Research and teaching profiles of public universities in Germany. A mapping of selected fields.

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Executive summary

This publication describes research and teaching profiles of public universities in Germany (1992 to 2015). Higher education policy and research has lacked a solid empirical basis both in terms of a suitable descriptive data basis and longitudinal development of university profiles. The present publication and the accompanying website provide such an empirical basis and address therefore an important research gap. We present eight indicators for 68 public universities in Germany (as of 2015). The website provides research and teaching profile maps for each of these universities, as well as relative specialisation maps.

The eight indicators are based on the staff, financial and student data from the Federal Statistical Office (Statistisches Bundesamt, StBA) and bibliometric data from the Competence Centre for Bibliometrics:

1. The **staffing** of universities with professors, and
2. with non-professorial academic and artistic staff,
3. the **funding** of universities in terms of basic appropriations and
4. third-party / grant funding,
5. the **research profile** with Web of Science (WoS) publications, as well as
6. the visibility, as measured in WoS citations,
7. the **teaching profile** on the basis of bachelor and master students, as well as
8. the total number of students (bachelor + master + teacher degree students).

While the indicators regarding staffing and basic appropriation reflect both research and teaching at a university, third-party / grant funding and bibliometric profiles can be regarded as indicators that relate exclusively to research, while the number of students allows statements about the teaching profile. In terms of research profiles, this publication is limited to a selection of 12

scientific fields, which were chosen according to their level of coverage in Web of Science (WoS) database (see 4th Annex). The teaching profiles, on the other hand, cover 56 fields.

The methodological steps which were required to prepare the available basic data for analysis are explained in this paper. For example, it was necessary to standardise the identification of individual universities using data of the Federal Statistical Office and to establish a concordance table between the subject categories of the Federal Statistical Office and a classification system for academic publications based on Archambault, Beauchesne and Caruso (2011). In addition, the selection and calculation of two specialisation measures is discussed on the basis of the relevant literature, and the way in which the tables and figures (research and teaching profile maps) are interpreted is explained in detail, using examples.

The presentation of relative specialisation presupposes that individual universities are compared with a relevant comparison group. To arrive at meaningful findings, two groups of universities were formed, within which the research and teaching profiles were measured. These are the Technical Universities (TUs) and the Non-Technical Universities (NTUs), which stand out clearly as distinctive groups in terms of their disciplinary profiles. Other possible groups could not be empirically substantiated. We present research and teaching profiles for 68 public universities in Germany, 51 of which were NTUs and 17 of which were TUs (medical faculties not included).

This publication has primarily a descriptive orientation. We point out that the specialisations illustrated should not be interpreted as a ranking of the universities. On the contrary, our objective is to provide detailed information for various groups of users on a statistically reliable basis, including university management and their planning staff; second, ministries of education and cultural affairs of the German Länder, which are responsible for both legal oversight and funding of the universities; third, the national and international communities for higher education research; and fourth, the general public, including interested students and journalists.

Our preliminary results are as follows. First, with a few exceptions, research and teaching profiles are clearly identifiable for the universities examined, with 31 universities demonstrating a high degree of conformity (correlation matrices) across all of the six variables considered in the research profiles which indicates good external construct validity. With the other universities, research profiles are less homogeneous across the six variables, which means that the picture of profiling is less clear. Second, it is evident that the long-term change in specialisation profiles should only be assessed with the support of additional contextual information regarding the quantitative development of the respective field in Germany. The same increase in relative specialisation has a different practical meaning in the context of a contracting field compared to a growing field (national scale). Third: although, at first glance, profile maps may give the impression that the relative development of fields at German universities is largely stable, a detailed analysis of the development of individual universities and individual field areas on the basis of the data presented is still outstanding.

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1. Introduction

The objective of this publication is to provide a description of public universities in Germany in terms of their research and teaching profiles. To date, there has been no systematic field-based mapping of the financial or staff resources of public universities, their student numbers, their academic publishing activities or their visibility. This publication is supplemented by a website, which includes graphs and respective data tables concerning 68 public universities (Annex 3-7; see also 3.1). This publication is part of a documentation project whose objective is the provision of longitudinal data of universities regarding their institutional profiles in research and teaching.

Following the literature of organisational and higher education research, the mapping of research and teaching profiles falls under the heading of "horizontal differentiation" (Banscherus et al. 2015, Hüther and Krücken 2016: 94-106). It describes the disciplinary areas that distinguish one higher education institution from another. Two striking examples of areas of special focus such as these are the German Sport University in Cologne and the German University of Administrative Sciences in Speyer, both of which cover a narrow range of fields and therefore have a clear profile. Highly specialised higher education institutions of this kind are not considered in this publication (for an overview, see WR 2010: 34-44). Rather, as described by the German Science Council: the "institutional default case" of public universities, i.e. the "relatively broadly based university that is research-intensive in certain areas of special focus" (WR 2010: 77, 111-15; our translation). If the frequently-used classification of the types of higher education institutions in Germany is considered (see Lundgreen, Scheunemann and Schwibbe 2008: 63-76, Teichler 2014: 70-74), this publication includes universities, technical universities and the former polytechnics (Gesamthochschulen) which were converted into universities, while pedagogical colleges, theological colleges, administrative colleges, art colleges and universities of applied sciences are not studied.

To date, the topic of "horizontal differentiation" has been overshadowed by a discourse focusing on excellence and elites which has dominated both higher education research and higher education policy for many years (e.g. Münch 2007, Münch 2014, Peter 2014). This discourse deals with "vertical differentiation", i.e. it relates to (actual or supposed) differences regarding performance and status (Hüther and Krücken 2016: 98-105, Schimank and Meier 2010, Teichler 2014: 148-61). The fact that this discourse, which has focused on the vertical differences in higher education systems at the national level, has had such an impact, is connected to the emergence and development of "Evaluative Bibliometrics" since the 1970s, an interdisciplinary field of research which has also supported the development of "quantitative research evaluation" as a professional area of expertise (Jappe, Pithan and Heinze 2018). Several indicators have been developed in this area for the quantitative measurement of research including rankings (Moed et al. 1983; Daniel and Fisch 1988, Hornbostel 1997: ; Moed et al. 2004; Moed 2005, Van Raan 1988). Furthermore, in the early 1980s, the highly influential *Centre for Science and Technology Studies (CWTS)* was founded at the University of Leiden (NL), which has set methodological standards and has also been active throughout Europe as an expert organisation in the field of quantitative research evaluation (Jappe 2019, Petersohn and Heinze 2018). In Germany, the *Institute for Research Information and Quality Assurance (iFQ)* was founded in 2005. In 2016, it became part of the *German Centre for Higher Education Research and Science Studies (DZHW)*.

The excellence discourse in Germany has been further supported by the work of two evaluation agencies. First, the Centre for Higher Education Development (CHE) in Gütersloh has been completing field-related rankings of universities and universities of applied sciences in Germany since 1998. On this basis, ranking groups (top, middle and bottom groups) were created according to weighted mean value comparisons (Berghoff et al. 2002a, Berghoff et al. 2002b, Berghoff et al. 2006). Although the CHE has further refined its methodology in the context of an increased attention given to the international rankings of higher education institutions since the 2000s, it has generally adhered to a field-ranking methodology (Federkeil 2013, Hachmeister and Ziegele 2015, Roessler 2013). Second, starting from 1999, Lower Saxony is the first and, to date, only Länder state in Germany to have had almost all of the disciplines at its universities, including the level of individual professors and/or working groups, assessed by the "Scientific Commission" (WKN). In contrast to the ranking approach of the CHE, the WKN completes its evaluations on the basis of an "informed peer review" (WKN 2017: 4-5, 13-14). Bibliometric analyses were tested in a pilot project, but not ultimately included in the evaluation design (WKN 2015: 8, WKN 2017: 18). In the WKN reports, field-related areas of special focus are presented both as part of the "horizontal" characterisation of the profiles of higher education institutions and for the purpose of "vertical" comparison with all of the other universities in Lower Saxony and/or the average throughout Germany (WKN 2015: 19-20, 111).

Since the mid-1980s, the German Science Council (Wissenschaftsrat; WR) has also repeatedly expressed its view regarding the vertical differentiation of the higher education system, thereby shaping the discourse on excellence. In its opinion, “resources should be concentrated where the best academics and the best students are to be found” (WR 1985: 31). This statement does not refer to higher education institutions as a whole, however, but to centres of excellence within higher education institutions: “The objective of a competition-oriented conceptualisation of the development of areas of special focus isn’t just a few leading universities, but rather, centres of excellence in one field or several fields at as many higher education institutions as possible. It must not be the case that the resources are concentrated in only a few higher education institutions” (WR 1985: 31). In the 2000s, the Science Council clarified this position by stating that “it does not make sense for resources to be used in areas which have proven to have limited profile-based relevance or effectiveness over an extended period of time” (WR 2000: 46, similarly: WR 2006: 20). Along similar lines to the evaluations of the WKN, these statements from the 2000s place field-related specialization (“horizontal”) in the context of profiles of excellence (“vertical”).

The power of the discourse on excellence and elites in higher education policy is also reflected by the fact that in the mid-2000s, the Excellence Initiative (which is now in its fourth funding phase) was launched by the German federal and state governments, which has the objective of increasing the international visibility of research at higher education institutions in Germany through a concentration of resources. This primary focus on funding stands out in comparison with the broader objectives of other national excellence initiatives, which also focus on institutional renewal and restructuring, as well as improved staff recruitment (z.B. Klumpp, Boer de and Vossensteyn 2014, Langfeldt et al. 2013, OECD 2014). Hence, the initiative has been heavily criticized for its narrowly-defined objectives and the (presumed) unintended effects of a concentration of resources (z.B. Hartmann 2006, Hartmann 2010, Münch 2007, Münch 2014). The Excellence Initiative only started a few years ago, so that conclusive evaluations of its impact would currently be premature. An initial bibliometric impact analysis has shown that the visibility (proportion of highly cited publications) of the funded universities has increased more than that of the non-funded universities, but that “no significant changes in the ranking of the universities have taken place so far” (Hornbostel and Möller 2015: 41-52). Since 2011, there has also been the “Quality Pact for Teaching”, which has the objective of improving the studying conditions at higher education institutions in Germany. All in all, we can conclude that evaluation practice (CHE, WKN) and higher education- and academic politics (WR) have frequently discussed field-related specialization of higher education institutions in Germany in the context of profile-building for excellence in research and teaching.

In contrast to this, however, there is also a discussion on the horizontal differentiation of national higher education systems that is separate from the the excellence discourse (z.B. Borgwardt 2013, van Vught 2009). Among the more recent descriptive studies in this area is, for example, the study by Huisman et al. (2015), who address the institutional diversity of 24 European higher education systems in the areas of research, teaching, knowledge and technology transfer as well as internationalisation. The authors identify, among others, higher education systems which exhibit a high degree of horizontal differentiation (such as Switzerland, Germany, Denmark), in contrast to systems which are characterised by low horizontal differentiation (Spain, Portugal, Greece, for example). Furthermore, the profiles of 34 national higher education systems were determined by means of the Web of Science (WoS); for each higher education system three areas with the highest and lowest number of publications were identified (Harzing and Giroud 2014). For Portugal, the field-related specialisations of the private and state higher education sectors were examined by Teixeira et al. (2012) using the *Relative Specialisation Index (RSI*), which is discussed below. The authors found that the area of special focus of the private higher education institutions – which are complementary to public higher education institutions – is less on the natural and engineering sciences, and more on the social and health sciences.

Moreover, with the *Activity Index (AI*), which is detailed below, Bonaccorsi et al. (2013) show that Italian universities specialized in applied fields and engineering have a positive impact on business start-ups in their regional environment, especially in the services sector, while universities specialized in basic disciplines are related to a greater number of business start-ups in the manufacturing sector. By far the most comprehensive mapping of university field profiles has been presented for the Nordic countries (Piro et al. 2011, 2014, 2017). In that case, the *RSI* was used in order to compare the field-related publication and citation percentages with the respective global field percentages, and to highlight those higher education institutions which have identifiable field-specific profiles on a global scale.

So far, the research profiles of German universities have primarily been compared with non-university research institutions. On the one hand, the publication and patenting activities by universities as a whole demonstrate that, in comparison with the institutes of the Max Planck Society (basic research-oriented profile) and the Fraunhofer Society (application-oriented profile), they occupy an intermediate institutional position (EFI 2012: 35, Heinze and Arnold 2008: 693-95). Furthermore, in the 1990s and 2000s, higher education institutions in Germany were specialized in biomedical research, while the institutes of the Max Planck Society, the Helmholtz Association and the Leibniz Association had a stronger natural sciences profile, and the Fraunhofer Society was characterised by a distinct engineering profile (Heinze and Arnold 2008: 692-93). In addition to the research profile, the mission statements of German universities were also examined (z.B. Jungblut and Jungblut 2017, Kosmützky 2016, Oertel and Söll 2017). These studies reached the conclusion that no identifiable institutional profile has yet been established that extends beyond the Humboldt mission statement. Rather, it points towards a high degree of institutional isomorphism in the German university system.

As with the discourse on excellence, the German Science Council published recommendations on "horizontal differentiation" in higher education policy. In this respect, it has called on higher education institutions in Germany to work harder to develop clear institutional profiles (above and beyond research excellence), for instance in terms of regional development, the diversification of organisational models or inter-institutional research alliances (WR 2010). This position was repeated also in its most recent statement on the future prospects of the German academic system (WR 2013: 48-50). Nonetheless, these recommendations could not refer to pertinent empirical studies, since there existed very little systematic, quantitatively robust knowledge regarding research and teaching profiles in the German higher education system.

This major gap is taken up by the present publication, which presents a total of eight indicators for the German public university system that are based on a uniform methodology, and which allow the university research and teaching profiles to be documented and compared. These indicators are used to describe specific fields on the following dimensions:

1. The **staffing** of universities with professors, and
2. with non-professorial academic and artistic staff,
3. the **funding** of universities in terms of basic appropriations and
4. third-party / grant funding,
5. the **research profile** with Web of Science (WoS) publications, as well as
6. the visibility, as measured in WoS citations,
7. the **teaching profile** on the basis of bachelor and master students, as well as
8. the total number of students (bachelor + master + teacher degree students).

When studying the indicators for staff and finance, it is necessary to take into account the fact that – with the exception of third-party / grant funding used exclusively for research – these represent both research and teaching. Accordingly, there are three indicators which exclusively represent field-related research profiles: third-party / grant funding, publications and citations; two indicators which represent teaching profiles only: bachelor and master students and students overall; as well as three indicators illustrating both research and teaching profiles: basic appropriations, professors as well as non-professorial academic staff.

The eight aforementioned indicators are calculated and presented for selected fields in two groups of universities: on the one hand for the technical universities (TUs), and on the other hand for the non-technical universities (NTUs). The precise definition of these two groups is provided below (section 3.1). Each university is compared, within its group (TU, NTU), for the selected fields with regard to both its staffing and financial resources as well as its publication activities and citations. This comparison serves to determine the field-related deviation of each university from the group-specific average. In this respect, there are three ideal types of positions. For a particular field, universities can be very similar to their group in terms of the staffing and financial resources, publication and citation frequencies and student numbers. In this case, they should be regarded as typical representatives of the respective group of TUs and/or NTUs. Universities can also be represented to a greater and/or lesser degree in certain fields, so that their indicators are either above or below the average for all the TUs or NTUs. Where universities have disproportionately low values, their staffing, funding etc. are below average. The operationalisation of the deviation from the group average takes place on the basis of the RESP/RSI index (see section 3.2).

This publication has a descriptive focus. We do not provide any explanations on why certain field-related research and teaching profiles have developed at individual German universities, or the extent to which the staffing and financial resources influence the publication and citation measures or the number of students (and vice-versa). Explanations of this kind are multi-dimensional and complex (e.g. Hartig et al. 2013, Kumbier, Haack and Zettl 2009, Paletschek 2001: 515-36). Nor do we provide a ranking of the universities examined in the respective fields. This would not even be feasible based only on the profiles created, as we will explain in section 3.2. This paper rather focuses on providing different user groups with information that is statistically reliable and differentiated content-wise (scientific fields) as well as temporally (1992-2015).

This publication primarily addresses the following user groups: (1) the universities themselves, including their management and planning departments; (2) the ministries of education of the German Länder, which are responsible for the legal oversight of the universities and which contribute significantly to their financing; (3) the national (and international) community for higher education and academic research; and (4) the wider general public, including students and journalists.

2. Basis for data

2.1 Data on staffing, funding and students from the Federal Statistical Office (StBA)

The data on staffing, funding and students were obtained directly from the Federal Statistical Office (Statistisches Bundesamt, StBA) as part of a special inquiry. The data corresponds to the published data of *Fachserie* 11, series 4.1, 4.4 and 4.5 (StBA 1992-2016a, StBA 1992-2016b, StBA 1992-2017) and were prepared at the level of the universities and their fields of teaching and research. The corresponding data in the StBA *Fachserien*, by contrast, are only available at a more aggregated level. For the data collection methodology of the underlying data, reference is made to the two publications of the StBA referred to above.

This publication does not cover fields of medicine/health sciences because a strict separation of the clinical units from their affiliated university institutions in terms of their staff data did not take place until the year 2000. In 1999, for example, the LMU Munich had 732 professorial staff. One year later (with the description "without clinic") this number plummeted to 567, while the separately listed clinic at LMU Munich listed 143 professorial staff. These staff positions relate to the field of human medicine/health sciences and the central services almost without exception.

While the *Fachserie* 11, series 4.1 (students at higher education institutions) covers enrolled students, the *Fachserie* 11, series 4.2 (examinations at higher education institutions), by contrast, lists graduates. The number of students is a quantitative feature that can be used as an indicator for the size of a university or a field, while the number of graduates can be used as a qualitative feature, especially in relation to the number of students. Both staff and funding data are also quantitative features.

As the statistics on students in higher education (series 4.1), the statistics on higher education financing (series 4.5) and the statistics on higher education staff (series 4.4) use different identification numbers (IDs) for the higher education institutions that they document, the first step was to assign unique IDs to the universities. In this respect, reference was made to institutional continuity. This applies in particular to polytechnics (Gesamthochschulen) which have been converted into universities. This means that in the data set we created, for example, a uniform ID was assigned to "Bergische Universität Wuppertal" *(University of Wuppertal)* and the former “Gesamthochschule Wuppertal” *(Wuppertal Polytechnic)*. Similarly, higher education institutions that have merged at some point were considered as one entity also in the years preceding the merger when they had still been independent. In 2003, for example, the universities of Duisburg and Essen were merged to create the “University of Duisburg-Essen”.

The statistics on staffing from the StBA contain five non-overlapping categories for professorial staff: temporary professors, C4/W3 professors, C3/W2 professors, C2 professors and junior professors. The variable of “professors” includes from these five categories. Furthermore, the staff statistics feature the following two categories for academic staff: Lecturers and assistants as well as academic and artistic staff. The variable of “non-professorial academic and artistic staff” integrates these two categories.

The financial statistics of the StBA distinguish between two categories of third-party / grant funding: public third-party / grant funding (e.g. German Federal Ministry of Education and Research, BMBF) and third-party / grant funding from other areas, typically from private sources (e.g. foundations, companies) or other sources (e.g. German Research Foundation, DFG). It was from these two categories that the “third-party / grant funding” variable was created. The basic appropriation variable is derived from the subcategories which are provided for in the financial statistics. In this respect, we follow the definition of the StBA (2012: 7), which defines basic appropriation as follows:

> *“*Current expenditure (basic funding) for teaching and research:
> This is the part of higher education expenditures which the Länder governments make available to the higher education institutions from their annual budget for current expenditures. The current expenditures (basic funding) are determined by adding the estimated social contributions (extras for pensions and healthcare) of university staff with civil servant status to the current expenses of the higher education institutions (staff expenditure and current administrative expenditure) and subtracting the revenue, including rents and leases. The current expenditure (basic resources) does not include any investments” (our translation).

On the basis of this definition by the StBA, the basic appropriations were calculated from the available data as follows: Administrative revenue, third-party / grant funding and investments were subtracted from the total expenditure. The total expenditure includes staff expenditure, rents and leases, energy costs, running costs, current administrative expenditure and other current expenditure. The financial variables were adjusted for inflation (base year: 2010).

The student statistics distinguish different groups of students according to their study objective (intended final examination). These groups have been aggregated by the StBA into the following groups: Teacher degrees, university degrees (without teacher degrees), doctorates, artistic degrees, degrees from a university of applied sciences, bachelor degrees, master degrees, other degrees (see 8th Annex). On this basis, two variables were then created for the present publication: first, the bachelor and master students, which combines the university degree, the bachelor degree and the master degree, and second, students overall, which, in addition to bachelor, master and university degree students includes students with a teacher training as the intended final examination.

Students who are studying for an artistic degree or a degree from a university of applied sciences are almost exclusively enrolled at art schools or universities of applied sciences, and are therefore not of interest in terms of the purely university-based perspective of this publication. Similarly, doctoral students were not considered either, as there is a high overlap between doctoral students and academic staff in the German higher education system, and therefore, many doctoral students are already represented in the staff variables. Finally, the “other degree” group consists of a residual category in which students who do not fit into any of the other groups are classified, for example, courses for senior citizens who do not have any previous academic qualifications.

In the course of the data preparation, the aforementioned staff, financial and student variables were plotted for each university and each field so as to identify and document outliers and gaps in the data. Missing values in an otherwise steady graph were estimated according to the average value of the respective variable for the previous and subsequent years (singular imputation). This method was primarily used for the staff data. For instance, it was applied to the staff data from the University of Cologne (2001), the Brandenburg University of Technology Cottbus-Senftenberg

(2001-2003) and the University of Potsdam (2003). Outliers which deviated by several orders of magnitude from previous and subsequent years, especially with the financial data, were recoded as missing values (N/A). The removal of outliers which are above the normal global range in a specific field ensures that all the RESP values of the indicator in that field are increased, and can therefore be displayed more realistically. The removal of outliers which are below the normal global range serves to present the data of an institution more homogeneously and to correct obvious errors in the data. Missing values were also recorded in the case of lacking information. This was the case, for example, for all Bavarian universities, the basic appropriations of which had not yet been allocated to the areas of teaching and research at the time of the data collection (2005). The same pattern was also found for the basic appropriation for the European University Viadrina Frankfurt/Oder (2004-2005) and the University of Halle (2005-2006) and the University of Bonn (2006-2007).

2.2 Publication and citation data from the Web of Science

The bibliometric analysis of publications and citations is based on university affiliations in the WoS. The "Science Citation Index" (SCI), which was first introduced by Garfield (1964) and from which WoS was subsequently developed, is the most widely-used multidisciplinary publication and citations database in the academic community. The basic idea of Garfield was to select the journals covered in the database according to their significance for the respective field area: the most relevant journals from each scientific field were to be covered *(core journals*). This selection procedure of WoS, which is largely based on the Journal Impact Factor (JIF) (Garfield 1972), led to the creation of a database which can be used for bibliometric analyses of a variety of natural sciences disciplines. The version of WoS on the internet which is licensed by many academic institutions, however, is suitable for bibliometric analyses only to a limited extent. Due to technical restrictions, the number of data records that can be processed in a single downloading process is restricted to 500. This is far from sufficient for a bibliometric evaluation which covers the whole of the university landscape in Germany. Another complicating factor is the fact that the internet version of the WoS provides the address information as free text and not as uniquely assigned identifiers (IDs). This means that there can be many different notations and abbreviations for any particular university name.

In 2008, the German Federal Ministry of Education and Research (BMBF) launched the Competence Centre for Bibliometrics (funding code: 01PQ17001) in order to allow the German academic system to carry out comprehensive and reliable bibliometric analyses. This centre initially consisted of the former iFQ, the Fraunhofer Institute for Systems and Innovation Research (Fraunhofer-ISI), the Institute for Interdisciplinary Studies of Science at the University of Bielefeld (IISS) and the Leibniz Institute for Information Infrastructure (FIZ Karlsruhe) and was expanded by three further consortium partners in 2016: the Leibniz Institute for Social Sciences (GESIS), the Max Planck Digital Library (MPDL) and the Research Centre Jülich (FZJ). The core task of this centre is to provide a data infrastructure which addresses the problems of data quality described above.

The processing of publication records as well as the capability to analyse all of the search fields is achieved on the basis of an Oracle database which was set up for this purpose and is also known as “local installation”. The tables in this database are normalised to each other according to the normal forms defined by Codd (1970). The objective is a redundancy-free form of data storage by splitting the data records into individual tables, as is generally the case with large amounts of data, so as to optimise running times and save memory. This means, for example, that information on journals can be found in a “Source” table, information on individual issues of journals in an “Issues” table, and the individual publication in an “Items” table. This data source is also enriched with adjusted address formats, i.e. the data are cleaned at the highest institutional level, using IDs. This is referred to by the Competence Centre for Bibliometrics as follows:

> “The structural schemes of the databases are conceptualised and optimised for the purpose of bibliometric investigations, i.e. in addition to the raw data supplied by the database manufacturers, the bibliometric databases contain further information and pre-calculated indicators. Of particular added value in the data infrastructure operated by the Competence Centre for Bibliometrics is the institutional coding which has been implemented, i.e., the different notations of German institutions which are contained in the address fields of the databases are adjusted and merged, so that an unequivocal allocation of the publications to the institutions is supported” (our translation).

Under these conditions, the WoS was chosen as our data source, with access via the local installation of the Competence Centre for Bibliometrics. Although the centre does not only provide the WoS but also the Scopus database, the WoS was chosen for the reasons mentioned above, especially in view of the selection of the *core journals*. The number of journals covered by Scopus appears to be significantly higher, however, the overlap between the two databases at the document level is approximately 90 %. This overlap did not change substantially during the period under review in this publication (Ball and Tunger 2006, Waltmann, Visser and van Eck 2018).

By using the local installation of the WoS via the Competence Centre for Bibliometrics, publication data with cleaned address information at the highest institutional level is available for the universities in Germany for the period under review, i.e. 1992–2015. The Competence Centre for Bibliometrics does not provide institutional affiliations at a more detailed level of aggregation, which means publications cannot be directly allocated to institutes, academic departments or faculties. Instead, a field classification was used in order to break down universities to their subject fields. The classification provided by the WoS *(subject categories, SCs*) is not suitable for this task. On the one hand, this is due to the heterogeneous nature of the subject categories, which means that certain categories are very disaggregated (e.g. medicine), while others, on the other hand, are presented in a far more aggregate form (e.g. physics). One of the major disadvantages of the WoS classification consists in that each journal can be assigned to up to five categories. This multiple assignment generates a considerable amount of redundancies, which makes the data less meaningful. For this reason, the choice fell on the classification provided by Archambault, Beauchesne and Caruso (2011), which assigns each journal to just one subject category and which, in terms of its degree of differentiation (with three hierarchical levels), is a good match with the field classification of the StBA. The Archambault categories were matched to the more aggregated categories of the StBA (concordance), allowing the connection between WoS publication data and the StBA data described above (see Annex 9th).

In this respect, two more things are important. First, there is one interdisciplinary Archambault subcategory which appears in two fields, namely Chemistry and Physics/Astronomy: Nano Science & Nanotechnology. Second, there are 10 StBA fields overall that could not be translated into the classification of Archambault, Beauchesne and Caruso (2011). One the one hand, these are subject categories which are referred to as “general” and have a more residual character: Linguistics and Cultural Studies in general; Law, Economics and Social Sciences in general; Mathematics, Natural Sciences in general; Agriculture, Forestry and Nutrition in general; Engineering in general. On the other hand, it relates to the following five fields: Special Education; Regional Sciences; Industrial Engineering with a focus on Economic Sciences; Landscape Management, Environmental Engineering; Surveying. These fields are not represented in the research profiles discussed herein. They are included indirectly in the RESP/RSI calculation, however, as they are taken into account for the total number of scientific staff and funding. This provision is important for two reasons. First, the calculation of RESP/RSI values would be distorted if these 10 StBA fields were not taken into account. Second, this way, the research profiles can be directly compared to the teaching profiles, with these fields having been incorporated in the analysis and shown in graphic form.

It was also verified as to whether the Archambault classification covers all the existing publications or whether (above all, German) journals are included in the database which had not yet been assigned to one of its subject categories and were not therefore documented (check of completeness at article level). To ensure an adequate representation, the coverage should amount to 95 % + x in each individual year. Only the period 2004 to 2007 achieved this level of coverage before supplementation. In all of the other years, the coverage was lower: furthermore, in the initial years (1992–1995) and in the last years (2013–2015), it was less than 90 %. Subsequently, a total of 595 journals were identified across all years which had not yet been assigned to an existing subject category. With the support of a co-citation analysis, suggestions were made as to which categories the journals could be assigned to. This list of suggestions was checked manually for all of the journals in order to create the corresponding supplementations for the classification. This procedure proved to be possible for the majority of journals. For the remaining 50 journals, the categorization took place solely on the basis of the journal title and the description of the journal on the internet. The effects of the reclassification are shown in Annex 10th.

In terms of the further procedure, this means that the publications are initially assigned to the universities as institutions and then to individual fields within the universities using the journal classification system according to Archambault, Beauchesne and Caruso (2011). In this way, each publication is counted just once for each institution and field. In the case of co-authorships of two or more institutions, an allocation to each of these institutions takes place in the same proportion according to the *whole count* method. A precise fractioning in the publication count would not currently be possible on the basis of the data cleaning of the Competence Centre for Bibliometrics, as only the publications of German institutions are cleaned in the institutional coding.

Every publication is counted that was published in a journal covered by the WoS, that was produced with the participation of at least one of the German universities investigated, and that corresponds to any of the document types “Article”, “Review” or “Letter”. Only these three types of document reflect academic publications. When citations are included, the same types of document are considered, and the same parameters apply as for publications. Citations counts include all citations received by a university per year, regardless of the publication years of the cited publications. With this counting method, the change in the citations obtained for a field in the respective year are easily observable.

The validity of bibliometric evaluations strongly depends on the rate of coverage for the respective field in the WoS. To estimate the coverage for German publications by fields, we analysed the proportion of their cited references which are in turn included in the WoS. This method is also used by CWTS and is called “overall” or “internal” WoS coverage of a field (Moed 2005). “Internal coverage” is an indicator for how well the WoS database reflects the scholarly practice within a scientific field. Our analysis documents that the internal coverage in many fields is insufficient for evaluative purposes. We have therefore used rates of coverage as a basis for field selection. Following Moed (2005), we apply a cut-off value of 50 % for the cited references which must be included (2006–2015). This includes the following 12 fields in descending order of coverage: Biology (Biologie); Chemistry (Chemie); Physics, Astronomy (Physik, Astronomie); Nutrition and Household Economics (Ernährungs- und Haushaltswissenschaften), Psychology (Psychologie); Agricultural Sciences (Agrarwissenschaften), Food and Beverages Technology (Lebensmittel- und Getränketechnologie); Mechanical Engineering/Process Engineering (Maschinenbau/Verfahrens-technik); Geosciences [excluding Geography] (Geowissenschaften [ohne Geographie]; Electrical Engineering (Elektrotechnik); Forestry, Timber Management (Forstwirtschaft, Holzwirtschaft); Economics (Wirtschaftswissenschaften); Mathematics (Mathematik). Pharmaceutics (Pharmazie) also has a rate of coverage of >50 %. However, since it is mostly offered at universities with medical faculties (with the exception of Braunschweig), it is not taken into account in the following discussion. In terms of the degree of coverage, all other fields shown, which Figure 1 shows very clearly, are below 50 % in terms of the cited references which are referred to as sources in the WoS.

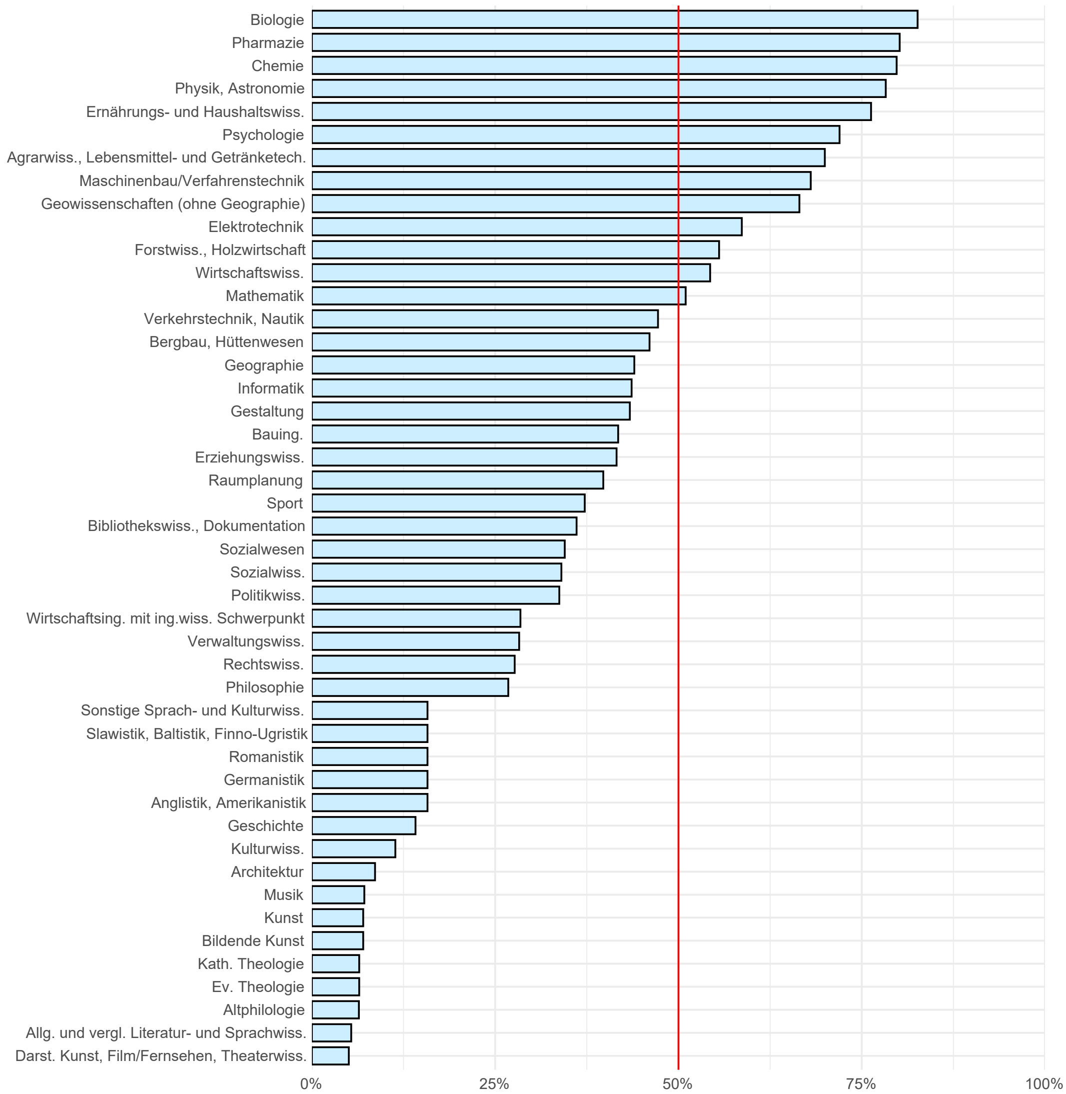


Figure 1: WoS rates of coverage (article, review, letter) for fields in percent (2006-2015)

3. Methodological foundations

3.1 Selection of units for analysis

According to the classification of the StBA, 102 higher education institutions in Germany award doctoral degrees. 82 of these universities are public entities and 20 are private entities (StBA 1992-2016a). In view of their small share of all enrolled students, their very limited range of fields, and their low volume of research activities (to date), private universities only play a subordinate role in the German higher education system (Hüther and Krücken 2016: 100-02). Therefore, they are not considered in this publication.

As mentioned above, there are several specialised public higher education institutions (some with university status), which, from a methodological perspective, are not suitable for comparison with (full) universities that offer a broad range of fields. On the basis of a tabular overview of the Council of Science and Humanities (WR 2010: 111-15), we have therefore excluded the eight following specialised public universities from further consideration: the Bauhaus University Weimar, the German Police College, the German Sport University Cologne, the Distance Education University Hagen, the Hafen City University Hamburg, the Medical University Hanover, the Veterinary University Hanover and the German University of Administrative Sciences Speyer. The University of Lübeck also offers a particularly narrow range of fields, so it is not considered any further. Nor are any of the colleges of education, theological colleges, administrative colleges, art colleges or universities of applied sciences included in the analysis.

Finally, it was not possible to consider further five public universities due to considerable gaps in the data, especially the staffing and funding data: the two universities of the German Armed Forces in Hamburg and Munich, as well as the Universities of Flensburg, Hildesheim and Vechta. All in all, our analysis therefore covers 68 state (full) universities in Germany, 51 of which are NTUs, and 17 of which are TUs (see Annexes 6th and 7th). Additional methodological information on the choice of universities examined is provided in 3rd Annex .

3.2 Index of relative specialisation

Which indicator is appropriate for a description of public universities in Germany in terms of their research and teaching profiles? Two main groups of indices can be found in the literature which appear to be useful for our purposes. The first group includes the *Revealed Comparative Advantage (RCA)*, which was proposed by Balassa (1965) for the measurement of sectoral country profiles (with the use of export data). The first group also includes the *Revealed Technological Advantage (RTA)*, which was introduced by Soete and Wyatt (1983) for measuring the technological specialisation of different countries (with the use of patent data) (see Debackere et al. 2002). It is also referred to in the literature with the neutral name of *Activity Index (AI)* (Narin, Carpenter and Woolf 1987, Piro et al. 2017), and in mathematical terms it is identical to the RCA. For the sake of simplicity, instead of RCA and RTA, in the following, we use the designation "AI".

$$RCA_{ij} = RTA_{ij} = AI_{ij} \coloneqq \frac{N_{ij}/\sum_i N_{ij}}{\sum_j N_{ij}/\sum_{ij} N_{ij}}$$

Formula 1: RCA, RTA, AI

Example of the AI for the variable "Professors":

$$\mathrm{AI_{ij}} \coloneqq \frac{\text{Professors of University i in Field j}/\text{All Professors in Field j}}{\text{Professors of University i }/\text{All Professors}}$$

Formula 2: AI in verbal form

The interpretation of the AI is somewhat complicated due to its value range of $[0, \infty]$, that means, it lacks an upper limit. Its expected value of 1 means that all AI values <1 indicate a negative specialisation (below-average values for the variable under consideration) and all AI values >1 indicate a positive specialisation (above-average values). Further details on the AI can be found in 1st Annex .

A better interpretation is possible if an index is symmetrical both above and below the expected value. The indices of a second group fulfil this condition. First, this is the *Revealed Symmetric Comparative Advantage (RSCA)*, which is used, for example, by Laursen (2000, 2015) and Malerba and Montobbio (2003) to analyse the country-specific technical specialisation. Second, there is the *Relative Specialisation Index (RSI*), which has been used to identify country-specific research profiles in Europe (z.B. EC 1997) and to map the professional profiles of Scandinavian universities (Piro et al. 2011, Piro et al. 2014, Piro et al. 2017). The RSCA/RSI is symmetrical in the sense of the relationship: $RSI(AI) = -RSI(AI^{-1})$ and mathematically defined as follows (here and in the following, the indices *i* and *j* are omitted for the sake of simplicity):

$$\mathrm{RSCA} = \mathrm{RSI} \coloneqq \frac{\mathrm{AI} - 1}{\mathrm{AI} + 1}$$

Formula 3: RSCA, RSI

The interpretation of the RSCA/RSI is simpler than that of the AI due to the symmetrical value range of $[-1, +1]$. Its expected value of 0 means that all RSCA/RSI values <0 indicate a negative specialisation (below-average values) and all RSCA/RSI values >0 indicate a positive specialisation (above-average values).

Another index variant based on the AI is the *Revealed Patent Advantage (RPA)* and derived *Revealed Patent Advantage Hyperbolic (RPAH)*, both of which were introduced by Grupp (1994, 1998). The RPAH uses the *hyperbolic tangent* attribute: $tanh = \frac{e^{2x} - 1}{e^{2x} + 1}$.

$$\mathrm{RPA} \coloneqq 100 \ln \mathrm{AI}$$
$$\mathrm{RPAH} \coloneqq 100 \tanh \frac{\mathrm{RPA}}{100} = 100\ \frac{\mathrm{AI}^2 - 1}{\mathrm{AI}^2 + 1}$$

Formula 4: RPA, RPAH

While the RPA is a logarithmic variant of the RCA/RTA and has a value range open on both sides $[-\infty, +\infty]$, the value range of the RPAH is limited to $[-100, +100]$. The expected values of RPA and RPAH both amount to zero. As the variables examined here do not constitute patent data, we use the designation “Relative Specialisation Index” (RESP) instead of “RPAH”. To avoid confusion with the RSI, in the following, we use the abbreviation throughout: RESP.

$$\mathrm{RESP} \coloneqq 100\ \frac{\mathrm{AI}^2 - 1}{\mathrm{AI}^2 + 1}$$

Formula 5: RESP

AI, RPA, RSI and RESP have the attributes that are listed in the following table:

	AI	RPA	RSI	RESP
Value range	$[0, +\infty)$	$(-\infty, +\infty)$	$[-1, +1]$	$[-100, +100]$
Value range, limited	No	No	Yes	Yes
Expected value	1	0	0	0
Symmetrical	No	Yes	Yes	Yes
Skewed	Skewed to left	None	None	None

Table 1: Comparison of AI, RPA, RSI and RPAH

It should be noted that each of these four indices can be converted into each other (see 2nd Annex). Therefore, the AI, RPA, RSI and RESP cannot provide qualitatively different statements. The difference is that certain indices are more suitable for mathematical methods (for example, AI and RPA for Least Square Methods), and others are more accessible to the observer (RSI and RESP). A comparison between RSI and RESP is provided in 2nd Annex .

The following example shows the RESP for the Bergische Universität Wuppertal (BUW) in the scientific field of mathematics in the year 1994. In this respect, the following data from the Federal Statistical Office is available (NTUs refer to Non-Technical Universities from the set considered):

Professors at the BUW in the field of mathematics	27
Professors at the BUW	300
Professors at NTUs in the field of mathematics	903
Professors at NTUs	13,483

Table 2: Calculation basis for RESP mathematics at the BUW in 1994

From these values, it is possible to make the following calculation: $AI = \frac{27 \cdot 13483}{300 \cdot 903} \approx 1{,}34$ and $RESP = 100 \cdot \frac{1{,}34^2 - 1}{1{,}34^2 + 1} \approx 29$. At this point there are three values which are able to describe the number of professors at the BUW in mathematics. First, the absolute number of 27 professors. This figure may seem impressive, but it does not indicate whether it is above or below average, or more in the middle, compared to other universities. Second, the percentage value may be considered: In 1994, $\frac{27}{903} = 3{,}0\%$ of all mathematics professors working at the universities in question were employed at the BUW. This number doesn't seem so impressive any more. It states that roughly every 33rd professor in mathematics at public universities is based at the BUW (related to 51 NTUs). In comparison with all the professors of state NTUs, it is noticeable that the BUW $\frac{300}{13483} = 2{,}2\%$ has an above-average share, i.e. mathematics has an above-average share in comparison with the total share of the BUW. Third, the RESP value of 29 for professors of mathematics at the BUW. As this RESP value is well above the expected value of 0, the BUW is therefore disproportionately endowed with professors in mathematics. Hence, in terms of its professors, the BUW has a field-specific research and teaching profile in mathematics.

It is important to note that the strength of the BUW in terms of staff does not play a role in the RESP value. According to the factor: $\frac{\text{Professors at all universities}}{\text{Professors at BUW}}$ the BUW has the same number of professors as any other university. In this respect, the RESP not only provides an abstract value that can be interpreted independently of other values, but also compensates for the existing differences in size between the universities under consideration.

To be able to better classify the RESP value for the BUW in mathematics, the University of Bonn (RFWUB) in mathematics should also be added for the purpose of comparison. If one wishes to compare the BUW and the RFWUB with regard to mathematics, this could be done again with absolute values. In 1994, the BUW had 27 mathematics professors and the RWFUB had 23 mathematics professors. By 1999, the BUW had lost 3 mathematics professors, while their number at RWFUB remained stable. As a preliminary conclusion from this consideration, it may be concluded that in mathematics the BUW is similar to the RFWUB.

	Year	BUW	RFWUB	NTUs
Professors in the field of mathematics	1994	27	23	903
Total number of professors (not incl. medicine)	1994	300	407	13,483
Number of NTUs	1994	1	1	51
Professors in the field of mathematics	1999	24	23	825
Total number of professors (not incl. medicine)	1999	283	402	13,174
Number of NTUs	1999	1	1	51

Table 3: Calculation basis for RESP mathematics at the BUW and at the RFWUB

Second, we consider percentage values. It should be borne in mind that in 1994, 51 universities were counted as NTUs, the same as in 1999. This means that, if the same number of professors was teaching at each university, each NTU would have to hold 2.0 % of the professors in mathematics. In 1994, 3.0 % of all professors in mathematics at NTUs were at the BUW (2.9 % in 1999), and 2.5% at RFWUB (2.8 % in 1999). In comparison with the absolute values, we obtain the information that both 3.0 % and 2.5 % are well above the German uniform distribution. Throughout Germany (without knowing the values of the other universities), both locations are disproportionately endowed with professors in mathematics. At the same time, it is evident that the BUW has followed the trend of the decreasing number of professors in mathematics throughout Germany, while the RFWUB was able to increase its share of the professor against the Germany-wide trend (by 0.3 %). Third, this brings us to the RESP, which looks like this for both cases:

	Year	BUW	RFWUB
RESP (professors in the field of Mathematics)	1994	29	-17
RESP (professors in the field of Mathematics)	1999	29	-9

Table 4: RESP values for mathematics at the BUW and the RFWUB

In 1994, the BUW had an RESP of 29 regarding professors in mathematics. At the same time, 3.0 % of all mathematics professors work at the BUW. This means that a disproportionately high number of professors at the BUW were in mathematics (in comparison with the average for Germany as a whole). The BUW had a focus in the field of mathematics.

The picture for the RFWUB is somewhat different. In 1994, it had an RESP of -17 regarding professors in mathematics. At the same time, however, 2.5 % of all mathematics professors were working at the RFWUB, i.e. only slightly less than at the BUW. It can be assumed that the RFWUB played a similarly important role in mathematics throughout Germany as the BUW. Going by the assumption that 23 professors are sufficient to represent the field of mathematics at a university in its disciplinary breadth, the RFWUB could certainly be regarded as being profiled in mathematics. Nevertheless, the RFWUB does not use as much of its resources for the field of mathematics to achieve the same number of professors as the BUW. Its RESP value therefore points to a slightly less than proportional endowment. Despite its absolute number of mathematics professors being comparable to that of the BUW, in a Germany-wide comparison of the NTUs, in quantitative terms, the field focus of the RFWUB is not so much on mathematics, but obviously on other fields which have a greater number of professors. This example further illustrates that in terms of the scientific staff, the relative field profiles should not be confused with quality assessments.

Through logarithmic transformations there is no direct translation of RESP values. It is only possible to interpret the statement of the positivity (algebraic sign) and the relative position (relation of order). The situation is different with the AI values, which express the relationship between the proportion of a field in a university and the average for Germany as a whole. In the case of the BUW, in 1994, mathematics had an AI value of 1.34. In specific terms, this means that the proportion of professors in mathematics in terms of all professors at the BUW is 34 % higher than the average for Germany as a whole.

The next step aims to briefly illustrate how the addition of a new university to an existing set of universities may change the RESP values of a particular university in the existing set. This illustrates as to why the choice of suitable sets (in this case, TUs and NTUs) is important. For this purpose, we carry out a model calculation with the RESP values of mathematics at the BUW, which change due to the addition of the fictitious University of Neustadt.

The AI value for mathematics at the BUW results as follows:

$$\frac{\text{Professors of Mathematics at BUW/All Professors in the field of Mathematics}}{\text{Professors at BUW /All Professors}}$$

Formula 6 (and following): Example AI mathematics at the BUW

Solving the compound fraction, one obtains:

$$\frac{\text{Professors of Mathematics at BUW} \cdot \text{All Professors}}{\text{All Professors in the field of Mathematics} \cdot \text{Professors at BUW}}$$

If the fictitious University of Neustadt with 450 professors, 32 of them in mathematics, is added to the set, this changes the RESP value of the BUW in the field of mathematics as follows:

$$\frac{\text{All Professors} + 450}{\text{All Professors in the field of Mathematics} + 32} \cdot \frac{\text{Professors of Mathematics at BUW}}{\text{Professors at BUW}}$$

The second factor, which depends solely on the indicators of the BUW, remains identical, while the first factor (coincidentally) also remains identical: what was previously $\frac{13483}{903}$ = 14.9 becomes $\frac{13933}{935} = 14.9$. The University of Neustadt affects the German average as a whole to the extent that the ratios of mathematics to other fields does not change from the average for Germany. As a result, the RESP value of the BUW in the field of mathematics remains constant.

Let us now assume, however, that the University of Neustadt doesn't offer the field of mathematics. Despite this, 450 professors would be working there. This would change the RESP value at the BUW for 1994 as follows:

$$\frac{\text{All Professors} + 450}{\text{All Professors in the field of Mathematics} + 0} \cdot \frac{\text{Professors of Mathematics at BUW}}{\text{Professors at BUW}}$$

The factor 14.9 (see above) would lead to the factor $\frac{14090}{889} = 15.4$, and the RESP value of 29 of the BUW would become 32. With the University of Neustadt in the set, a lower proportion of mathematics professors would become the "normal case" in terms of the average for Germany as a whole, and the RESP value of the BUW would therefore increase slightly.

It occurs more frequently in the data set, that individual universities do not offer all of the fields under discussion. In the case of mathematics at the BUW, the slight "distortion" caused by the addition of the University of Neustadt would therefore appear tolerable. This means that universities are compared which do not always have an identical field structure. The distortion becomes a problem, however, when the lack of fields is systematic or widespread in certain groups of universities. If it is necessary to assume that certain universities have a significantly different range of fields to others, this distortion occurs systematically. It would then be useful to compare these two groups of university separately. For this reason, highly specialised universities should not be compared with higher education institutions that have a broad range of fields. Specialised higher education institutions were therefore excluded from the present analysis (see section 3.1) because they offer very few fields, and can therefore only be compared with universities which offer a broad range of fields by accepting considerable distortions.

Therefore, the central prerequisite for a meaningful inter-university comparison is for the universities to have a sufficient degree of similarity within the set. In addition to distinguishing between highly specialised higher educational institutions and universities, the requirement of similarity that is necessary for a comparison can be operationalised in such a way that criteria are found which divide the universities into meaningful groups.

The selected universities could be grouped according to whether or not they have a high proportion of teacher degree students, for instance. In this way, within the set of universities, those that focus on "teacher training" (not to be confused with the teacher training colleges located in Baden-Württemberg, which were excluded from the analysis) could be distinguished from the other universities. In the attempt to apply this criterion, however, no empirically plausible threshold value could be determined that would have allowed for such a group classification.

The widely accepted distinction between Technical Universities (TUs) and Non-Technical Universities (NTUs) exists, however. From an institutional perspective, "technical" can be defined as all of those universities that have either a corresponding name suffix or are members of the "TU9" alliance (TU9 2019). We were able to successfully validate this institutional perspective on an empirical basis. In specific terms, this means that the TUs and NTUs are more similar within each group than they are when all these universities are considered together. The decisive factor here is that the technical fields at the TUs are strongly staffed and funded, while the humanities and social sciences are represented rather poorly. It is precisely this attribute that distinguishes them from NTUs, where this different distribution of resources is less pronounced.

An example would be psychology at the BUW, as this field is not generally taught as an area of special focus at TUs:

Professors at the BUW in the field of Psychology	8
Professors at the BUW	300
Professors at NTUs in the field of Psychology	398
Professors at NTUs	13,483
Professors at TUs in the field of Psychology	59
Professors at TUs	4,125

Table 5: Values to calculate the RESP for psychology at the BUW for the year of 1994

If NTUs are considered as a comparison set, the result for the BUW in psychology in 1994 is a $AI = \frac{8 \cdot 13483}{300 \cdot 398} = 0{,}903$ and $RESP \approx -10$. As far as this field is concerned, the BUW therefore has a slightly lower profile in psychology than all the other NTUs (the BUW is also an NTU).

If psychology at the BUW is considered with the groups of NTUs and TUs in the comparison set, however, one obtains the values $AI = \frac{8 \cdot 17608}{300 \cdot 457} = 1{,}03$ and $RESP \approx 3$. As far as the field of psychology is concerned, in comparison with all the universities considered, the BUW is therefore (almost) exactly equal to the average for Germany as a whole. It is noticeable that the sign of the RESP has changed. It is therefore clear that the RESP depends strongly on its comparison set. For the present calculation of RESPs (and RSIs), a distinction was made between TUs and NTUs in order to meet the methodological requirement of a largely homogeneous comparison set.

When interpreting the RESP values, an important methodological issue is the comparability of the different AI/RESP values across the three dimensions (university, field, year) and therefore the comparability of the universities with each other (we continue to use the professor variable). The RESP value of a university and a certain field is usually comparable with all the other RESP values of the same year and the same group, as the information about the Germany-wide number of professors (TUs, NTUs) is included in the RESP value. A higher RESP value points to a higher concentration of resources than a lower RESP value. This comparability is also maintained for the annual calculation of AI/RESP values.

AI/RESP values for different years, by contrast, are not directly comparable. The lack of direct comparability of annual RESP values is due to the fact that it only contains information for one year, but no information for any other years. If an RESP value for a field at a university is higher than the previous year's value, this does not necessarily indicate that an accumulation of resources has taken place. In fact, it could also be the case that the other universities have fewer professorial positions in the following year than they did in the previous year. This means that an indirect comparison of AI/RESP values from different years is possible. An increase in the RESP value in comparison with two points in time can therefore have five reasons: first, the university under consideration could have more professors in the respective field (field-specific resource growth at focal university); second, all the other universities could have cut professorial positions (field-specific reduction of resources in the comparison set), third, the university under consideration could have cut professorial posts in other fields (outside-field reduction of resources at focal university); fourth, all other universities could have more professors in the other fields (outside-field resource growth in the comparison set); fifth, it could be a combination of the first four points.

In order to ascertain whether a resource growth in a particular field has taken place at a focal university or a reduction of resources in the comparison set, all RESP/RSI figures were supplemented with a further figure showing the logarithmic percentage change of the variables under consideration from the base year (typically 1994). Therefore, the reader can identify directly as to whether an increase or reduction of resources has taken place in the field in question (see section 4.3). The percentage change was scaled along the same lines as the RESP definition, so that both use the same scaling [-100,+100].

3.3 Bibliometric indicators

We use a uniform method for normalisation across all eight variables. All the indicators considered are field normalised on the basis of the population of TUs or NTUs in Germany. The two relevant organisational fields are the TUs and NTUs. If the bibliometric indicators were to be interpreted as performance indicators (which we do not), this would constitute a national performance evaluation across fields within Germany. By contrast, in an international comparison, a field normalisation (i.e. a normalisation method in which the average publication or citation frequency within the respective academic field in the WoS database as a whole would serve as a reference

(Moed 2005)) could only be applied to publication and citation data, and not to the other indicators, such as staffing and finances, which are considered here. For example, Piro et al. (2017) use the *Mean Normalized Citation Score (MNCS)*, i.e. a field normalisation in an international comparison. The authors only present bibliometric profiles, however, and do not offer personnel, funding and student profiles, as is the case in this publication. In terms of the two input indicators (staff and finances), the data cannot even be approximately compared on an international level due to the national governance of the universities. To ensure comparability across all eight variables, we use a uniform field normalisation on the basis of the population of TUs and NTUs within Germany.

4. *Explanations regarding figures*

The website mentioned above provides figures at the level of individual universities (N = 68, 17 TUs, 51 NTUs). The research profiles of each university are presented both in terms of RESP values (logarithmic transformation, value range -100; 100) and RSI values (value range -1; 1) for the six indicators (professors, non-professorial academic staff, basic appropriation, third-party / grant funding, publications, citations). The teaching profiles include bachelor and master students, as well as total number of students, but no bibliometric indicators.

The calculation of the RESP/RSI generally takes place for all of the 56 fields defined by the StBA in combination with the classification of Archambault. Of these, however, only those 46 fields for which a concordance with the Archambault classification could be established are included in the research profiles, and of these, in turn, only those 12 fields are shown in graphic form which have at least 50% coverage in WoS publications (2006-2015) (see section 2.2): Biology; Chemistry; Physics, Astronomy; Nutrition and Household Economics, Psychology; Agricultural Sciences, Food and Beverages Technology; Mechanical Engineering/Process Engineering; Geosciences (excluding Geography); Electrical Engineering; Forestry, Timber Management; Economics and Mathematics. The remaining fields, whose rates of coverage are below 50 %, are included in the RESP/RSI values, but are not reported graphically. Excluding the remaining fields from the calculation would lead to a strong distortion (see section 3.2). With regard to the teaching profiles, all 56 StBA scientific fields are considered, because there is no need for a concordance with the number of students and the WoS-coverage rate.

All of the plotted data is also available in Excel files which supplement the figure files (PDF) on the website. This means it is possible to trace the coverage of specific fields in the WoS for each university in detail. In addition, fields for which only a few data points were available were not taken into consideration when creating the figures. That is why the following criteria were established:

- For figures at university level (by field; see below), each field at each university is represented by six indicators. As the figures show five points in time, this results in 30 RESP values and 30 percentage changes. If fewer than 15 RESP values or fewer than 15 percentage changes could be represented, the corresponding field was removed from the overall presentation (but still included in the calculation of RESP values of other fields/universities).

- For the profile mapping (figures at university level, by variable, and figures at field level), the *additional* rule applies that there must be at least five units (fields/universities) in at least one indicator, each representing at least 15 RESP values. Otherwise, no profile map was created for the corresponding university or field.

4.1 Figures at the university level

For both indicators (RESP/RSI) a PDF document is available for each university which contains two figures for each of the fields represented at that university in terms of the set referred to above. The upper figure shows the RESP and RSI values for the respective variables in the years 1994, 1999, 2004, 2009 and 2014. It should be noted that the variables were smoothened using three-year moving averages before the calculation. This means, for example, that the RESP/RSI values for 1994 are based on the average of the years 1993-1995. The year 1992 was not considered in the choice of dates observed due to the German reunification and the associated changes in the German higher education landscape. The three-year moving averages were therefore calculated for the first time for 1994 and then at five-year intervals. The lower figure shows the percentage changes of the respective variable in comparison with the base year (as a rule 1994) in logarithmic scale (range of values: -100 to +100). These figures also show whether and to what extent there have been changes (e.g. an increase or reduction in staff capacity) for the six variables. In section 4.3, an interpretation guide is provided on how these two figures can be interpreted together. The research profile for the field of mathematics at the BUW shall serve as an example. All indicators show a pronounced specialisation of the BUW in the field of mathematics (upper figure in Figure 2). At the same time, a decline in the number of professors and a strong percentage increase in third-party / grant funding and citations is evident (lower figure in Figure 2).

At the university level, there is an additional PDF document for each of the two indices, RESP and RSI, which contains a profile map (*heat map*) for each of the six indicators that are relevant to the research profiles. Accordingly, the teaching profiles include a PDF document which contains a profile map (*heat map*) for the relevant indicators. In contrast to the first PDF document, in which all the relevant variables of a field are displayed on one page, the second PDF document represents a variable at a university across all fields and all years. In the upper part of this figure (orange-coloured), the fields are shown which – averaged over all the variables shown – have a disproportionately high level of development, in the middle part (yellow-coloured) those fields which correspond to the average for the university groups (TU, NTU), and in the lower part (blue-coloured) those which have a disproportionately low level of development. The example of the indicator of third-party / grant funding at the University of Duisburg-Essen shows that in relative terms, this university has the strongest profile in Electrical Engineering and Mechanical Engineering/Process Engineering, and the lowest profile in Psychology and Geosciences (Figure 3). Fields are sorted in descending order of their average RESP or RSI values over all the relevant variables in all years; the same applies to universities at the field level (see 4.2).

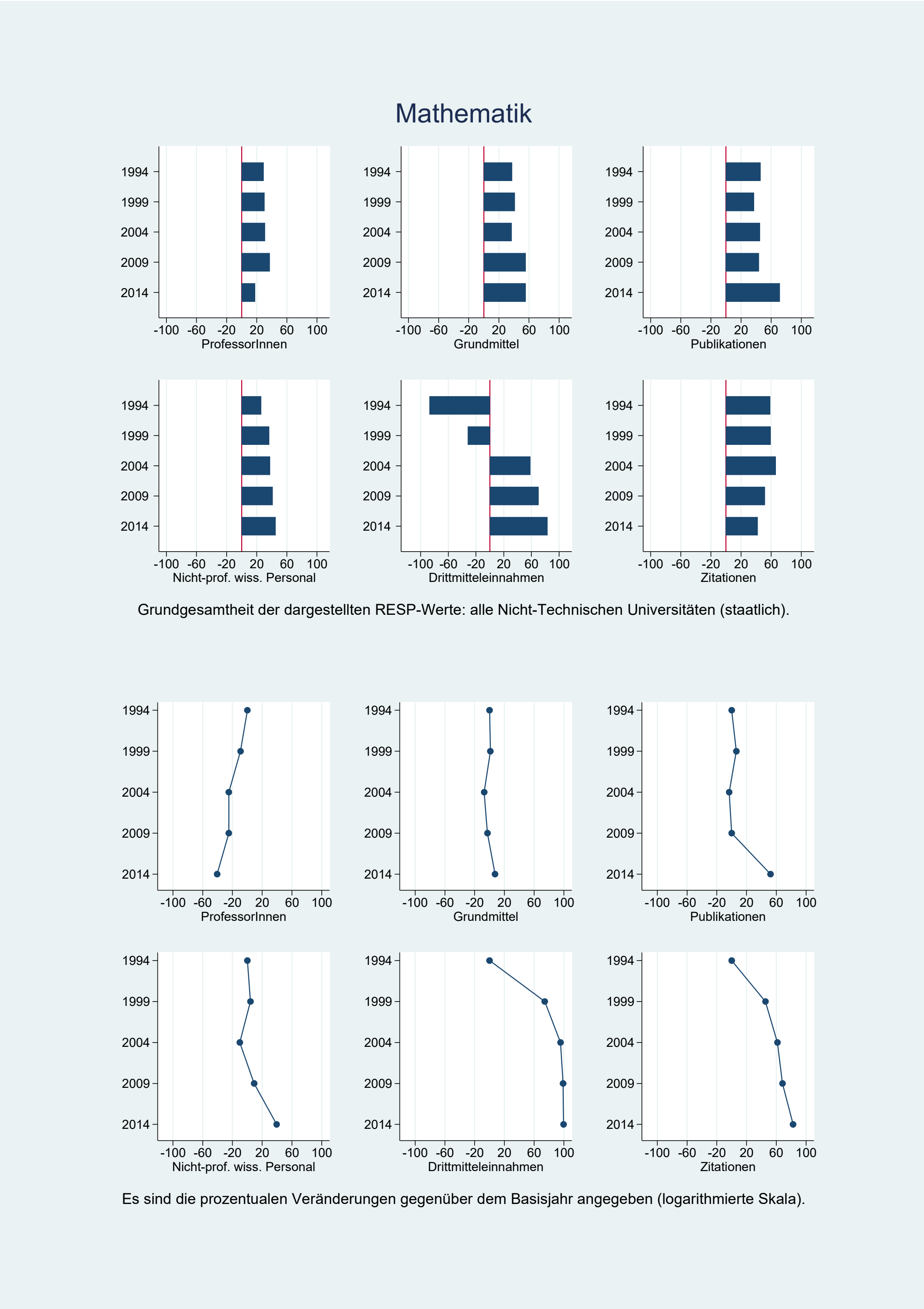


Figure 2: First and second respective figure of a field at a university (here: Wuppertal), research profiles

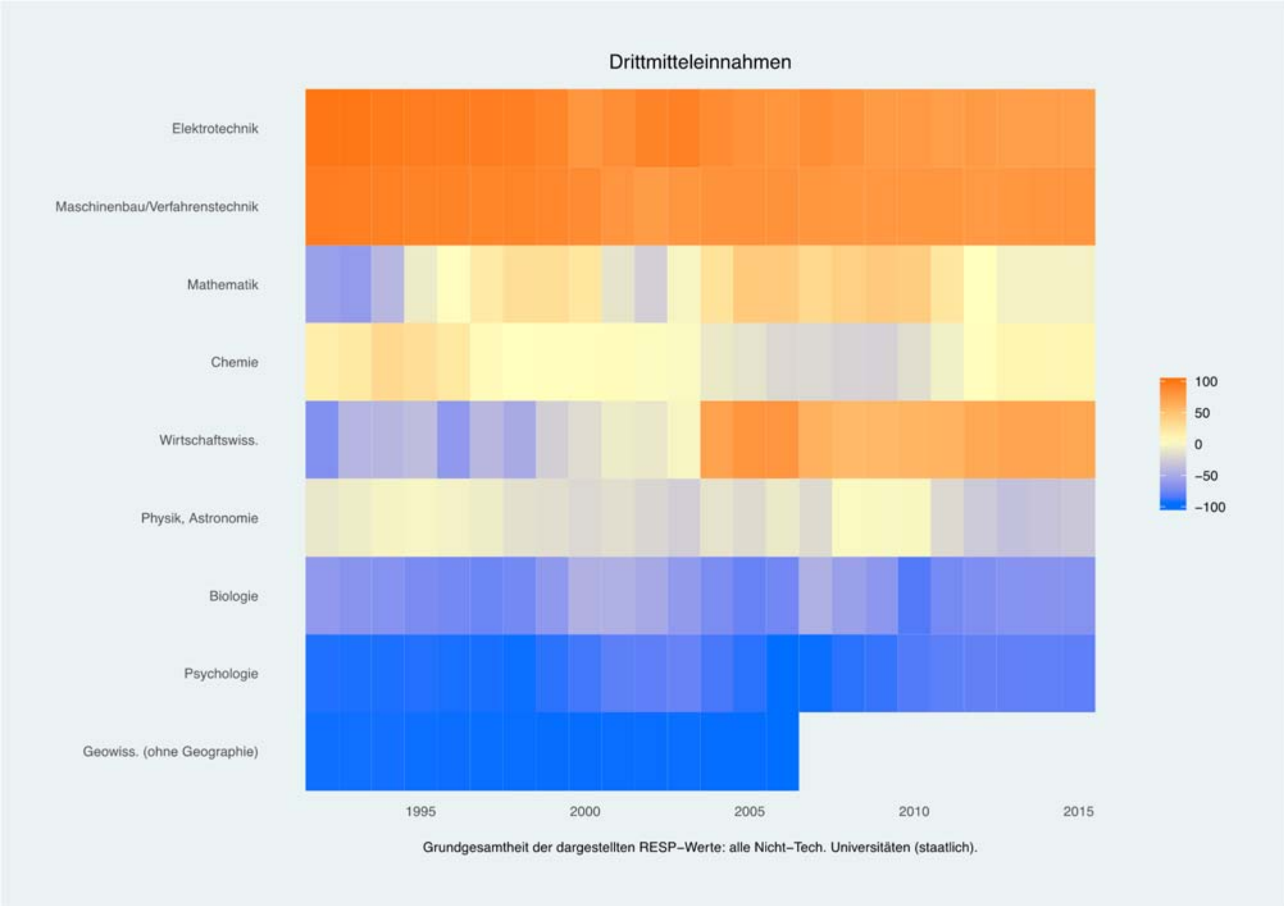


Figure 3: Variable-related representation of all fields at the University of Duisburg-Essen (RESP), research profiles

4.2 Figures at the field level

A further figure was created for the overall presentation of all universities, one group at a time (TUs, NTUs) in one field and one indicator each year. This enables a field-related overview for Germany as a whole. The example of the "publications" indicator in mathematics in the NTU group shows that the University of Passau has the strongest specialisation in mathematics publications, while the Universities of Luneburg and Hohenheim are the least specialised of all the NTUs in this field (Figure 4). When viewed across all of the relevant indicators (here: research profiles), the specialisation of the University of Augsburg in mathematics is the most pronounced, with Passau University in fourth place overall (Figure 4).

At this point, we shall explain the fundamental difference between profiling a university and profiling in a research field once again. In 2014, the University of Passau has a RESP value in mathematics for publications of 86, which means that its share of publications in mathematics measured against the total share of its publications is considerably higher than the share of all NTU publications in mathematics measured against all NTU publications (RESP = 0). However, it already reaches this value with 4 publications. In the same year, Hohenheim recorded 6 publications in mathematics, but had an RESP value of -92. The two universities therefore differ in terms of one crucial point, which is expressed in the RESP value: Passau has just 4 publications in mathematics, but only 46 publications in total. Hohenheim, on the other hand, has 6 publications in mathematics, but a total of 488 publications. Accordingly, the RESP determines that mathematics is of greater importance at the University of Passau (with 9 % of its publications) than it is at the University of Hohenheim (with 1 % of its publications).

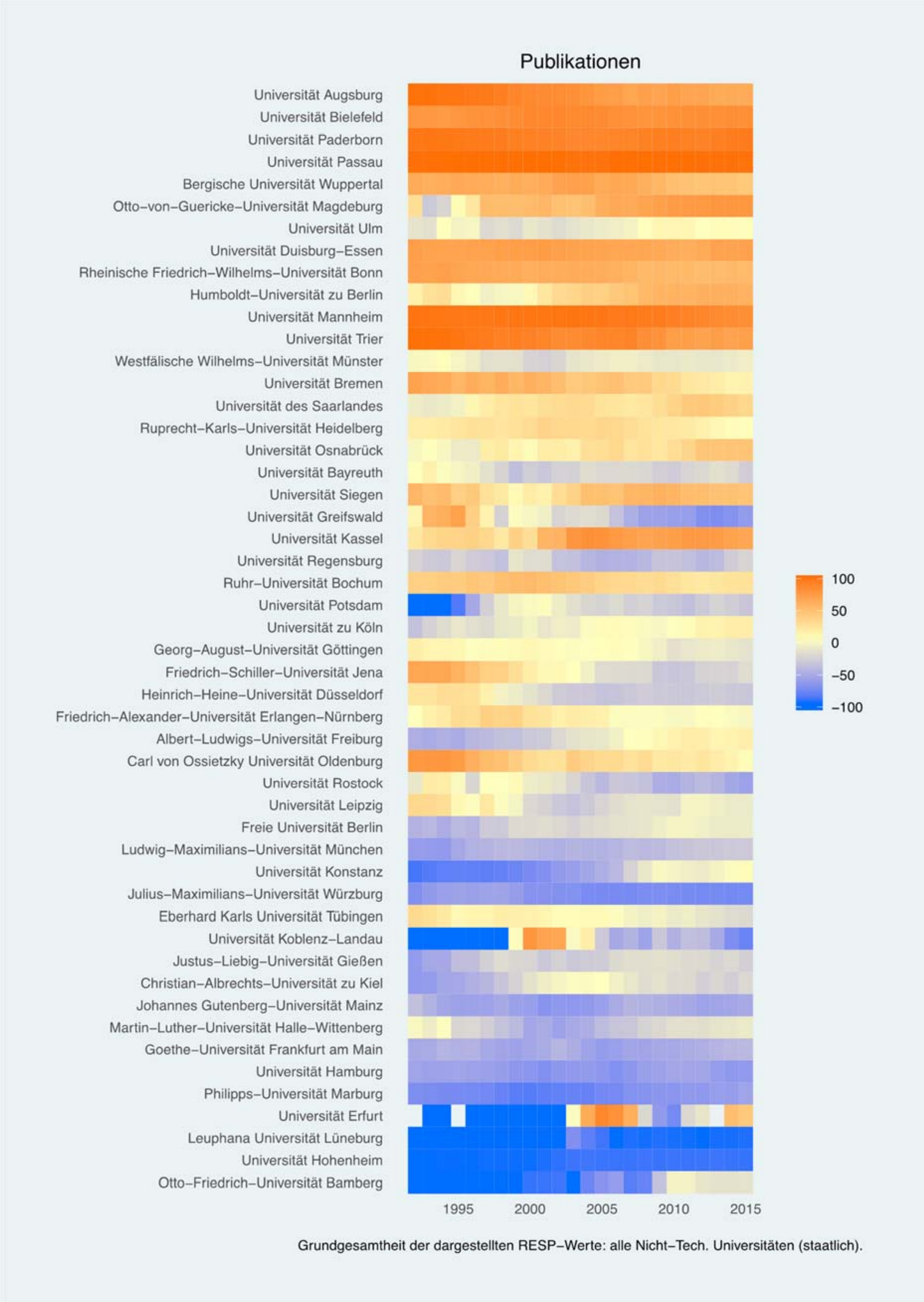


Figure 4: Variable-based presentation of the field of mathematics at all NTUs (RESP), research profiles

4.3 How to interpret figures

A change in the RESP values at a university may be based on complex processes. The RESP/RSI values can be better interpreted, if information is also available on the changes (growth, degrowth) of the six variables. In the following, four example-based combinations (in this case: the number of professors) are discussed.

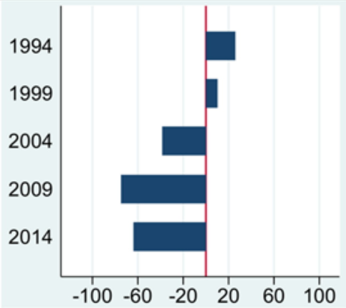
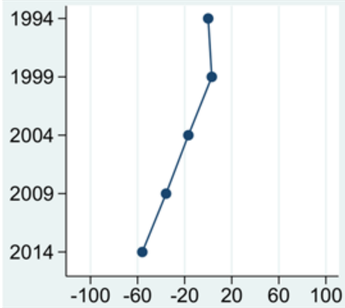
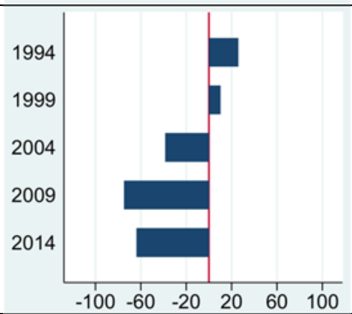
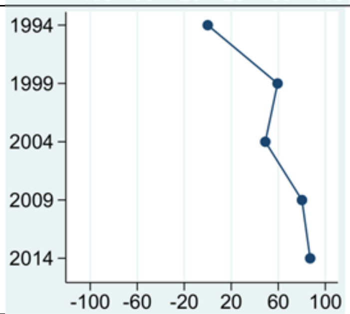
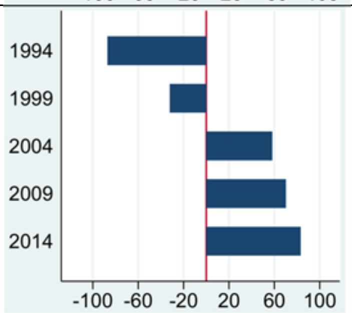
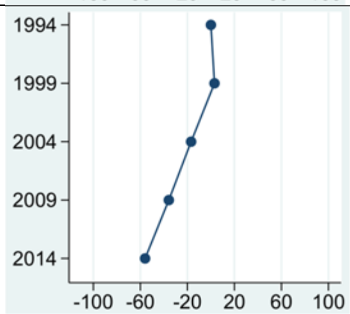
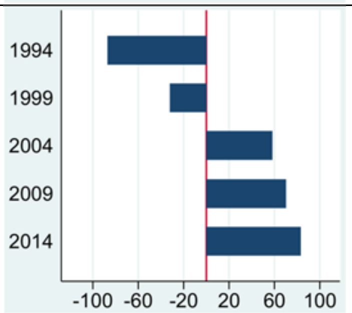
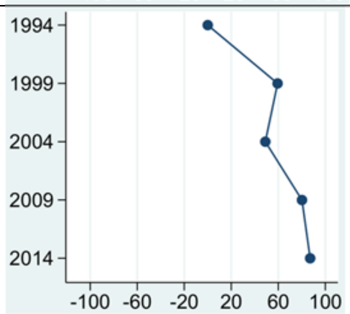
<table>
<tr><th>RESP values</th><th>Percentage change (logarithmic scale)</th><th>Factual description</th><th>Possible interpretation</th></tr>
<tr><td>
</td><td>
</td><td>RESP falls, jobs are cut</td><td>University reduces its number of positions in the field (if it reduced positions across the board, the RESP would remain stable). The field may have grown.</td></tr>
<tr><td>
</td><td>
</td><td>RESP falls, new jobs are created</td><td>RESP is falling although the university creates new jobs in field. In terms of the average for Germany as a whole, field growth is higher, so that university has a falling share of resources by comparison.</td></tr>
<tr><td>
</td><td>
</td><td>RESP increases, jobs are cut</td><td>Although jobs are being cut, the RESP is increasing. Accordingly, the job cuts in other fields at university will be stronger or the field is being scaled back even more at other universities.</td></tr>
<tr><td>
</td><td>
</td><td>RESP increases, new jobs are created</td><td>In creating new jobs, the university counters the trend in Germany. If all other universities were expanding the field as well, the RESP would remain stable.</td></tr>
</table>

Table 6: Interpretation aid for RESP values in connection with the rate of change (log. scale)

5. *Selected results*

We will now discuss briefly selected results from an initial overview of the university data sets documented on the website mentioned above. In this respect, the focus here is on two questions: first, to which extent do the 68 universities examined display research and teaching specialisations; and second, have their profiles changed in recent years (1992-2015)?

First, it should be noted that the correlations between the RESP/RSI values of the six variables that are relevant to the research profiles allow a statement about the extent to which the profile maps for academic staff, financial resources and bibliometric parameters correlate in the fields at certain universities. High positive values (>0.6) are an indication of correlation. In this case, the RESP/RSI values of the academic staff are similar to those of the financial variables and these, in turn, are similar to those of the bibliometric indicators. Low values (<0.3), by contrast, are an indication that the RESP/RSI values of the six variables are, at least partially, very different and, if the correlations turn out to be negative, may even be going in the opposite direction.

An example of a fairly uniform overall picture (high positive correlations) is Erlangen-Nuremberg, whose correlation matrix of RESP values are as follows:

	Profs.	Non-prof. acad. staff	Basic approp.	TP / grant funds	Pub.	Cit.
Professors						
Non-prof. acad. staff	0.6764 ***					
Basic appropriations	0.7595 ***	0.8066 ***				
Third-party / grant funds	0.5017 ***	0.8795 ***	0.6129 ***			
Publications	0.7012 ***	0.6646 ***	0.5897 ***	0.544 ***		
Citations	0.8231 ***	0.6782 ***	0.6698 ***	0.5513 ***	0.9263 ***	

(p–value: * < 0.05; ** < 0.01; *** < 0.001)

Table 7: RESP correlation matrix for Erlangen-Nuremberg (research profiles)

If, in addition to this correlation matrix, the set of slides for the RESP/RSI figures from Erlangen-Nuremberg is considered, it becomes clear that it is disproportionately equipped and/or academically active and visible in the two fields of “Mechanical Engineering, Process Engineering” and “Electrical Engineering”. On the other hand, it is disproportionately under- equipped and/or less academically active and visible in the fields “Psychology”, “Biology” and “Geosciences (without geography)”. For the remaining five fields, the RESP/RSI values are more or less about the average, which means that these five fields correspond roughly to their research capacity at all the other NTUs.

A similar picture of marked correlation across the indicators examined emerges for a further 30 – i.e. just under half – of all the universities examined here (in alphabetical order): Augsburg, Bayreuth, Bamberg, Bochum, Bremen, Clausthal, Dresden, Duisburg-Essen, Düsseldorf, Freiberg, Freiburg, Giessen, Hamburg, Heidelberg, Hohenheim, Kassel, Luneburg, Magdeburg, Mainz, Mannheim, Marburg, Munich (TU), Paderborn, Passau, Rostock, Saarbrucken, Siegen, Trier, Ulm and Wuppertal. All these universities have recognisable field research and teaching profiles. At the same time, however, their degree of representation in other fields is comparatively weak and/or average.

Oldenburg is an example of a rather uneven overall picture of the six variables relevant to the research profiles (low to negative correlations):

	Profs.	Non-prof. acad. staff	Basic approp.	TP / grant funds	Pub.	Cit.
Professors						
Non-prof. acad. staff	0.4702 ***					
Basic appropriations	0.2639 ***	0.4237 ***				
Third-party / grant funds	-0.09568	0.5707 ***	0.2939 ***			
Publications	-0.3721 ***	-0.3871 ***	-0.03132	-0.09286		
Citations	-0.3268 ***	-0.1513	0.02737	0.1963 ***	0.6517 ***	

(p–value: * < 0.05; ** < 0.01; *** < 0.001)

Table 8: RESP correlation matrix for Oldenburg (research profiles)

If the set of slides for the RESP/RSI figures is considered in addition to the correlation matrix, it can be seen that Oldenburg has very heterogeneous RESP/RSI values across the six variables and over the years. It is therefore much more difficult to clearly identify disproportionately well-equipped or academically active and visible fields than it is for the aforementioned universities, and in return: clearly disproportionately under-endowed or less academically visible fields. For Oldenburg, therefore, no concise, uniformly pronounced research profile can be discerned for the six variables. A similarly uneven picture of the RESP correlation matrix as the one for Oldenburg can be found for three other universities (in alphabetical order): Aachen, Berlin (HU) and Leipzig.

All the other universities have either matrices with fairly heterogeneous or mainly medium-high correlations (>0.3; <0.6) Although most of them also have field-specific research profiles, they are not as uniformly pronounced as in the first group of universities.

To give a first summary: it can be stated that, with a few exceptions, field research profiles are clearly identifiable for all the universities examined, wherein these profiles show a high degree of agreement across all six variables considered for about half of all universities, so in these cases, a high external validity of the measurement can be assumed. At this point, it is important to note that the correlation matrices can only be a first step in the analysis. There are conditional relationships between the six indicators which are not documented by a simple annual comparison. For example, it can take up to a year before non-professorial academic staff can be recruited with the use of third-party / grant funding. Similarly, the research activities carried out in projects with third-party / grant funding are only published following a (sometimes considerable) delay, and it usually takes several months to years before they are taken up and cited. Such conditions need to be examined more closely in more extensive multivariate procedures.

Some initially interesting findings can also be identified with regard to the second question of whether the research profiles have changed in recent years (1992-2015). Changes in the research and teaching profiles can refer to two opposing developments: either the growth or the dismantling of field-related areas of special focus. The structure of a field can be illustrated particularly well with the variable of third-party / grant funding in the field of electrical engineering at Freiburg (Figure 5). The growth path began in the mid-1990s and culminated in high RESP values in the mid-2000s, which is also clearly reflected in the other variables relating to the field (see website). A similar structure of field profiles can be seen, for example, in Psychology at Greifswald and Chemnitz, in Mathematics at the FU Berlin, or in Biology at Dresden.

The case of Electrical Engineering in Freiburg is interesting, because this field was not part of the curriculum in Freiburg before 1995 and Freiburg therefore enlarges the set of universities active in Electrical Engineering at the time. This case is comparable to the case of the fictitious "University of Neustadt" 3.2 above. The effect of adding electrical engineering to the research profile now has a dampening effect on the RESP values of other fields, whose values do not clearly stand out from the German trend as a whole. This applies, for example, to Psychology and Chemistry, both of which had lower RESP values in the mid-2010s (Figure 5). The decrease in relative specialisation in these two fields does not relate to a reduction in resources, but a shift in emphasis. The new field shifts the weightings between the fields, so fields that were formerly stronger now appear weaker due to the introduction of the new field.

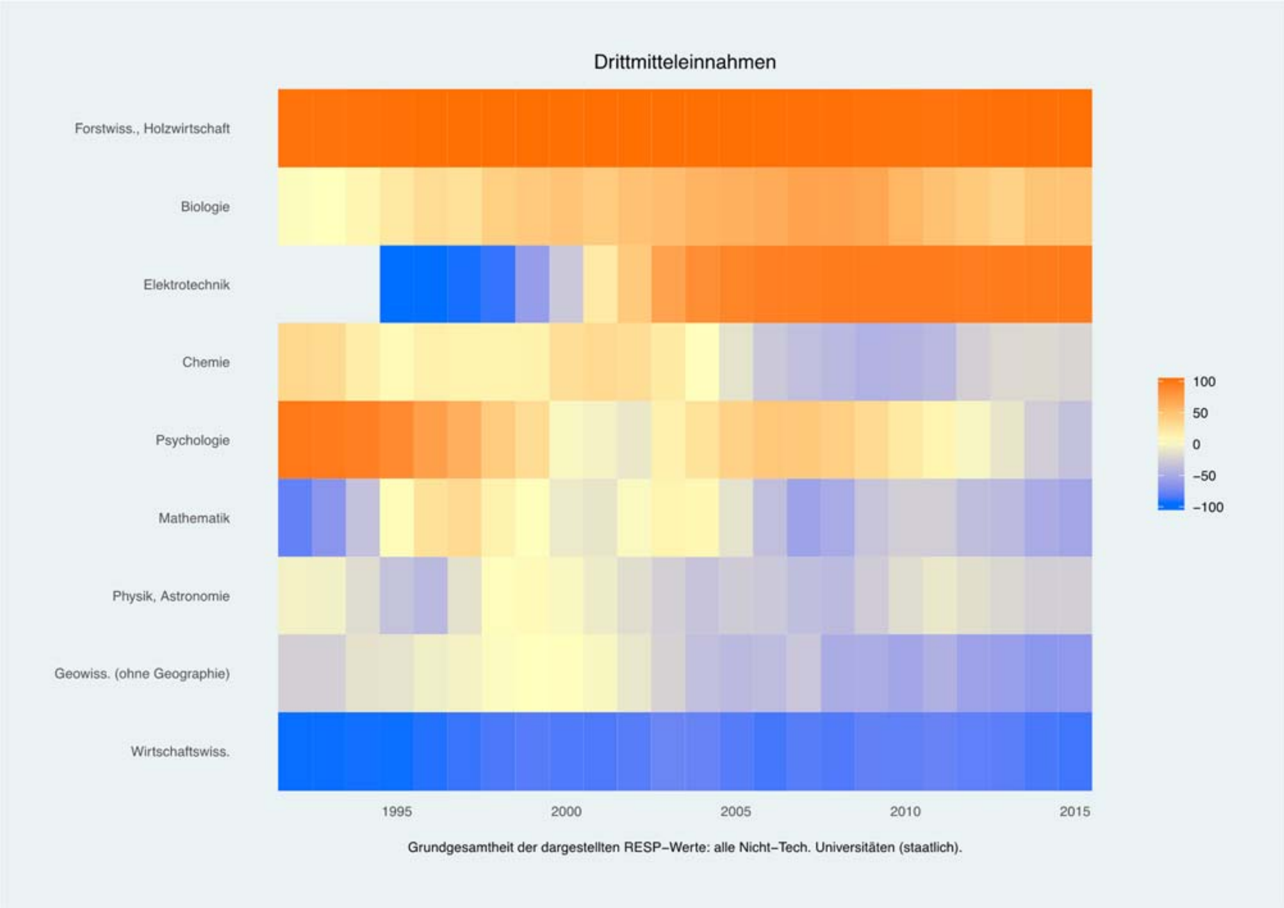


Figure 5: RESP values for third-party / grant funding, University of Freiburg (research profiles)

In Würzburg and Marburg, on the other hand, an actual reduction in the number of scientific fields can be seen in Geosciences (excluding geography) and in Mathematics in Heidelberg (see website). Also interesting are the cases in which there is a shift of focus from teaching to research (and vice versa) within fields. An illustrative case, i.e. a shift of emphasis from research to teaching, can be seen in the field of Economics at TU Munich (Figure 6). Here, the RESP values for students studying for a degree and students overall are increasing significantly, while at the same time the RESP values for third-party / grant funding are falling sharply.

Figure 6: RESP values for the field of economics at the TU Munich (teaching profiles)

There are also many universities in which the RESP values do not change or only change slightly over time. These universities have a stable research profile. This phenomenon is evident at Ilmenau (Figure 7), but also at the universities of Mainz, Erlangen Nuremberg, Düsseldorf, Freiberg, Bamberg or Aachen, for example. In this context, it is important to note that stable research profiles should not be confused with “immobility”. For a university to have stable RESP values over time, it is necessary for its absolute variable values to follow the trend in Germany as a whole.

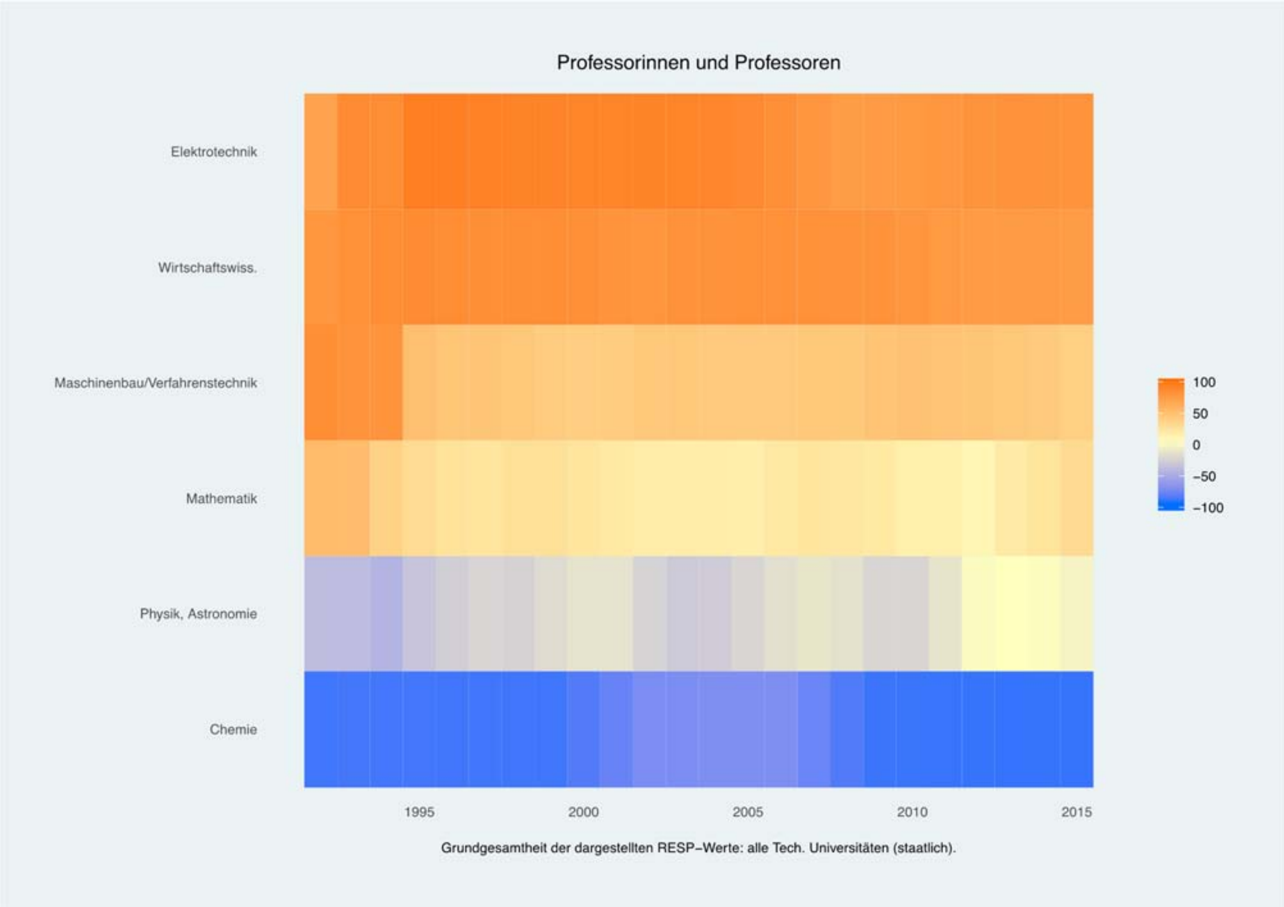


Figure 7: RESP values for professors at the TU Ilmenau (research profiles)

Section 3.2 discussed the way in which RESP values of scientific fields can change by adding new cases to the comparison set of universities. In particular, it was demonstrated that RESP values can increase if universities are included in the set which do not contribute to the variable under consideration, but nonetheless contribute to the overall range of fields. Accordingly, RESP values in Electrical Engineering are extremely high with the NTUs (Figure 8). As a result, their RESP values are almost always greater than 50. Offering the field of Electrical Engineering constitutes a profile at German NTUs. The same phenomenon can be found in other technical fields at NTUs.

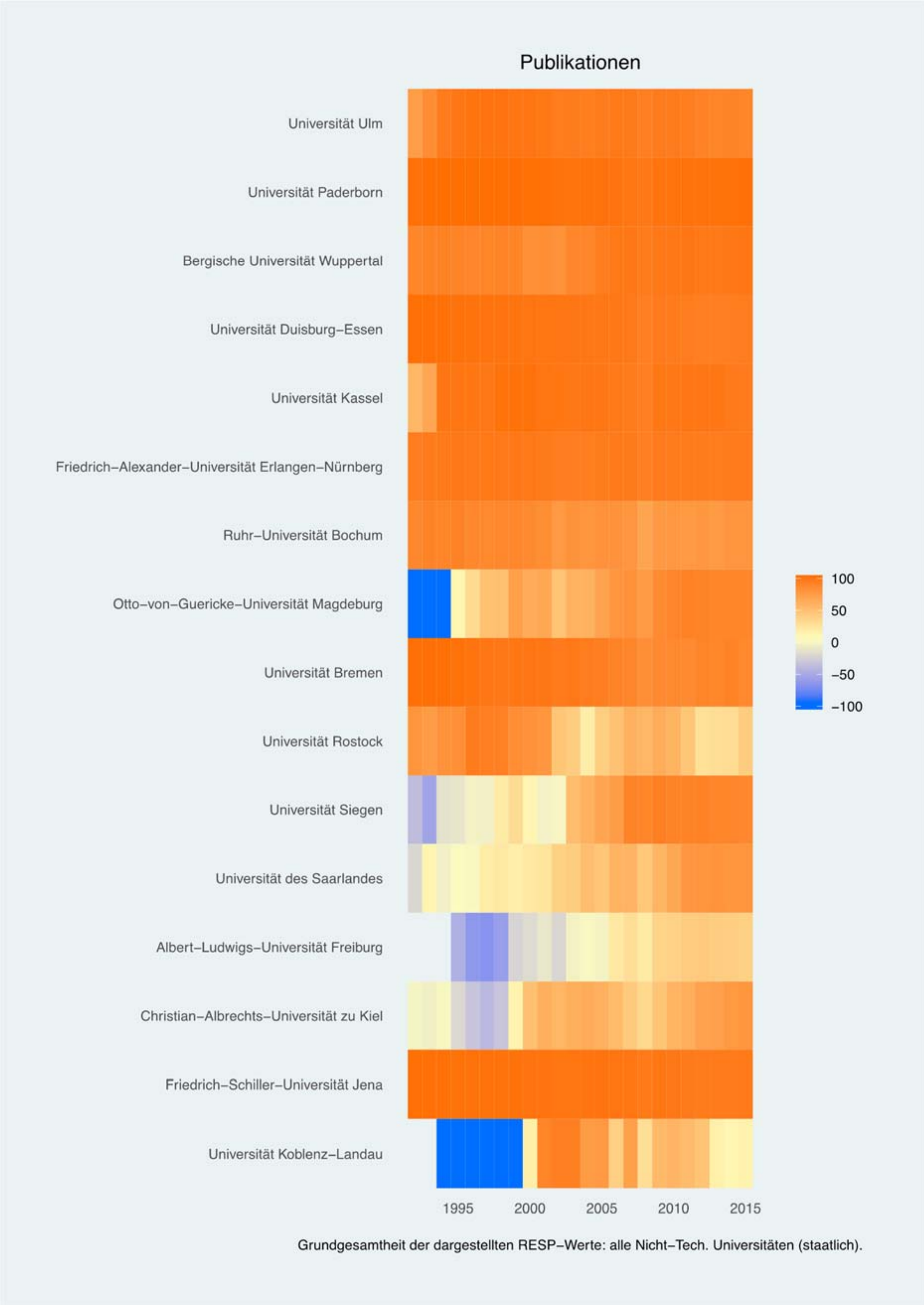


Figure 8: RESP values for publications on the field of electrical engineering at all NTUs (research profiles)

6. Outlook

The RESP/RSI values allow for the creation of field-related research and teaching profiles for public universities. Nevertheless, certain points have remained open. The most obvious point is the contextual embedding of RESP and RSI. One of their disadvantages has already been discussed: although they reflect the importance of a field at a university, they do not reflect the absolute importance of the university in the respective field within groups of universities (TUs, NTUs). Therefore, in absolute terms, two universities can have the same publication value, but different RESP values at the same time. For the complete interpretation of the development of technical profiles, further context information and comparison groups are therefore necessary, which can be collected and analysed in the course of case studies, for example (see Jappe and Heinze 2016).

The second point addresses the horizontal (RESP/RSI values for certain fields that are consistently high over time), temporal (RESP/RSI values field to considerable change over time) and diffuse (RESP/RSI values which remain indistinguishable in all years) profiling. These three profiles have been discussed so far. It was not discussed, however, as to whether and how this information can be used to classify the university landscape; whether profiling only is of descriptive or also of evaluative character; and whether the development of a profile typology is possible and can be transferred to other areas (e.g. universities of applied sciences). In this respect, the description of the research and teaching profiles using RESP/RSI values is a first step towards the horizontal description of the German university landscape. At the same time, there is also much room for further development. After all, the objective is to use indicators or composite indices to identify and map areas of special focus and development potential across universities.

The third point relates to the more in-depth national group comparison. In further studies, for example, the universities funded by the Excellence Initiative could be compared with the non-funded universities in terms of their field profiles and their development over time. It would also be useful to compare the “old” universities founded before the last major restructuring of the educational landscape during the 1960s and 1970s with the “new” ones, again in terms of their field-related research and teaching profiles. A question that is relevant in that context is how many professors are necessary to cover the full range of fields, and to what extent universities can (and want to) maintain this differentiation.

The fourth point relates to the international group comparison. In this respect, Jappe and Heinze (2016) compared public universities in Bavaria with those in California (University of California system) with regard to the diffusion of research breakthroughs in physics and chemistry. This comparison demonstrated that the public UC universities provide an institutional context in which research breakthroughs disseminate faster and in which the growth of new research fields is encouraged. In the future, a comparison of this kind could be more closely linked to the field profiles in the respective universities. A further, intra-European comparison could be directed towards the public universities of North Rhine-Westphalia (NRW) and the neighbouring Dutch universities. Not only are NRW and the Netherlands quite similar in terms of their population and size of territory, they also have a similar number of public universities whose field profiles could be compared on a systematic basis.

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1st Annex - Explanatory notes on the Activity Index (AI)

In mathematical terms, the AI is defined as follows: Let I and J be two finite index sets and $b: I \times J \rightarrow \mathbb{R}$ a figure with the three properties: (1.) $b(i,j) \geq 0 \; \forall \; (i,j) \in I \times J$, (2.) $\forall \; i \in I \; \exists \; j \in J: b(i,j) > 0$ and (3.) $\forall \; j \in J \; \exists \; i \in I: b(i,j) > 0$. AI is the defined as:

$$AI_b(p,q) := \frac{b(p,q) \cdot \sum_{i \in I} \sum_{j \in J} b(i,j)}{\sum_{i \in I} b(i,q) \cdot \sum_{j \in J} b(p,j)} \, , (p,q) \in I \times J$$

Formula 7: Alternative definition of the AI

The index sets by which each consideration can be uniquely identified are given by the institution (higher education institution ID) and the field of teaching and research (field ID). However, several observations are assigned to each higher education-field combination, one for each year in the period under consideration. This means that the AI values and therefore the RESP values have to be calculated on an annual basis. Moreover, four conditions must also be taken into account for the calculation of the AI:

(1.) the variable must be proportionally scaled,

(2.) all observations of the variable must be non-negative,

(3) the variable must be aggregation capable, and

(4.) all observations aggregated over both the first index and the second must be positive.

All four conditions are fulfilled for these eight variables. Of these variables, six are counting variables (professors, non-professorial academic staff, publications and citations, students), while two are financial variables (basic appropriation, third-party / grant funding). All eight variables are therefore proportionally scaled (ad 1.).

Counting variables are always non-negative, but the two financial variables are not negative either, because they do not constitute balance sheets in which negative values could occur. Negative basic appropriation and third-party / grant funding – if any – were removed from the data set (ad 2.).

In addition, all variables can be aggregated: the financial volume of a university and the financial volume of a second university together add up to the sum of the two financial volumes. This sounds trivial, but examples of proportionally scaled variables exist that can be aggregated mathematically but not in terms of their meaning, e.g. ratio variables such as third-party / grant funding per professor (ad 3.).

The fourth condition means that no AI values can be calculated for a university or for a field for which no values exist in a variable. This means, nevertheless, that a university still may have no values for a field. If a university has no values in all fields, however, no AI can be calculated for the respective university in any field (ad 4.).

2nd Annex - Conversion into RESP values / comparison of RESP and RSI

So far, four indices have been presented: Activity Index (AI), Revealed Patent Advantage (RPA), Relative Specialisation Index (RSI) and Relative Specialisation Index (RESP). This is the same index insofar each can be converted into the other three. The following applies:

$$\mathrm{RPA(AI)} \coloneqq 100 \ln \mathrm{AI}$$

$$\mathrm{RSI(AI)} \coloneqq \frac{\mathrm{AI} - 1}{\mathrm{AI} + 1}$$

$$\mathrm{RESP(AI)} := 100 \, \frac{\mathrm{AI}^2 - 1}{\mathrm{AI}^2 + 1}$$

Formula 8: RPA, RSI, RESP depending on AI

And in the other direction:

$$\mathrm{AI(RPA)} = \mathrm{e}^{0{,}01\ \mathrm{RPA}}$$

$$\mathrm{AI(RSI)} = \frac{1 + \mathrm{RSI}}{1 - \mathrm{RSI}}$$

$$\mathrm{AI(RESP)} = \sqrt{\frac{1 + 0{,}01 \cdot \mathrm{RESP}}{1 - 0{,}01 \cdot \mathrm{RESP}}}$$

Formula 9: AI depending on RPA, RSI, RESP

Additionally, this results in the relationship:

$$\mathrm{RESP(RSI)} = \frac{200\ \mathrm{RSI}}{1 + \mathrm{RSI}^2}$$

Formula 10: Relationship between RESP and RSI

Finally, a direct comparison between the RSI and RESP values is shown (Figure 9 and Figure 10). AI values are shown on the X-axis. The AI values in the first figure are arranged on a linear basis from 0 to 2 (Figure 9) to consider the behaviour of the indices around the expected AI value of 1. In the second figure, the value range 0 to 1 occupies the first third, the value range 1 to 10 the second third, and the value range 10 to 100 the last third of the X-axis (Figure 10). This classification was chosen for the purpose of considering the index development at high values, while the range from 0 to 1, which corresponds to the range 1 to $+\infty$, can be seen clearly at the same time. Two scales were chosen for the ordinate axis, from -1 to 1 for the RSI and from -100 to 100 for the RESP, so as to identify the slope variations between the two indices.

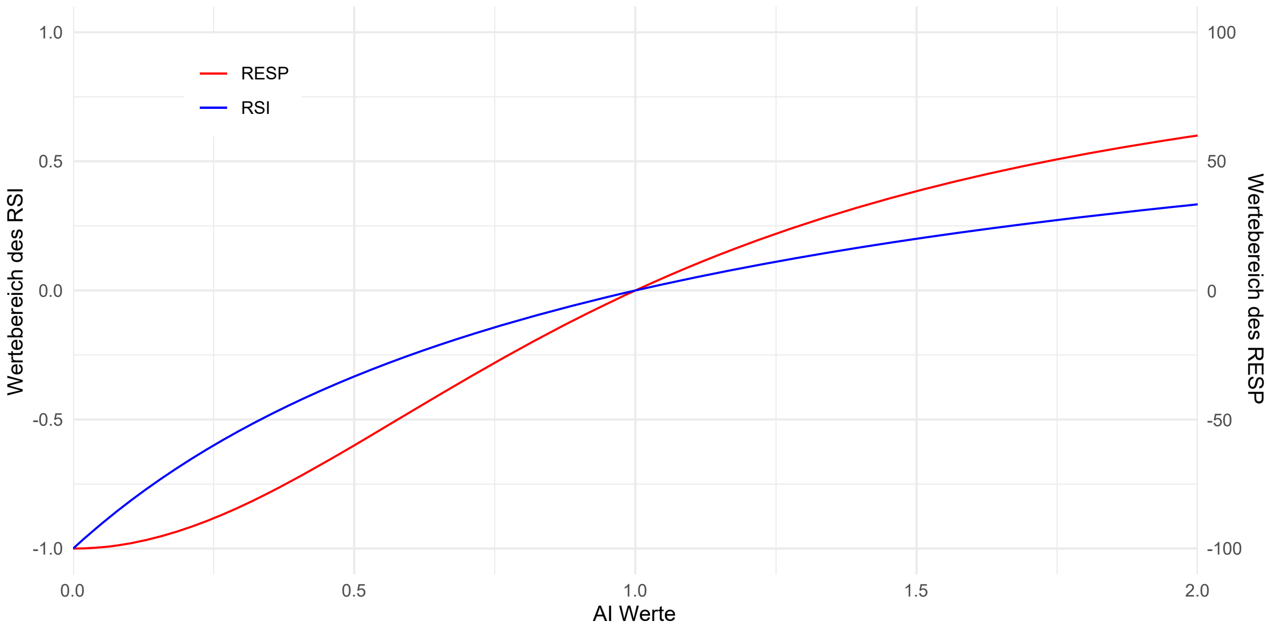

Figure 9: Comparison of RSI and RESP on the AI interval [0.2]

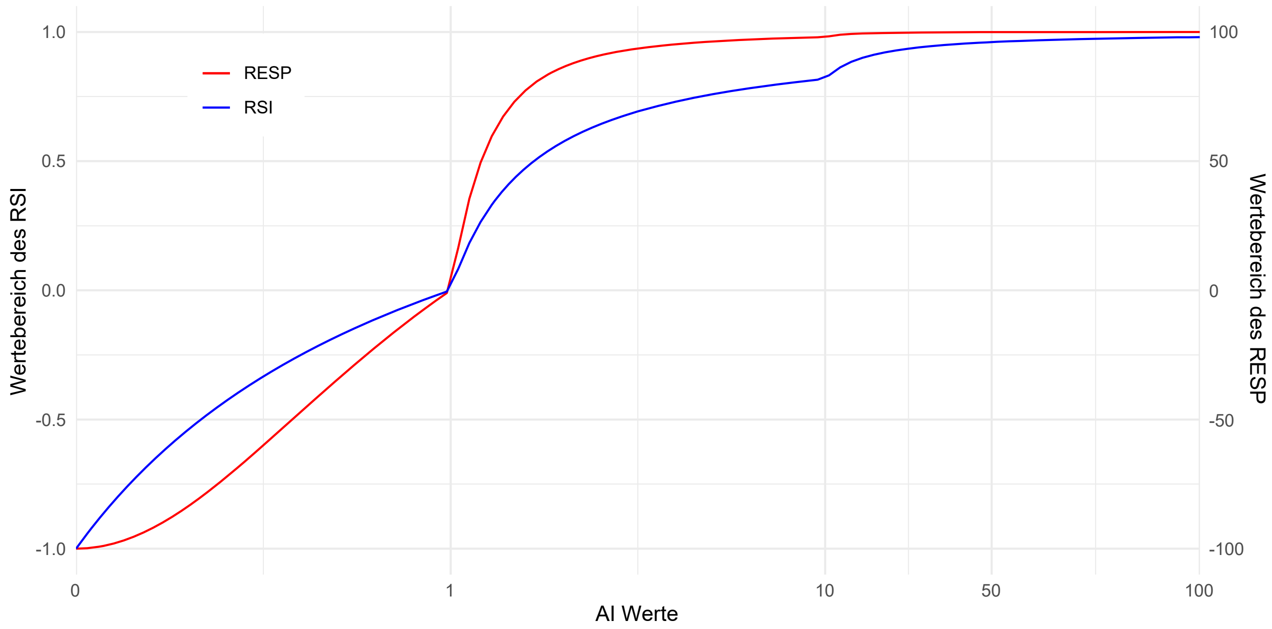

Figure 10: Comparison of RSI and RESP on the AI interval [0.100]

It is evident that the values of the RESP develop faster (the curve is steeper by the AI value 1) than those of the RSI. The RSI appears subdued in relation to the RESP. In a specific example, we consider the two important AI values 0.5 and 2, which show that the relative share of resources allocated to a particular field is only half or twice the average for Germany as a whole. In this respect, the RESP values of -60 and +60 and the RSI values -0.33 and +0.33 are obtained. If we now consider the fact that the scales of the two indices go from -100 to +100 and/or from -1 to +1, it is clear that the RESP reach the limits of the value range more quickly. If we are only interested in university field combinations with a RESP value above 50, a considerable number of combinations still reach this value. In RESP, the consideration becomes coarser at the margins, but finer by the AI value of 1. The exact opposite is the case for the RSI. If we are interested in values above 0.5, equivalent to the RESP, this criterion will be fulfilled by significantly fewer university-field combinations. The observation of the margins of the value range is therefore more refined, while the observation of the AI value is coarser.

The terms finer and coarser observations are used in such a way that fewer combinations which fulfil a given criterion allow for a finer observation, while more combinations that meet the criterion result in a coarser observation. Since values exceeding an RESP of 50 or an RSI of 0.5

were cited as a criterion for consideration, the corresponding AI values are as follows: for the RESP this is the AI value 1.72; for the RSI it is the AI value of 3.0.

For a similar reason, the scaling of the RESP was also used for the percentage rates of change in the variables over time. In some cases, these rates ranged between 0 % and 200 %, in other cases between 0 % and 15,000 %. A linear scaling of such differences is difficult to show in graphic form. For reasons of better representation, the linear scale was therefore expressed in a logarithm with a value range of [-100, +100]. The following figure shows the translation of the percentage values on the X-axis to the scale transformed according to the RESP values, shown on the Y-axis (Figure 11).

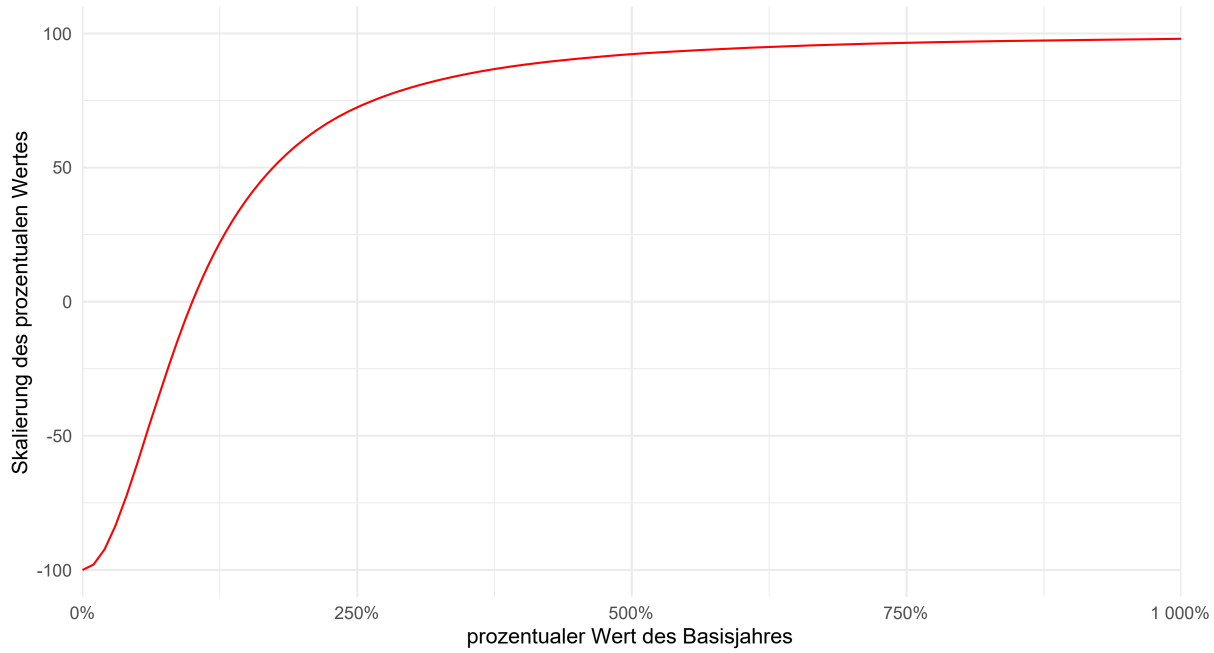

Figure 11: Comparison of percentage change with the scaled rate of change [-100, +100]

3rd Annex - Differentiation of university groups

A total of 17 universities were included in the group of TUs. These include the universities belonging to the TU9 Alliance: Aachen, TU Berlin, Braunschweig, Darmstadt, Dresden, Hanover, Karlsruhe, Munich (TU) and Stuttgart (TU9 2019). In addition, eight further institutions officially include "Technical University" in their name: Cottbus-Senftenberg, Chemnitz, Clausthal, Dortmund, Freiberg, Hamburg (TU), Ilmenau and Kaiserslautern (see 6th Annex).

There is no grouping into teacher training universities, i.e. universities which focus more strongly on teacher training, and universities which do not offer teaching training courses. In principle, it is possible to differentiate students according to the degree they are studying for, and therefore their differentiation according to prospective teacher training students in the data set of the Federal Statistical Office. However, our analysis has shown that the higher education landscape is so heterogeneous in this respect that it was not possible to differentiate between individual universities according to whether or not they offer teacher training courses in all the fields on offer on a proportionally strong basis. Considering the proportion of teacher training students of all students in all years and in all fields, although differentiated according to universities, results in a standard deviation of 10.3 % for NTUs and 7.0 % for TUs. From this finding, it may be concluded that the universities are very similar on this point: it is obviously the case that most see it as their task to offer teacher training courses.

Mention must also be made of the fact that in certain years, 16 fields at NTUs or TUs have no teacher training students: Library Science and Documentation, General and Comparative Literature and Linguistics, Cultural Studies in the proper sense, Regional Studies, Administrative Sciences, Industrial Engineering focusing on Economics and Engineering, Pharmacy, Geosciences excluding Geography, Forestry and Timber Management, Industry, Mining and Metallurgy, Transport Studies and Nautical Engineering, Architecture, Spatial Planning, Surveying, Performing Arts, Film and Television, Theatre Studies. A grouping into certain field categories, which are attended differently by teacher training students and students studying for a degree, would therefore make sense. In the present analysis, however, no such grouping took place, as the different regulations of the individual federal states would have to be taken into account. An analysis of this kind would clearly go beyond the objective of this publication.

A grouping according to the size of the universities was also dispensed with. On the one hand, the question would have arisen as to which consideration is used to determine the size of a university. In addition to financial and staff resources, the indicators derived from these would also be considered as well as attributes that were not documented. On the other hand, the distribution of financial and staff resources demonstrated the homogeneity of the German higher education system. On the basis of the existing distributions, it would not have been possible to group the universities which were considered without using arbitrary size thresholds.

4th Annex - List of fields for research profiles (alphabetical order)

Agricultural Sciences, Food and Beverages Technology
Biology
Chemistry
Economics
Electrical Engineering
Forestry, Timber Management
Geosciences (excluding Geography)
Mathematics
Mechanical Engineering/Process Engineering
Nutrition and Home Economics
Physics, Astronomy
Psychology

Note: the units referred to here as “fields” correspond to the classification of the StBA, which uses the term “Fachbereiche” [departments]. To avoid confusion with departments as the organisational units of universities, we use the term “fields”.

5th Annex - List of fields for teaching profiles (alphabetical order)

Administrative Sciences
Agricultural Sciences, Food and Beverages Technology
Agricultural, Forestry and Nutrition Sciences in general
Architecture/Interior Design
Art, General Aesthetics
Biology
Business Administration focusing on Engineering
Business studies focusing on Economics
Catholic Theology
Chemistry
Civil Engineering
Classical Philology
Computer Science
Cultural Studies (in a narrow sense)
Design
Economics
Educational Sciences
Electrical Engineering
Engineering in general
English Studies, American Studies
Fine Arts
Forestry, Timber Management
General and Comparative Literature and Linguistics
Geography
Geosciences not including Geography
German Studies
History
Landscape Management, Environmental Design
Law, Economics and Social Studies
Legal Sciences
Library Sciences, Documentation, Journalism
Linguistics and Cultural Studies in general
Mathematics
Mathematics, Natural Sciences in general
Mechanical Engineering/Process Engineering
Mining, Metallurgy
Music, Musicology
Non-European Linguistics and Cultural Studies
Nutrition and Home Economics
Performing Arts, Film and Television, Theatre Studies

Pharmacy
Philosophy
Physics, Astronomy
Political Sciences
Protestant Theology
Psychology
Regional Studies
Romance Studies
Slavic Studies, Baltic Studies, Finno-Ugric Studies
Social Sciences
Social Welfare
Spatial Planning
Special Education
Sports, Sports Science
Surveying
Transport Studies/Nautics

Note: the units referred to here as “fields” correspond to the classification of the StBA, which uses the term “Fachbereiche” [departments]. To avoid confusion with departments as the organisational units of universities, we use the term “fields”.

6th Annex - List of Technical Universities (in alphabetical order)

Brandenburgische Technische Universität Cottbus-Senftenberg (Brandenburg University of Technology Cottbus-Senftenberg)
Karlsruher Institut für Technologie (Karlsruhe Institute of Technology)
Leibniz Universität Hannover (Leibniz University Hannover)
Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen University)
Technische Universität Bergakademie Freiberg (Freiberg University of Mining and Technology)
Technische Universität Berlin (Technical University of Berlin)
Technische Universität Braunschweig (Technical University of Braunschweig)
Technische Universität Chemnitz (Chemnitz University of Technology)
Technische Universität Clausthal (Clausthal University of Technology)
Technische Universität Darmstadt (Technical University of Darmstadt)
Technische Universität Dortmund (TU Dortmund University)
Technische Universität Dresden (Dresden University of Technology)
Technische Universität Hamburg (Hamburg University of Technology)
Technische Universität Ilmenau (TU Ilmenau)
Technische Universität Kaiserslautern (University of Kaiserslautern)
Technische Universität München (Technical University of Munich)
Universität Stuttgart (University of Stuttgart)

7th Annex - List of non-technical universities (in alphabetical order)

Albert-Ludwigs-Universität Freiburg (University of Freiburg)
Bergische Universität Wuppertal (University of Wuppertal)
Carl von Ossietzky Universität Oldenburg (University of Oldenburg)
Christian-Albrechts-Universität zu Kiel (University of Kiel)
Eberhard-Karls-Universität Tübingen (Eberhard Karls University of Tübingen)
Europa-Universität Viadrina Frankfurt (Oder) (European University Viadrina)
Freie Universität Berlin (Free University of Berlin)
Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU University of Erlangen-Nuremberg)
Friedrich-Schiller-Universität Jena (Friedrich Schiller University Jena)
Georg-August-Universität Göttingen (University of Göttingen)
Goethe-Universität Frankfurt am Main (Goethe University Frankfurt)
Heinrich-Heine-Universität Düsseldorf (Heinrich Heine University Düsseldorf)
Humboldt-Universität zu Berlin (Humboldt University of Berlin)
Johannes-Gutenberg-Universität Mainz (Johannes Gutenberg University Mainz)
Julius-Maximilians-Universität Würzburg (JMU Würzburg)
Justus-Liebig-Universität Gießen (Justus Liebig University of Giessen)
Leuphana Universität Lüneburg (Leuphana University Lüneburg)
Ludwig-Maximilians-Universität München (LMU Munich)
Martin-Luther-Universität Halle-Wittenberg (Martin Luther University Halle-Wittenberg)
Otto-Friedrich-Universität Bamberg (University of Bamberg)
Otto-von-Guericke-Universität Magdeburg (Otto von Guericke University Magdeburg)
Philipps-Universität Marburg (Philipps University Marburg)
Rheinische Friedrich-Wilhelms-Universität Bonn (University of Bonn)
Ruhr-Universität Bochum (Ruhr University Bochum)
Ruprecht-Karls-Universität Heidelberg (Heidelberg University)
Universität Augsburg (University of Augsburg)
Universität Bayreuth (University of Bayreuth)
Universität Bielefeld (Bielefeld University)
Universität Bremen (University of Bremen)
Universität des Saarlandes (Saarland University)
Universität Duisburg-Essen (University of Duisburg-Essen)
Universität Erfurt (University of Erfurt)
Universität Greifswald (University of Greifswald)
Universität Hamburg (University of Hamburg)
Universität Hohenheim (University of Hohenheim)
Universität Kassel (University of Kassel)
Universität Koblenz-Landau (University of Koblenz - Landau)
Universität Konstanz (University of Konstanz)
Universität Leipzig (Leipzig University)
Universität Mannheim (University of Mannheim)
Universität Osnabrück (Osnabrück University)
Universität Paderborn (Paderborn University)

Universität Passau (University of Passau)
Universität Potsdam (University of Potsdam)
Universität Regensburg (University of Regensburg)
Universität Rostock (University of Rostock)
Universität Siegen (University of Siegen)
Universität Trier (Trier University)
Universität Ulm (Ulm University)
Universität zu Köln (University of Cologne)
Westfälische Wilhelms-Universität Münster (University of Münster)

8th Annex - Aggregation scheme of the examination groups of the Federal Statistical Office

The Federal Statistical Office (StBA) documents the final examinations of the enrolled students and divides these into examination groups. The table below shows the aggregated groups and, where possible, the aggregated examination groups. Where it was not possible to list examination groups, final examinations were listed instead. This occurs when different final examinations from the same examination groups are assigned to different aggregated groups. For the exact classification, reference is made to *Fachserie* 11, series 4.1. (StBA 1992-2016b).

Aggregated group	**Examination groups (standard font), final examinations (italic)**
University degree (without teacher training examinations)	*Master degree; licentiate; ecclesiastical examination; state examination/1st state examination; state examination (single-phase education); faculty examination; diploma (U); diploma (U-GH); diploma (U) - interpreter; diploma (U) - translator; certified translator; diploma (U) - teacher; final examination without academic degree*
Bachelor degree (without teacher training examinations)	*Multi-field bachelor without teacher training option; multi-field bachelor with teacher training option; bachelor (U) - teacher; bachelor at universities; bachelor at art colleges; bachelor at universities of applied sciences*
Master degree (without teacher training examinations)	*Multi-field master; master (U) – teacher; master at universities (final examination required); master at art colleges (final examination required); master at universities of applied sciences (final examination required)*
Teacher training examinations	Teacher training, bachelor and master examinations (TT/BA/MA) at primary and lower secondary schools/primary level; teacher training, bachelor and master examinations (TT/BA/MA) at intermediate level (secondary level I/primary schools/primary level); teacher training, bachelor and master examinations (TT/BA/MA) at secondary schools/technical secondary level I; teacher training, bachelor and master examinations (TT/BA/MA) comprehensive examination for secondary level II/secondary level I; teacher training, bachelor and master examinations (TT/BA/MA) at grammar school/secondary level II, general schools; teacher training, bachelor and master examinations (TT/BA/MA) at special schools; teacher training, bachelor and master examinations (TT/BA/MA) at vocational schools/secondary level II, vocational schools; TT bachelor; TT master; other TT according to school types/school levels
Doctorates	Doctorates
Artistic degree	Artistic degree (not including *bachelor degree at art colleges* or *master degree at art colleges (final examination required)*)
University of Applied Sciences degree	University of Applied Sciences degree (not including *bachelor degree at universities of applied sciences* or *master degree at universities of applied sciences (final examination required)*)
Other academic qualification	Other academic qualification

9th Annex - Concordance table of StBA field classification with Archambault classification

Field classification of the StBA	**Archambault sub-field**
Agricultural Sciences, Food and Beverages Technology	Agronomy & Agriculture
Agricultural Sciences, Food and Beverages Technology	Food Science
Agricultural Sciences, Food and Beverages Technology	Horticulture
Agricultural Sciences, Food and Beverages Technology	Dairy & Animal Science
Biology	Toxicology
Biology	Bioinformatics
Biology	Biotechnology
Biology	Anthropology
Biology	Biochemistry & Molecular Biology
Biology	Biophysics
Biology	Developmental Biology
Biology	Genetics & Heredity
Biology	Microbiology
Biology	Ecology
Biology	Entomology
Biology	Evolutionary Biology
Biology	Marine Biology & Hydrobiology
Biology	Ornithology
Biology	Plant Biology & Botany
Biology	Zoology
Chemistry	Analytical Chemistry
Chemistry	General Chemistry
Chemistry	Inorganic & Nuclear Chemistry
Chemistry	Medicinal & Biomolecular Chemistry
Chemistry	Organic Chemistry
Chemistry	Physical Chemistry
Chemistry	Polymer
Chemistry	Nanoscience & Nanotechnology
Electrical Engineering	Optoelectronics & Photonics
Electrical Engineering	Electrical & Electronic Engineering
Electrical Engineering	Networking & Telecommunications
Nutrition and Home Economics	Dairy & Animal Science
Nutrition and Home Economics	Nutrition & Dietetics
Forestry, Timber Management	Forestry
Geosciences (excluding Geography)	Geological & Geomatics Engineering
Geosciences (excluding Geography)	Geochemistry & Geophysics
Geosciences (excluding Geography)	Geology
Geosciences (excluding Geography)	Meteorology & Atmospheric Sciences
Geosciences (excluding Geography)	Oceanography
Geosciences (excluding Geography)	Palaeontology
Geosciences (excluding Geography)	Environmental Sciences

Mechanical Engineering/Process Engineering	Energy
Mechanical Engineering/Process Engineering	Biomedical Engineering
Mechanical Engineering/Process Engineering	Chemical Engineering
Mechanical Engineering/Process Engineering	Materials
Mechanical Engineering/Process Engineering	Environmental Engineering
Mechanical Engineering/Process Engineering	Industrial Engineering & Automation
Mechanical Engineering/Process Engineering	Mechanical Engineering & Transports
Mathematics	Applied Mathematics
Mathematics	General Mathematics
Mathematics	Numerical & Comp. Mathematics
Mathematics	Statistics & Probability
Physics, Astronomy	Acoustics
Physics, Astronomy	Applied Physics
Physics, Astronomy	Astronomy & Astrophysics
Physics, Astronomy	Chemical Physics
Physics, Astronomy	Fluids & Plasmas
Physics, Astronomy	General Physics
Physics, Astronomy	Mathematical Physics
Physics, Astronomy	Nuclear & Particles Physics
Physics, Astronomy	Optics
Physics, Astronomy	Nanoscience & Nanotechnology
Psychology	Behav. Science & Comp. Psychology
Psychology	Clinical Psychology
Psychology	Developmental & Child Psychology
Psychology	Experimental Psychology
Psychology	Gene Psychology & Cognitive Sciences
Psychology	Human Factors
Psychology	Social Psychology
Economics	Operations Research
Economics	Accounting
Economics	Agricultural Economics & Policy
Economics	Business & Management
Economics	Development Studies
Economics	Econometrics
Economics	Economic Theory
Economics	Economics
Economics	Finance
Economics	Industrial Relations
Economics	Logistics & Transportation
Economics	Marketing
Economics	Sports, Leisure & Tourism

10th Annex - Improved coverage for the universities examined through the additional classification of missing journals

WoS	**without classification of missing journals**				**including classification of missing journals**			
	Publications of universities (N=68)	documented publications using Archambault class.	Share documented	Share not documented	Publications of universities (N=68)	documented publications with Archambault class.	Share documented	Share not documented
1992	38242	31832	83.2 %	16.8 %	38242	36646	95.8 %	4.2 %
1993	40503	33916	83.7 %	16.3 %	40503	39008	96.3 %	3.7 %
1994	42588	36655	86.1 %	13.9 %	42588	41204	96.8 %	3.2 %
1995	46921	41361	88.2 %	11.8 %	46921	45500	97.0 %	3.0 %
1996	51162	45807	89.5 %	10.5 %	51162	50001	97.7 %	2.3 %
1997	56592	51184	90.4 %	9.6 %	56592	55376	97.9 %	2.1 %
1998	59031	54340	92.1 %	7.9 %	59031	58009	98.3 %	1.7 %
1999	59661	55039	92.3 %	7.7 %	59661	58639	98.3 %	1.7 %
2000	60343	56282	93.3 %	6.7 %	60343	59476	98.6 %	1.4 %
2001	60983	56942	93.4 %	6.6 %	60983	60156	98.6 %	1.4 %
2002	62083	57855	93.2 %	6.8 %	62083	61287	98.7 %	1.3 %
2003	62269	58350	93.7 %	6.3 %	62269	61575	98.9 %	1.1 %
2004	66662	62524	93.8 %	6.2 %	66662	65982	99.0 %	1.0 %
2005	69609	65395	93.9 %	6.1 %	69609	68964	99.1 %	0.9 %
2006	73154	69101	94.5 %	5.5 %	73154	72470	99.1 %	0.9 %
2007	79600	75296	94.6 %	5.4 %	79600	78670	98.8 %	1.2 %
2008	83999	78704	93.7 %	6.3 %	83999	82665	98.4 %	1.6 %
2009	87493	81590	93.3 %	6.7 %	87493	85787	98.1 %	1.9 %
2010	89473	82859	92.6 %	7.4 %	89473	87359	97.6 %	2.4 %
2011	93928	86028	91.6 %	8.4 %	93928	91517	97.4 %	2.6 %
2012	97489	88042	90.3 %	9.7 %	97489	94771	97.2 %	2.8 %
2013	101579	90224	88.8 %	11.2 %	101579	98481	97.0 %	3.0 %
2014	103478	89616	86.6 %	13.4 %	103478	100229	96.9 %	3.1 %
2015	106329	90448	85.1 %	14.9 %	106329	102583	96.5 %	3.5 %
Total	**1914011**	**1715351**	**89.6 %**	**10.4 %**	**1914011**	**1867089**	**97.5 %**	**2.5 %**

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