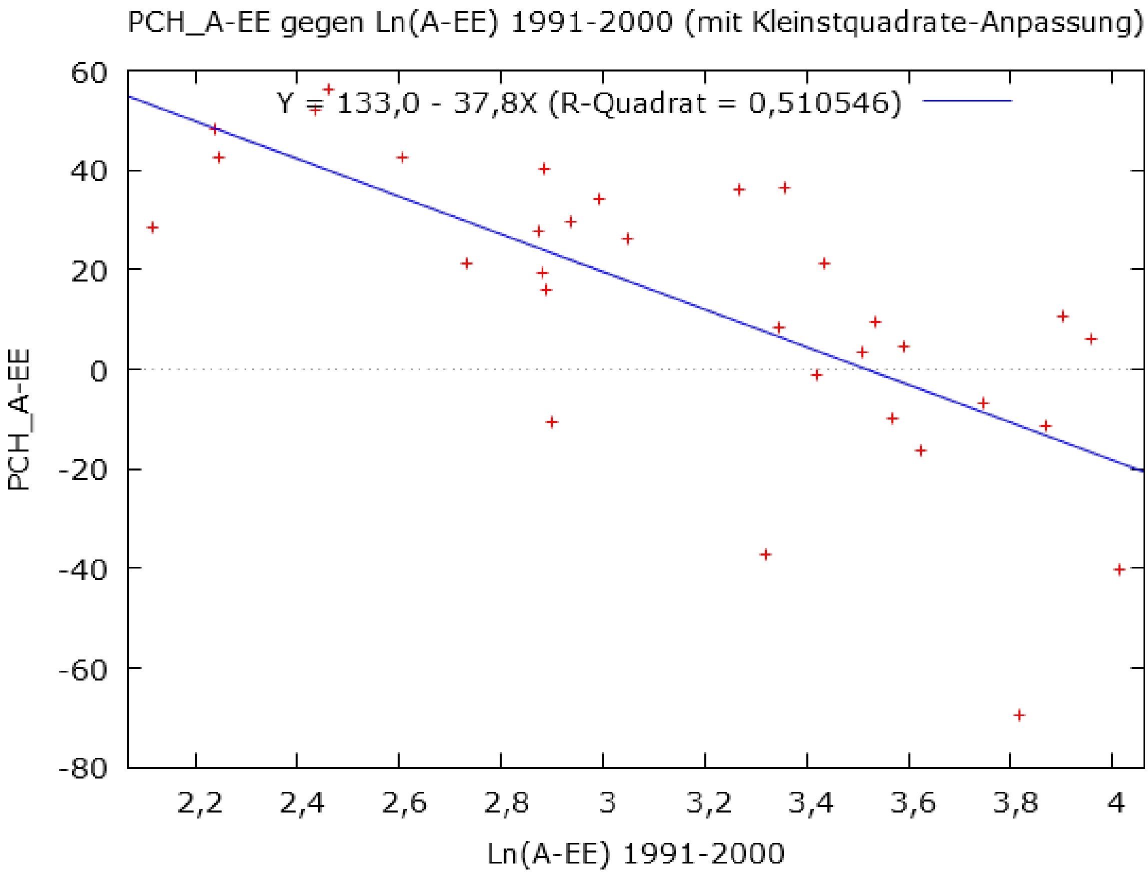
The situation is different for the shares of patents with foreign inventors and domestic applicants (cf. Fig. 6). There is no significant correlation here between the levels of internationalization in the first sub-period and the rate of change from the first to the second sub-periods. As a result, the differences between the countries remain relatively stable.

Figure 6: Test for beta-convergence for the shares of patents with domestic applicant and foreign inventor



On the other hand, there is a clear tendency towards a convergence in the degree of internationalization of innovation activities for the shares of patents with domestic and foreign inventors (cf. Fig. 7). While these shares decreased in the second sub-period for those countries, which had high values in the first sub-period, or increased only slightly in the second sub-period, those countries, which had only a relatively small share of international inventor cooperations in all their patents in the first sub-period increased significantly in the second sub-period.

Figure 7: Test for beta-convergence for the shares of patents with domestic and foreign inventors



In the following, the relationships between the patent indicators on the internationalization of innovation activities and other indicators on the innovative capacity of countries, on the one hand, and on the internationalization of trade and production on the other hand will be examined. The corresponding correlation coefficients are shown in Table 4.

Both the shares of patents with domestic inventors and foreign applicants (A-EA) and the shares of patents with domestic and foreign inventors (A-EE) are negatively correlated with the R&D intensities of the countries at a significance level below 1 % in the country cross-section from 2001 to 2010. The correlation coefficients with the total gross expenditure on R&D (GERD) in relation to the gross domestic product (GDP) are somewhat higher than the correlations with the intensities for the business-financed R&D expenditure. In contrast, R&D intensities are not significantly correlated with the shares of patents with domestic applicants and foreign inventors (A-AE).

Looking at the internationalization of R&D, there are significant correlations here only for the shares of patents with domestic inventors and foreign applicants (A-EA) and the shares of patents with domestic and foreign inventors (A-EE). For the shares of patents with domestic inventors and foreign applicants, there is a significant positive correlation with the shares of total R&D expenditure financed from abroad in total gross expenditure on R&D. Even more marked is the positive correlation with the shares of R&D expenditure of foreign branches in business R&D expenditure (BERD). In the case of the share of international co-inventions, however, there is only a highly significant correlation with the latter R&D internationalization indicator.

Table 4: Country cross-sectional correlations between patent indicators and R&D and internationalization indicators

	n	A-EA	A-AE	A-EE
R&D Intensities				
GERD/GDP	34	-0.65***	0.07	-0.49***
BERD/GDP	34	-0.60***	0.09	-0.46***
Internationalization of R&D				
GERD from abroad/GERD	34	0.29*	0.11	0.19
BERD from abroad/BERD	34	0.20	0.07	0.10
R&D in foreign branch offices/ Corporate R&D	25	0.59***	0.30	0.43**
Foreign Trade				
Export/BIP	34	0.19	0.59***	0.30*
Import/BIP	34	0.29*	0.63***	0.43**
International Production				
FDI inflows/domestic investment	34	0.30*	0.81***	0.53***
FDI inflows/domestic investment (excluding Luxembourg)	33	0.22	0.69***	0.40**
FDI outflows/domestic investment	34	0.15	0.81***	0.43**
FDI outflow/domestic investment (excl. Luxembourg)	33	0.10	0.74***	0.16

*** The correlation coefficients are different from zero at a significance level of 1%.
** The correlation coefficients are different from zero at a significance level of 5%.
* The correlation coefficients are different from zero at a significance level of 10%.

There are also significant correlations with foreign trade activities. The shares of patents with domestic inventors and foreign applicants are positively correlated (at a one-sided significance level of 5 %) with the respective share of imports in gross domestic product, while there is no significant linear correlation for the respective export shares. With a certain degree of caution, this finding can be interpreted as meaning that the motives behind the internationalization of innovations are “home base exploiting” as discussed in the introduction. The other two patent indices are statistically significantly correlated with both the export and import shares of the respective gross domestic product. According to Picci and Savorelli (2012), the link between bilateral trade and international cooperation in invention activities (measured here by the shares of co-inventions) can be seen as evidence that “home base exploiting” motives are relevant.

At the same time, the high correlations between the foreign trade indicators and the two latter indicators also reflect “size effects” already mentioned in the negative correlations between patent indicators and absolute patent numbers. Smaller countries are more open in terms of both innovation activities and foreign trade. A relatively small country size allows only a limited range of activities or higher specialization and thus a stronger integration into the international division of labor. With regard to the shares of patents with a national inventor and a domestic applicant, it should be added that here - as already shown - some smaller countries with strong multinational companies have high values.

For direct investment activities, there are no significant correlations between the ratios of inflows or outflows of FDI to domestic investment and the shares of patents with domestic inventors and foreign applicants (A-EA). As Luxembourg can be considered an outlier for very high FDI flows, all estimates have been made with and without Luxembourg. The correlation between direct investment inflows and A-EA shows that Luxembourg alone is to blame for the significance.

On the other hand, the correlation coefficients between the shares of patents with domestic inventors and domestic applicants (A-AE) point to highly significant positive correlations, regardless of whether Luxembourg is included or not. With regard to the shares of co-inventions (A-EE), if Luxembourg is omitted, there is only a significant positive correlation with direct investment inflows.

Finally, for the cross-section analysis, the two robust factors that could be identified in connection with the internationalization of innovations, namely the size of the country and the technological equipment, are to be included in a regression model to explain the three patent-based internationalization indicators. The country size is approximated by the real gross domestic product (GDP_real) and the technological equipment by the gross R&D intensity (GERD/GDP), whereby both variables are logarithmically included in the estimates (cf. Guellec and van Pottelsberghe de la Potterie 2001).

Table 5: Cross-section regressions to explain the internationalization of innovation activitiesa)

	A-EA	A-AE	A-EE
constant	82.70	94.75	87.95
	(5.04)	(3.19)	(5.99)
ln(GDP_real)	-3.38	-5.53	-4.47
	(-2.64)	(-2.49)	(-4.03)
ln(GERD/GDP)	-14.17	4.67	-8.24
	(-4.54)	(1.10)	(-3.27)
R^2	0.52	0.23	0.51
F-value	19.27	3.12	15.63
P-value (F)	0.00	0.06	0.00
observations	34	34	34

a) OLS estimates with heteroskedasticity-consistent standard errors; t-values in brackets

For all three patent indicators, the influence of the real gross domestic product is highly significantly negative, providing further confirmation that - under otherwise identical conditions - smaller countries are more internationalized (see Table 5). The R&D intensities have a highly significant negative impact on A-EA and A-EE, confirming that it is mainly countries with lower technological endowment where domestic inventors and foreign applicants increasingly come together. The same applies to cooperation between domestic and foreign inventors. For the shares of patents with foreign inventors and domestic applicants (A-AE), the sign for the influence of domestic R&D intensity is positive, but not statistically significant. However, the negative impact of the real gross domestic product remains almost unchanged if the R&D intensity is excluded from the estimate. Also with regard to the linear coefficients of determination of the estimates, the statistical explanatory power of the estimates for A-EA and A-EE is significantly higher than for A-AE.

Figure 8: Countries with degrees of internationalization above and below the estimated values (in percent) for the shares of patents with domestic inventor and foreign applicants (A-EA)

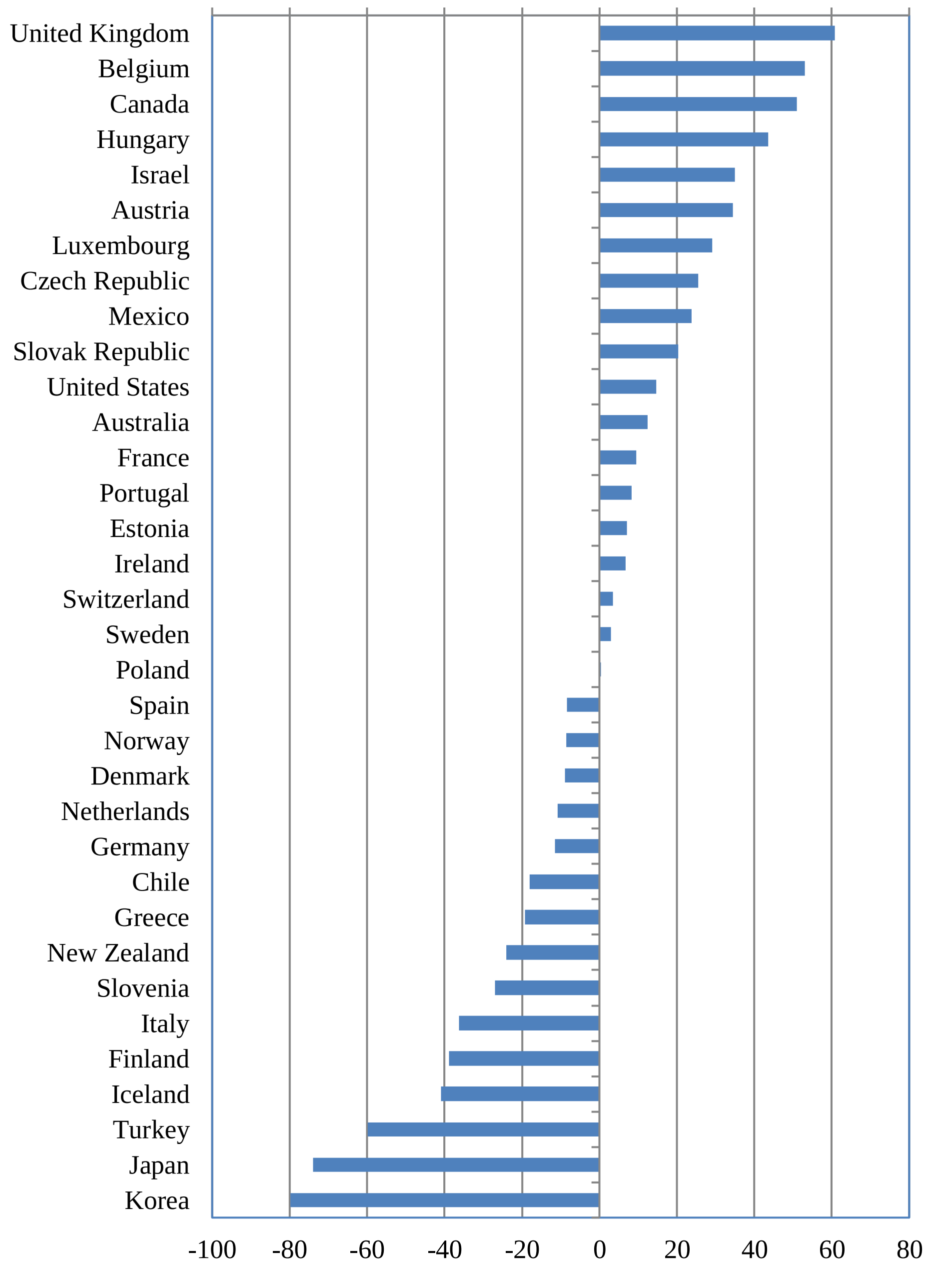
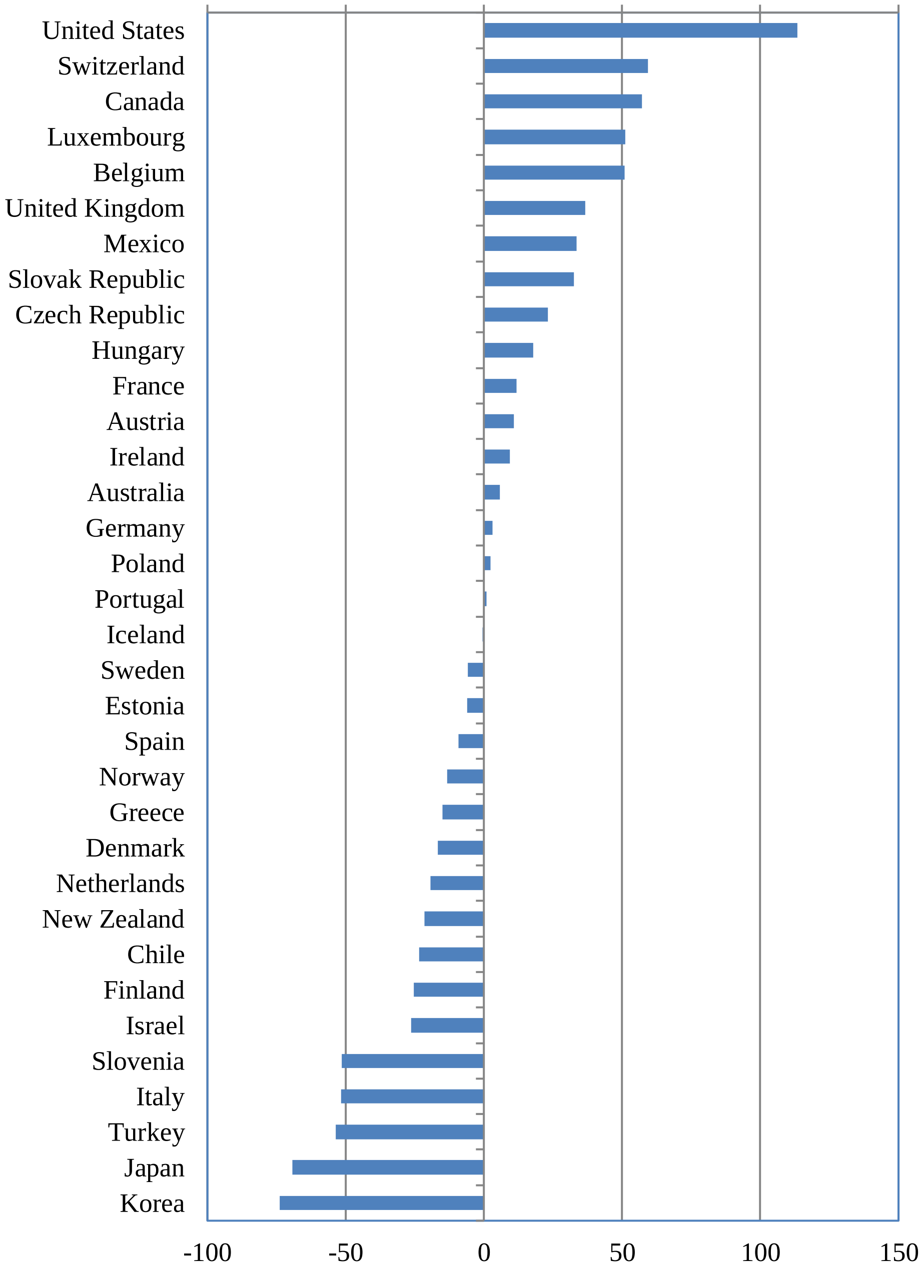


Figure 9: Countries with degrees of internationalization above and below the estimated values (in percent) for the shares of patents with domestic and foreign inventors (A-EE)



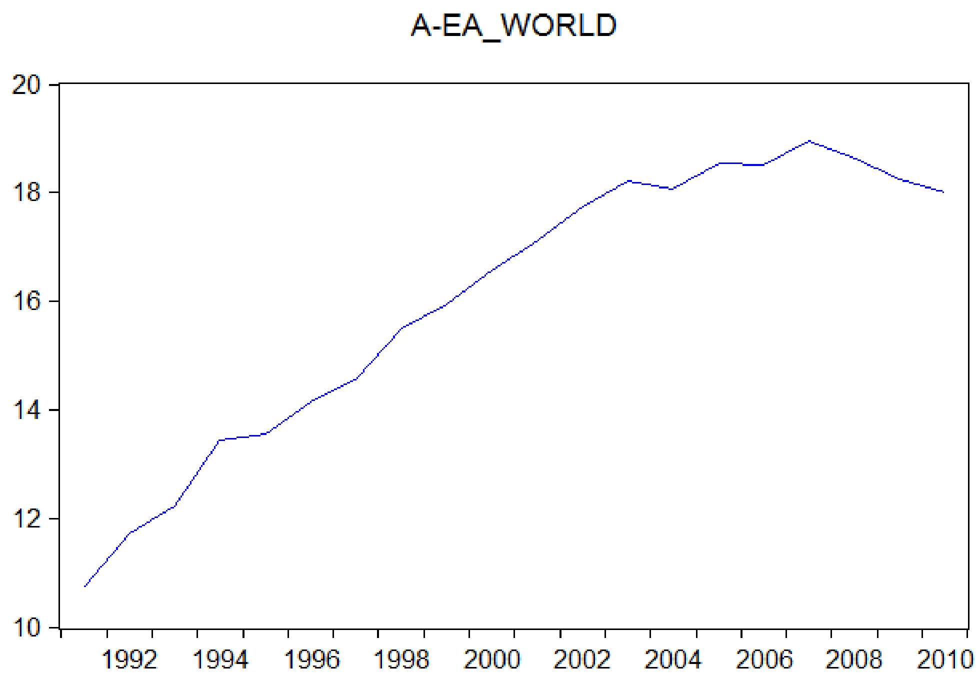
If the residuals of the estimate, i.e. the proportions of patent indicators that cannot be explained by the regression model, are put in relation to the estimated proportions, it can be estimated whether individual countries will be internationalized more or less than expected. Figure 8 shows the degree of internationalization above or below the estimated level (in percent) for the shares of patents with domestic inventors and foreign applicants (A-EA). The three relatively patent-strong countries United Kingdom, Belgium and Canada have the highest shares above the estimated shares of patents with domestic inventors and foreign applicants. The reverse case can be observed for the relatively patent-strong countries Korea, Japan, Finland and Italy. They are well below their estimated level. Other countries with strong patent dynamics, such as Germany, France, the Netherlands and Sweden, are close to their estimated values.

The shares of patents with domestic and foreign inventors, i.e. international research collaborations, are significantly higher in the US, Switzerland and Canada than might be expected due to their size and R&D intensity (cf. Fig. 9). At the other end are Korea, Japan and Italy, countries with strong patent dynamics, which however remain clearly below their estimated values. Other countries, which are strong in terms of patents, such as Germany, France, the Netherlands and Sweden, are again close to their estimated values.

4. Empirical findings for the temporal development in selected countries

In the following, the temporal development of the indicators for the internationalization of innovation activities worldwide as well as for Germany and the Netherlands are examined in more detail beginning with the development of patent shares with domestic inventors and foreign applicants (A-EA). Fig. 10 shows the worldwide development of this indicator. Accordingly, the worldwide growth of the shares of patents with domestic inventors and foreign applicants (A-EA) came to a standstill around 2003. A more precise analysis of the trend development can be carried out by explaining the logarithmic share values by a segmented trend, whereby the structural break points were determined based on statistical criteria using the Bai-Perron test. This was done with a significance level of 5 %.

Figure 10: Development of shares of patents with domestic inventor and foreign owner - worldwide



The trend estimate for the worldwide development of the shares of patents with domestic inventors and foreign applicants (A-EA) is shown in Figure 11. Accordingly, the trend growth from 1991 to 1994 amounts to 7.1 % per year, from 1995 to 2002 it slows down to 3.9 % per year, but is still statistically highly significantly different from zero. From 2002 to 2006, a phase of stagnation can be observed, and from 2007, annual growth is significantly negative at -1.8 %.

Figure 11: Segmented trend development of patents with domestic inventors and foreign applicants - worldwide

Dependent Variable: LOG(SHIA_WORLD)
Method: Least Squares with Breaks
Date: 03/11/15 Time: 11:20
Sample: 1991 2010
Included observations: 20
Break type: Bai-Perron tests of L+1 vs. L sequentially determined breaks
Break selection: Trimming 0.15, Max. breaks 5, Sig. level 0.05
Breaks: 1995, 2003, 2007

Variable	Coefficient	Std. Error	t-Statistic	Prob.
	1991 - 1994 -- 4 obs			
C	2.378063	0.007982	297.9157	0.0000
@TREND	0.070903	0.004267	16.61759	0.0000
	1995 - 2002 -- 8 obs			
C	2.455076	0.011545	212.6528	0.0000
@TREND	0.038758	0.001472	26.32738	0.0000
	2003 - 2006 -- 4 obs			
C	2.808382	0.057798	48.58949	0.0000
@TREND	0.007415	0.004267	1.737908	0.1078
	2007 - 2010 -- 4 obs			
C	3.218934	0.074820	43.02231	0.0000
@TREND	-0.017363	0.004267	-4.069434	0.0016

R-squared	0.998120	Mean dependent var	2.759902
Adjusted R-squared	0.997023	S.D. dependent var	0.174853
S.E. of regression	0.009541	Akaike info criterion	-6.177323
Sum squared resid	0.001092	Schwarz criterion	-5.779030
Log likelihood	69.77323	Hannan-Quinn criter.	-6.099572
F-statistic	909.9638	Durbin-Watson stat	3.098275
Prob(F-statistic)	0.000000		

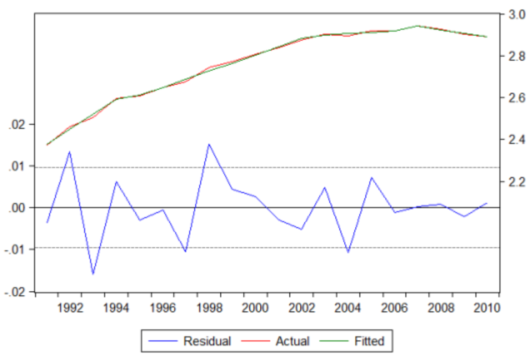
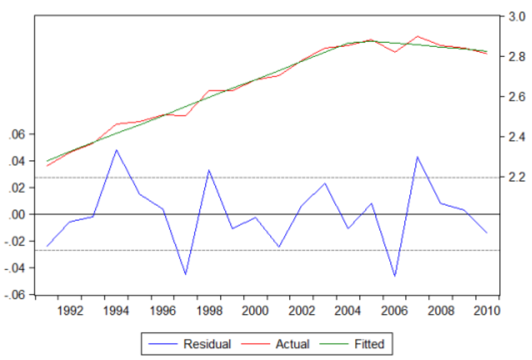


Figure 12: Segmented trend development of patents with domestic inventors and foreign applicants - Germany

Dependent Variable: LOG(SHIA_DE)
Method: Least Squares with Breaks
Date: 03/11/15 Time: 11:28
Sample: 1991 2010
Included observations: 20
Break type: Bai-Perron tests of L+1 vs. L sequentially determined breaks
Break selection: Trimming 0.15, Max. breaks 5, Sig. level 0.05
Breaks: 2005

Variable	Coefficient	Std. Error	t-Statistic	Prob.
	1991 - 2004 -- 14 obs			
C	2.278266	0.013922	163.6504	0.0000
@TREND	0.044944	0.001820	24.69226	0.0000
	2005 - 2010 -- 6 obs			
C	3.015223	0.108863	27.69750	0.0000
@TREND	-0.010034	0.006563	-1.528980	0.1458

R-squared	0.984943	Mean dependent var	2.654178
Adjusted R-squared	0.982120	S.D. dependent var	0.205311
S.E. of regression	0.027454	Akaike info criterion	-4.175779
Sum squared resid	0.012059	Schwarz criterion	-3.976633
Log likelihood	45.75779	Hannan-Quinn criter.	-4.136904
F-statistic	348.8724	Durbin-Watson stat	2.509948
Prob(F-statistic)	0.000000		



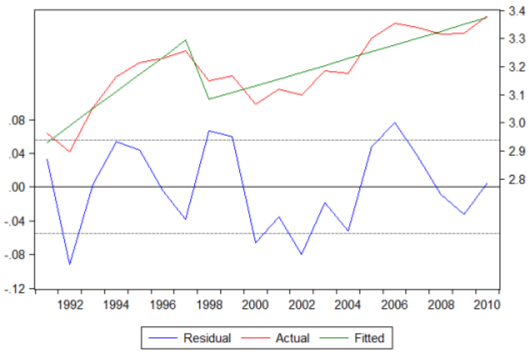
Developments in Germany are somewhat different. There is only one statistically significant structural break. From 1991 to 2004, the trend growth in the share of patents with domestic inventors and foreign applicants amounted to 4.5 % per year (cf. Fig. 12). From 2005 to 2010, the estimated coefficient has a negative sign, but is not statistically different from zero at the usual levels of significance.

Figure 13: Trend in the shares of patents with domestic inventor and foreign owner, by segment - Netherlands

Dependent Variable: LOG(SHIA_NL)
Method: Least Squares with Breaks
Date: 03/11/15 Time: 11:31
Sample: 1991 2010
Included observations: 20
Break type: Bai-Perron tests of L+1 vs. L sequentially determined breaks
Break selection: Trimming 0.15, Max. breaks 5, Sig. level 0.05
Breaks: 1998

Variable	Coefficient	Std. Error	t-Statistic	Prob.
1991 - 1997 -- 7 obs				
C	2.927979	0.037900	77.25547	0.0000
@TREND	0.060918	0.010512	5.795340	0.0000
1998 - 2010 -- 13 obs				
C	2.912296	0.055775	52.21553	0.0000
@TREND	0.024294	0.004123	5.892314	0.0000

R-squared	0.846992	Mean dependent var	3.187032
Adjusted R-squared	0.818303	S.D. dependent var	0.130488
S.E. of regression	0.055622	Akaike info criterion	-2.763622
Sum squared resid	0.049501	Schwarz criterion	-2.564476
Log likelihood	31.63622	Hannan-Quinn criter.	-2.724747
F-statistic	29.52319	Durbin-Watson stat	1.651304
Prob(F-statistic)	0.000001		



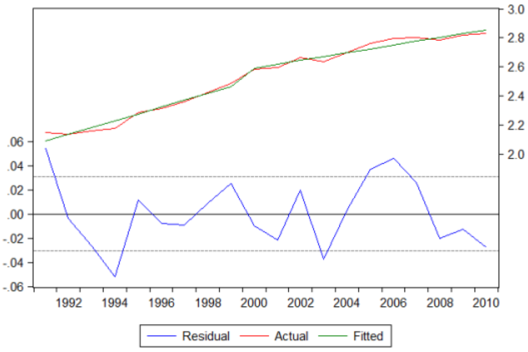
In addition to Germany, the development of the patent indicators for the Netherlands as a smaller open economy, which is also relatively strong in innovation, is considered. Here, the development of the shares of patents with domestic inventors and foreign applicants is significantly more volatile than for Germany (cf. Fig. 13). With regard to trend growth, it can be noted that from 1991 to 1997 it was 6.1 % per year and then fell to 2.4 % after a slump in levels.

Figure 14: Segmented trend development of the shares of patents with foreign inventors and domestic owners - Germany

Dependent Variable: LOG(SHAI_DE)
Method: Least Squares with Breaks
Date: 03/11/15 Time: 11:44
Sample: 1991 2010
Included observations: 20
Break type: Bai-Perron tests of L+1 vs. L sequentially determined breaks
Break selection: Trimming 0.15, Max. breaks 5, Sig. level 0.05
Breaks: 2000

Variable	Coefficient	Std. Error	t-Statistic	Prob.
1991 - 1999 -- 9 obs				
C	2.090119	0.018969	110.1848	0.0000
@TREND	0.046352	0.003984	11.63352	0.0000
2000 - 2010 -- 11 obs				
C	2.354054	0.042235	55.73756	0.0000
@TREND	0.026416	0.002943	8.977107	0.0000

R-squared	0.987467	Mean dependent var	2.522122
Adjusted R-squared	0.985117	S.D. dependent var	0.252979
S.E. of regression	0.030863	Akaike info criterion	-3.941693
Sum squared resid	0.015240	Schwarz criterion	-3.742546
Log likelihood	43.41693	Hannan-Quinn criter.	-3.902817
F-statistic	420.2061	Durbin-Watson stat	1.426164
Prob(F-statistic)	0.000000		



In the development of the shares of patents with foreign inventors and domestic applicants (A-AE), a significant increase can be observed for Germany over time, with continuity being interrupted by a structural break (cf. Fig. 14). From 1991 to 1999, the trend growth was 4.6 % per annum; from 2000 to 2010, it decreased to 2.6 % per annum, but remained statistically highly significant different from zero.

For the Netherlands, too, the development of the shares of patents with foreign inventors and domestic applicants is much more volatile than for Germany (cf. Fig. 15). From 1991 to 1995, these shares remained at the same trend level, followed by a sharp slump, which lasted from 1996 to 2001. A leap in growth can then be observed for 2002, but it lost ground again between 2002 and 2010 with an annual growth trend of -2.6 %.

Figure 15: Trend in the shares of patents with foreign inventors and domestic owners, by segment - Netherlands

Dependent Variable: LOG(SHAI_NL)
Method: Least Squares with Breaks
Date: 03/11/15 Time: 11:48
Sample: 1991 2010
Included observations: 20
Break type: Bai-Perron tests of L+1 vs. L sequentially determined breaks
Break selection: Trimming 0.15, Max. breaks 5, Sig. level 0.05
Breaks: 1996, 2002

Variable	Coefficient	Std. Error	t-Statistic	Prob.
	1991 - 1995 -- 5 obs			
C	3.687252	0.039370	93.65555	0.0000
@TREND	0.014097	0.016073	0.877070	0.3952
	1996 - 2001 -- 6 obs			
C	3.617094	0.093457	38.70318	0.0000
@TREND	-0.018098	0.012150	-1.489550	0.1585
	2002 - 2010 -- 9 obs			
C	4.080100	0.099873	40.85272	0.0000
@TREND	-0.026240	0.006562	-3.998956	0.0013

R-squared	0.872156	Mean dependent var	3.632194
Adjusted R-squared	0.826497	S.D. dependent var	0.122023
S.E. of regression	0.050827	Akaike info criterion	-2.877457
Sum squared resid	0.036167	Schwarz criterion	-2.578737
Log likelihood	34.77457	Hannan-Quinn criter.	-2.819144
F-statistic	19.10170	Durbin-Watson stat	2.263012
Prob(F-statistic)	0.000008		

In the proportion of patents with domestic and foreign inventors (A-EE), worldwide trend growth has slowed considerably since 2001 (cf. Fig. 16). From 1991 to 2000, it was 6.6 % per year; in the following period from 2001 to 2010, it decreased to 1.3 % per year.

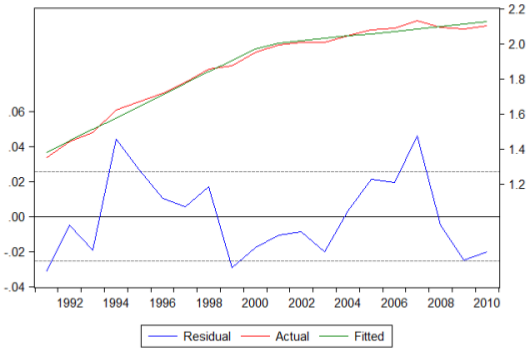
For Germany, the structural break observed in these proportions was even more drastic. As shown in Fig. 17, the share of international co-inventions in Germany increased by 6.5 % per year between 1991 and 2002, almost in line with global trends. In the second period from 2003 to 2010, however, the share stagnates at the level reached: trend growth is not statistically different from zero.

Figure 16: Segmented trend development of the shares of patents with domestic and foreign inventors - worldwide

Dependent Variable: LOG(SHII_WORLD)
Method: Least Squares with Breaks
Date: 03/11/15 Time: 11:52
Sample: 1991 2010
Included observations: 20
Break type: Bai-Perron tests of L+1 vs. L sequentially determined breaks
Break selection: Trimming 0.15, Max. breaks 5, Sig. level 0.05
Breaks: 2001

Variable	Coefficient	Std. Error	t-Statistic	Prob.
	1991 - 2000 -- 10 obs			
C	1.379303	0.014837	92.96666	0.0000
@TREND	0.065586	0.002779	23.59946	0.0000
	2001 - 2010 -- 10 obs			
C	1.867586	0.041080	45.46162	0.0000
@TREND	0.013492	0.002779	4.854887	0.0002

R-squared	0.991024	Mean dependent var	1.868833
Adjusted R-squared	0.989341	S.D. dependent var	0.244504
S.E. of regression	0.025243	Akaike info criterion	-4.343698
Sum squared resid	0.010195	Schwarz criterion	-4.144552
Log likelihood	47.43698	Hannan-Quinn criter.	-4.304823
F-statistic	588.8631	Durbin-Watson stat	1.248864
Prob(F-statistic)	0.000000		



For the Netherlands, after an initial growth of 11.8 % per year in the share of international co-inventions from 1991 to 1995, no further growth trend can be identified (cf. Fig. 18). From 1996 to 2001, there is only a downward shift followed by an upward shift from 2002 to 2010.

Figure 17: Segmented trend development of the shares of patents with domestic and foreign inventors - Germany

Dependent Variable: LOG(SHII_DE)
Method: Least Squares with Breaks
Date: 03/11/15 Time: 11:54
Sample: 1991 2010
Included observations: 20
Break type: Bai-Perron tests of L+1 vs. L sequentially determined breaks
Break selection: Trimming 0.15, Max. breaks 5, Sig. level 0.05
Breaks: 2003

Variable	Coefficient	Std. Error	t-Statistic	Prob.
	1991 - 2002 -- 12 obs			
C	1.871985	0.019224	97.37884	0.0000
@TREND	0.065376	0.002960	22.08348	0.0000
	2003 - 2010 -- 8 obs			
C	2.558235	0.085590	29.88947	0.0000
@TREND	0.005833	0.005463	1.067824	0.3014

R-squared	0.986338	Mean dependent var	2.398392
Adjusted R-squared	0.983776	S.D. dependent var	0.277935
S.E. of regression	0.035401	Akaike info criterion	-3.667271
Sum squared resid	0.020052	Schwarz criterion	-3.468125
Log likelihood	40.67271	Hannan-Quinn criter.	-3.628396
F-statistic	385.0369	Durbin-Watson stat	2.363468
Prob(F-statistic)	0.000000		

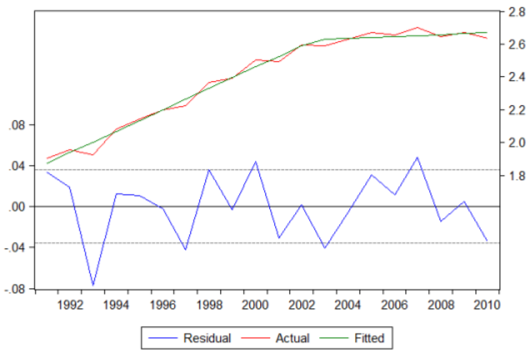
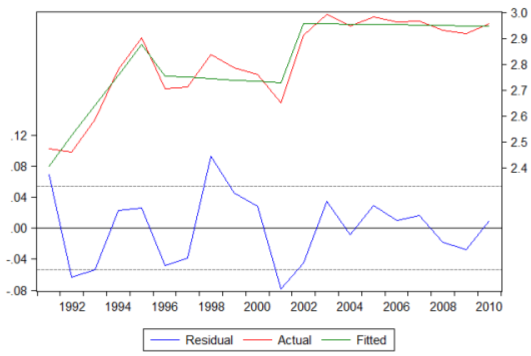


Figure 18: Segmented trend development of the shares of patents with domestic and foreign inventors - Netherlands

Dependent Variable: LOG(SHII_NL)
Method: Least Squares with Breaks
Date: 03/11/15 Time: 11:58
Sample: 1991 2010
Included observations: 20
Break type: Bai-Perron tests of L+1 vs. L sequentially determined breaks
Break selection: Trimming 0.15, Max. breaks 5, Sig. level 0.05
Breaks: 1996, 2002

Variable	Coefficient	Std. Error	t-Statistic	Prob.
1991 - 1995 -- 5 obs				
C	2.404973	0.041312	58.21450	0.0000
@TREND	0.117661	0.016866	6.976344	0.0000
1996 - 2001 -- 6 obs				
C	2.779438	0.098067	28.34223	0.0000
@TREND	-0.005103	0.012749	-0.400252	0.6950
2002 - 2010 -- 9 obs				
C	2.975369	0.104800	28.39104	0.0000
@TREND	-0.001583	0.006885	-0.229929	0.8215

R-squared	0.925116	Mean dependent var	2.810653
Adjusted R-squared	0.898372	S.D. dependent var	0.167301
S.E. of regression	0.053334	Akaike info criterion	-2.781164
Sum squared resid	0.039823	Schwarz criterion	-2.482444
Log likelihood	33.81164	Hannan-Quinn criter.	-2.722850
F-statistic	34.59136	Durbin-Watson stat	1.846569
Prob(F-statistic)	0.000000		



5. Cross-sectional findings at sector level

In principle, the patent indicators for techno-globalization can also be determined at a sectoral level. However, these data are not regularly provided by the OECD, but would have to be extracted from patent databases. The only relatively recent study on this subject is to be found in Danguy (2017). Based on the PATSTAT database, the author has determined the average patent indicators for the period from 1980 to 2005 for 21 industrial sectors as well as the annual growth rates in this period, although no differentiation by country is made. Table 6 shows these data. At first glance, it is noticeable that the dispersion of levels between industrial sectors is much smaller than between OECD countries. This suggests that the differences in the internationalization of innovation activities are much more due to country-specific than to sector-specific factors. In terms of level, innovation activities in the sectors of food production, textiles, coal and mineral oil as well as chemicals and chemical products are relatively strongly internationalized. This applies both to the shares of patents with domestic and foreign inventors and to the shares of patents where inventors and applicants come from different countries. In general, the shares of patents with international co-inventors are smaller than the shares of patents where inventors and applicants differ in nationality.

Table 6: Sector structure of techno-globalization

Branch of industry	Level 1980 to 2005		Average growth rate (in %) 1980 to 2005	
	Share EE	Share EA/AE	Share EE	Share EA/AE
Simple technology				
food	10.11	21.89	5	2
tobacco products	4.38	12.24	6	8
textiles	7.81	16.75	7	5
apparel	3.93	10.45	5	5
leather goods	3.92	15.17	2	1
wood processing	2.69	7.77	7	4
papermaking	5.30	12.13	5	2
Miscellaneous	2.64	8.83	7	4
Simple medium technology				
Coal and oil	7.82	17.44	7	4
Rubber and plastic	4.41	13.67	9	5
Mineral Products	5.05	12.49	10	5
base metals	5.57	11.63	5	4
metal products	3.21	10.24	7	3
Higher medium technology				
Chemical products	9.23	17.65	6	4
mechanical engineering	3.86	11.07	7	4
Electrical devices	3.43	11.18	9	6
car manufacturing	3.34	10.13	8	6
Other means of transport	3.01	6.88	5	3
high technology				
computer	3.87	12.84	11	7
Communication etc.	4.49	14.81	9	7
Instruments etc.	5.28	13.35	7	6

Source: Danguy (2017), pp. 81-82

If the industrial sectors are subdivided according to their technology intensity in accordance with the OECD classification, the respective mean values for the two proportions show relatively minor differences. For the shares for patents with international co-inventors, they are 5.1 % and 5.2 % for the simple technology and simple medium technology sectors, respectively, while they are 4.6 % and 4.5 % for the higher medium technology and high technology sectors, respectively. The shares of patents with applicants and inventors from different countries show average values of 13.2 %, 13.1 % and 13.7 % for the sectors of simple, simple medium technology and high technology, respectively, while the average value for the sector of higher medium technology is "only" 11.8 %. Without the chemical industry, which is relatively strongly internationalized in terms of innovation activities, the fields of higher medium and high technology would be somewhat less internationalized than the two fields of simpler technology.

Moreover, in contrast to the country cross-sectional view, there is no significant correlation between the internationalization indicators and the absolute number of patents in the individual sectors in the sectoral cross-sectional view. With values of 0.005 and 0.007, the linear coefficients of determination here do not show a hint of statistical significance.

The growth rates show that these are generally higher for the shares of patents with international co-inventors than for the shares of patents with inventors and applicants of differing nationality. However, this is also obvious, as the level values of the former are lower and thus it is easier to achieve higher growth rates. For both proportions, however, the mean values of the growth rates increase with technology intensity. The growth rates of the shares of patents with foreign co-inventors range from 5.5 % in simple technology and 7.6 % in simple medium technology to 7.0 % in higher medium technology to 9.0 % in high technology, while the growth rates of the shares with inventors and applicants from different countries increase from 3.9 % in simple technology and 4.2 % in simple medium technology to 4.6 % in higher medium technology and 6.7 % in high technology.

6. Summary

The patent indices proposed by Guellec and van Pottelsberghe de la Potterie (2001) make it possible to consistently analyze both global technological cooperation and the global acquisition of innovations as facets of techno-globalization. In summary, the three patent indicators used show that there are large differences in the extent to which innovation activities are internationalized between the countries considered. Smaller countries and/or countries with weak patent dynamics are often more internationalized in terms of their innovation activities. This is also confirmed by negative correlations between the indicators (especially the shares of patents with domestic inventors and foreign applicants as well as the shares of co-inventions) and with the absolute patent figures as well as the real gross domestic product. Overall, these findings suggest that the smaller the “technological base” of a country, the greater the proportion of this base controlled by foreign applicants and the more domestic inventors cooperate with foreign inventors. The more recent figures thus confirm the findings already made in Guellec and van Pottelsberghe de la Potterie (2001).

A comparison of the shares of patents with domestic inventors and foreign applicants and the reverse constellation of patents with domestic applicants and foreign inventors shows that the majority of the countries considered are “net exporters” of innovations, i.e. the former share value is greater than the latter. The countries where this is not the case are either very large countries, such as the US, or smaller countries with very strong multinationals.

Correlation calculations also showed that both the shares of patents with domestic inventors and foreign applicants (A-EA) and the shares of patents with domestic and foreign inventors (A-EE) in the country cross-section from 2001 to 2010 are significantly negatively correlated with the R&D intensities of the countries. With regard to the relationship between the internationalization of R&D and the patent indicators, there are also a number of significant positive correlations, which in turn do not concern the shares of patents with domestic applicants and foreign inventors, but only the other two indicators.

The existing correlations between foreign trade activities and patent indicators can be interpreted with a certain caution to the effect that in the internationalization of innovation activities “home base exploiting” motives play at least a relevant role. At the same time, however, the high correlations between the foreign trade indicators and the two latter indicators also reflect “size effects”, which were previously mentioned with regard to the negative correlations between the patent indicators and the absolute patent figures. Smaller countries are more open both to innovation activities and to foreign trade.

Finally, regression estimates confirm that countries with lower R&D intensities and small countries make greater use of international cooperation due to their lower technological capabilities. In this respect, they benefit from knowledge flows from abroad. At the same time, comparisons between the realized and estimated patent shares for patents with domestic inventors and foreign applicants as well as for co-inventions show that some countries with strong patent dynamics are internationally active well above their estimated share values, while other countries, which are strong in terms of patents, lag far behind the estimated values.

Simple tests for beta convergence also show, however, that the patent shares with domestic inventors and foreign applicants as well as the patent shares with international cooperations of inventors between the OECD countries are converging over time. Exceptions to this development are Japan and South Korea, which, with their very low internationalization of innovation activities, are statistical outliers. On the other hand, this convergent development is not observed for patent shares with foreign inventors and domestic applicants.

The development over time of the individual patent indicators for technology globalization also varies considerably between the individual countries. Worldwide, both the global acquisition of innovations and global technological cooperation have increased significantly. Since 2001/2002, however, the global increase in both the global acquisition of innovations and global technological cooperation has slowed significantly. In the case of Germany, the shares of patents with domestic and foreign inventors and the shares of patents with domestic inventors and foreign applicants remained unchanged since 2003 and 2005, respectively. In contrast, the shares of patents with foreign inventors and domestic applicants in Germany has slowed down since 2000.

A look at the sectoral level shows that the sectoral differences in the internationalization of innovations are much less pronounced than the differences between OECD countries. Since these sectoral data are not available differentiated by country, it is not possible to answer the question of whether the internationalization of innovations is also oriented towards comparative advantages. Assuming that high-income countries have comparative advantages in high technology R&D and lower income countries have comparative advantages in R&D in areas with simpler technologies, the exploitation of these comparative advantages could lead to complementarities strengthening knowledge production. In a first empirical study and a division of R&D into three categories (high technology, simple and medium technology and knowledge-intensive services), D'Agostino, Laursen and Santangelo (2013) find such complementarity only in the field of simple and medium technology. However, there is still a clear need for research in this area.

Finally, some considerations will also be made on the relationship between the internationalization of entrepreneurial R&D activities and domestic employment. The employment effects of this are closely related to the productivity effects resulting from internationalization. It is usually argued that efforts to develop new products, and thus open up new markets, lead to new jobs, while labor saving process innovations result in job losses. However, since product innovations can also result in productivity effects, the employment effects are not always clear. If a new or improved product requires a change in production methods or input composition, this may increase or reduce labor input. Thus, Bogliacino and Pianta (2010) show that the employment effects of new or improved products are not the same for all industries and also that a distinction between manufacturing and services is of little importance for understanding their empirical findings.

Even the few empirical studies that directly analyze the employment effects of the internationalization of R&D activities at company level do not produce uniform results. For example, Fryges (2004) finds positive effects of international R&D activities on both labor productivity and employment for a sample of young small technology-oriented enterprises in Germany and the UK for the period from 1987 to 1996. Bürgel et al. (2004), on the other hand, use the same sample of companies in an earlier phase of their life cycles and show that international high-tech activities have no influence on employment growth. Moncada-Paternò-Castello, Voigt and Vivarelli (2011) therefore speculate that employment effects only occur in the advanced development of high-tech companies.

The latter authors also summarize the results of a series of studies analyzing the differences in employment development between domestic and foreign-owned enterprises. For both groups of enterprises, the contribution of product innovation to employment growth is smaller than that of old products, but new products play a greater role in employment growth in foreign-owned enterprises than in domestically owned enterprises. This applies to both European and non-European foreign affiliates.

With regard to the direct employment of R&D personnel, according to Moncada-Paternò-Castello, Voigt and Vivarelli (2011) the dominant trend in the internationalization of R&D until recently was not the outsourcing of R&D activities to poorer regions for cost reasons, but an exchange between countries. Recently, R&D offshoring has taken place both in emerging countries, such as China and India, and in developed countries. However, as R&D capabilities in the poorer countries are increasingly improving, they will also account for a larger share of the total outsourced R&D. In this respect, the pressure from less developed countries is not necessarily that they have lower R&D costs, but that they have a growing number of R&D talents that are very well educated, attracting investment from the rest of the world. Germany and Europe need an excellent R&D and innovation system to be able to compete with them.

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