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by Maria Olivares and Heike Wetzel

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Competing in the Higher Education Market: Empirical Evidence for Economies of Scale and Scope in German Higher Education Institutions

Maria Olivares*   Heike Wetzel †

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Since the late 1990s, the European higher education system has had to face deep structural changes. With the public authorities seeking to create an environment of quasi-markets in the higher education sector, the increased competition induced by recent reforms has pushed all publicly financed higher education institutions to use their resources more efficiently. Higher education institutions increasingly now aim at differentiating themselves from their competitors in terms of the range of outputs they produce. Assuming that different market positioning strategies will have different effects on the performance of higher education institutions, this paper explores the existence of economies of scale and scope in the German higher education sector. Using an input-oriented distance function approach, we estimate the economies of scale and scope and the technical efficiency for 154 German higher education institutions from 2001 through 2007. Our results suggest that comprehensive universities should indeed orientate their activities to the concept of a full-university that combines teaching and research activities across a broad range of subjects. In contrast, praxis-oriented small and medium-sized universities of applied sciences should specialise in the teaching and research activities they conduct.

Keywords: Higher Education Production, Economies of Scale and Scope, Technical Efficiency, Stochastic Frontier Analysis, Input Distance Function

JEL-Classification: L25, I23, D24

*University of Zurich, Department of Business Administration, Plattenstrasse 14, 8032 Zurich, Switzerland. e-mail: maria.olivares@business.uzh.ch

†University of Cologne, Institute of Energy Economics, Alte Wagenfabrik, Vogelsanger Str. 321, 50827 Cologne, Germany. e-mail: heike.wetzel@uni-koeln.de

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1 Introduction

Since the late 1990s, the European higher education system has had to face deep structural changes, both to make Europe into one of the most competitive knowledge-based economies in the world as mandated by the Lisbon Strategy of 2000 (Council of the European Union, 2000), and to account for the growing cost pressures on higher education. These structural changes have intensified the interest of politicians and university administrators in streamlining production processes and improving the efficiency in European higher education institutions (HEIs). Authorities from national governments and the European Union have begun a radical deregulation of the higher education system by introducing new market- or quasi-market-like mechanisms into the system (Teixeira et al., 2004). Given this growing 'marketisation' of the higher education sector (Dill, 2003), European HEIs are increasingly encouraged to develop strategies that allow them to differentiate themselves from their competitors and to increase their efficiency based on their strengths and their institutional missions, e.g. the provision of discipline-specific teaching or the provision of cutting-edge research, or both (Bonaccorsi et al., 2006).

The economic theory of industrial organisation shows that multi-product firms, such as HEIs, can improve their efficiency by exploiting economies of scale and scope (e.g., Baumol et al., 1988). If these economies of scale and scope exist, HEIs can increase their efficiency by expanding their scale of operation and by using common inputs for the joint production of multiple outputs. In contrast, if diseconomies of scale and scope are observed, HEIs can realise efficiency gains by concentrating on a small scale of operation and the production of only one specific output. Hence, differentiation strategies of HEIs considering the presence of economies or diseconomies of scale and scope in higher education production can lead to efficiency gains, thus ensuring their successful positioning in the marketplace.

A variety of studies have investigated the cost structure and the existence of economies of scale and scope for higher education production in Anglo-Saxon and European countries (e.g. Agasisti and Johnes, 2010; Cohn et al., 1989; Dundar and Lewis, 1995; Izadi et al., 2002; Johnes, 1997; Koshal and Koshal, 1999). However, there is only one noteworthy study on Germany by Johnes and Schwarzenberger (2011). Based on the concept of multiple-product cost functions introduced by Baumol et al. (1988), previous studies have explored differences in the economies of scale and scope between public and private HEIs, between (discipline-specific) teaching and research and between undergraduate and graduate education. However, these studies use a cost function approach that relies on a cost-minimisation assumption on the basis of observed market prices. As in other non-profit sectors, such as health or the cultural sector, it seems questionable whether this pre-imposed assumption holds true for the publicly funded and governmentally controlled higher education sector, such as that in Germany and many other European countries. If it is true that cost-minimising based on market prices is not an appropriate assumption in that sector (see e.g. Bowen, 1980; Deming, 2005; Ehrenberg, 2000), the results that rely on such an assumption should be interpreted carefully.

This paper seeks to fill the gap in the previous research by analysing the efficiency and the existence of economies of scale and scope in German HEIs, first, through the use of an input distance function approach. The input distance function approach is dual to a cost function approach, but it does not rely on a cost-minimisation assumption on the basis of observed market input prices. Rather, this approach assumes a shadow cost-minimising behaviour, where the decision-making units minimise their costs relative to unobserved input shadow prices. Secondly, we extend the previous research for Germany by including not only universities, but also universities of applied sciences (*Fachhochschulen*), in our analysis.[1] Given the recent reform processes undertaken in the German higher education sector, the clear distinction between the missions of universities and universities of applied sciences—a distinction originally mandated by the German Federal Legislature—is increasingly disappearing (Wissenschaftsrat, 2010*b*). Hence, both types of universities are now acting in a common higher education market and are competing for students, academic personnel, and research funding in the same manner.

To our knowledge, this study is the first to (i) use an input distance function approach for analysing economies of scale and scope in German HEIs, (ii) investigate two types of German universities, that is, universities and universities of applied sciences, and (iii) account for the heterogeneity of scientific fields by differentiating among four outputs, namely, teaching and research in the non-sciences and teaching and research in the sciences.[2] Using a Bayesian stochastic frontier approach, we estimate a 'true' random effects model that controls for unobserved heterogeneity and allows efficiency to vary over time. The extensive and unique panel dataset employed covers the period of 2001-2007 and includes 74 public German universities and 80 public German universities of applied sciences. The dataset provides detailed information on input and output measures, such as operating and personnel expenditures, third-party funding, and the number of students enrolled at the bachelors, masters and diploma levels.

The remainder of this paper is organised as follows. Section 2 discusses the theoretical background for the increasing marketisation of higher education and relates to the concepts of economies of scale and scope in the production of higher education. Section 3 presents an overview of the previous research on scale and scope effects in the same sector and discusses the critical issues to be considered for estimations. Section 4 introduces the methodology, while Section 5 provides information on the dataset used in this analysis. The results are presented in Section 6, followed by a concluding discussion in Section 7.

[1] While a university offers usually a broad range of programmes in a variety of subjects and has a strong emphasis on basic research, a university of applied sciences concentrates on rather praxis-oriented teaching and research mainly in the fields of engineering and social sciences.

[2] The term 'sciences' refers to all natural and technical disciplines and subjects, such as mathematics and the natural sciences, agricultural, forestry, and food sciences and engineering. To distinguish humanities and social sciences from these, we use the term 'non-sciences' to refer to all 'non'-natural and 'non'-technical disciplines and subjects, such as linguistics, the cultural sciences, the arts, sport and legal, economics and the social sciences.

2 Marketisation, competition and differentiation in the higher education sector

As economic theory suggests, competitive pressure will affect the organisational efficiency of a firm's production processes by forcing profit-maximising firms to strive constantly to produce more efficiently. In the context of HEIs, the argument that such market-like mechanisms can be applied with equal force might not hold true for at least three reasons: (i) the higher education system in Germany as in many other European countries, is almost completely publicly financed and government controlled; (ii) as HEIs are non-profit entities, the 'market-driven' cost-minimisation assumption for production might not be the primary behavioural objective; and (iii) in the higher education market, price information of inputs and outputs are either difficult to obtain or totally unavailable.

However, an essential transformation process that has occurred in the European higher education sector since the late 1990s does demonstrate that certain rationales remain for introducing competitive market- or market-like structures or both into the higher education system. Given the aim of increasing global competitiveness and efficiency of the European higher education system (Lisbon Agenda 2000) and to account for the growing cost pressures faced by HEIs in nearly all European countries, politicians and university administrators have been increasingly interested in streamlining the production processes in the HEIs by enhancing their autonomy and institutional accountability. Aghion et al. (2010) particularly argue that both greater autonomy and greater accountability induced by an increased reliance on competitive funding and enhanced competition for leading scientists and high-performing students are, when taken together, two of the main key drivers for performance improvements in the HEIs. In particular, two recent reform processes reflect the reshaping of the European higher education sector.

The first major reform, referred to as New Public Management, led to the introduction of new governance structures in the higher education sector all across Europe (Pollitt and Bouckaert, 2000). State control and governmental steering instruments have been replaced by structures that provide more institutional autonomy for European HEIs in terms of more decentralised decision-making with respect to internal governance and control mechanisms, budgeting, curricula design, study programmes, student selection and faculty employment. In addition, a number of 'market-like' funding mechanisms such as competitive and performance-oriented funding were implemented. At the same time accountability rules that relate to reporting, auditing, and quality assurance were established, obliging HEIs to prove that they were using their resources efficiently (De Boer and File, 2009). Using these market-inspired instruments, the governmental authorities have created an environment of 'quasi-markets' where market behaviour is induced among the public European HEIs (Teixeira et al., 2004).[3]

The second reform process began with the signing of the Bologna Declaration in 1999 (Bologna Declaration, 1999). In line with the Lisbon Strategy of 2000, the objective of

[3] For more information on implementing the concept of New Public Management into higher education, see e.g. De Boer and File (2009); Jongbloed (2008); Jongbloed and Vossensteyn (2001); Leisyte and Kizniene (2006); Pollitt and Bouckaert (2000); Schubert (2009).

which was to create the 'most competitive and dynamic knowledge-based economy in the world' (Council of the European Union, 2000), the ministers of education from 29 European countries agreed to establish a common European higher education area by 2010. Among other goals these reform processes, known as the Bologna reforms, include the implementation of a pan-European, three-cycle system of degrees based on credit points, the aim of strengthening student and academic mobility and the introduction of pan-European standards of quality assurance. Further follow-up documents from the European Union highlight that higher education, research, and innovation are important pillars for improving European competitiveness (European Commission, 2003, 2005, 2007).

In Germany, the national and international challenges of reforming the higher education system were transposed into several legal frameworks such as in the Higher Education Act of 1999 (*Hochschulrahmengesetz*), corresponding legislation by the 16 Federal States (the *Länder*), and the Compensation Act of 2002 (*Professorenbesoldungsreformgesetz*).[4] The introduction of new internal governance and funding allocation mechanisms along with the implementation of Bologna conform bachelors and masters degrees led to a more institutional flexibility of German HEIs. It further induced a process of differentiation and the development of special profiles of teaching and research in HEIs (Hartwig, 2011). The German Council of Science and Humanities (*Wissenschaftsrat*)[5] recently confirmed these differentiation processes for German HEIs. Thereby, the council emphasised that institutional diversity may contribute and increase the overall performance of the whole German higher education system (Wissenschaftsrat, 2010*a*).

Not only German HEIs, but institutions all across Europe, have begun to develop differentiation strategies according to their special profiles and their stated institutional missions (De Boer and File, 2009). Speaking with Porter (1985), who argues that a firm's strength refers to cost advantages and differentiation, or both, one might also presume that HEIs are attempting to leverage their institutional strengths strategically in order to maintain or achieve a leading market position.

In the context of higher education, institutions may differentiate themselves from their competitors horizontally and vertically, or both.[6] From an economic perspective, horizontal differentiation refers to horizontal product differentiation, that is, the offering of diverse products that differ in their characteristics (Daraio et al., 2011). In particular, it is about the different allocation of institutional efforts and resources to teaching, research and third-mission activities. HEIs may decide which mix of subjects (wide or

[4]For more information on the German higher education system, see e.g. Hartwig (2011).

[5]The German Council of Science and Humanities (*Wissenschaftsrat*) advises the German Federal Government and the Federal States in the areas of science, research and higher education. It considers quantitative and financial aspects in its recommendations for the development of German science and humanities in an international competitive environment. See `http://www.wissenschaftsrat.de/1/home/` for more information.

[6]Detailed information on the concept of horizontal and vertical differentiation for the German HEIs is given by the German Council of Science and Humanities (Wissenschaftsrat, 2010*a*).

narrow)[7], they wish to offer and whether they want to focus on undergraduate, graduate or doctoral education. At the same time, HEIs may decide to become leading institutions in cutting-edge research, focus on industry-oriented research or concentrate on research activities that are the most germane to the specific needs of their regional economic and social environment. Finally, HEIs may differentiate their profile with respect to their third-mission activities, such as providing entrepreneurial and political consultancy (Bonaccorsi and Daraio, 2007).

Vertical differentiation refers to a hierarchical distinction, that is, being positioned in teaching and research according to 'performance' and 'quality' aspects (Wissenschaftsrat, 2010*a*). For example, to become a top research institution, HEIs may ensure they have excellent research conditions to attract highly qualified researchers, or they may offer innovative graduate programmes to attract highly talented international students. Vertical differentiation is signalled, e.g., by accreditation labels received, the HEI's ranking position, and may also be established through the introduction of competitive funding (Daraio et al., 2011).

Recent German policy changes point to accelerated specialisation in terms of horizontal and vertical differentiation in the German higher education sector. In 2006, the German Federal Government introduced an initiative aimed at establishing 'internationally visible research beacons' in Germany. The objective of this *Initiative for Excellence* was to enhance and ensure there is world-class research at German HEIs. To achieve this goal, the Federal Government provides project-oriented funding and fosters the establishment of (i) research schools for young scientists; (ii) internationally visible excellence clusters at universities with possibilities for co-operation between non-university research institutions, universities of applied sciences and the private sector; and (iii) institutional specific excellence clusters at universities that improve a university's research profile (German Federal Ministry of Education and Research, 2011).[8]

Strategic considerations with respect to horizontal and vertical differentiation likewise aim at improving the efficiency of higher education production. Arguably, efficiency may not be seen as the only relevant strategic issue; however, economically, it is one of the most important issues, especially in times of constrained financial resources, growing cost pressures, and enhanced competition in the higher education sector.

The (neo-classical) economic theory of industrial organisation shows that multi-product firms, such as HEIs, can increase their efficiency by exploiting economies of scale and scope (e.g. Baumol et al., 1988). HEIs can realise economies of scale by reducing average costs (cost per unit) through expanding their scale of operation. In contrast, economies of scope will arise when the costs of producing two or more outputs jointly are lower than the cost of producing the same outputs separately.

In higher education production, there are several sources for economies of scale and scope. Efficient HEIs must be large enough in terms of student numbers and research activities to ensure full utilisation of their assets such as infrastructure entities like

[7] The German Rector's Conference (*Hochschulrektorenkonferenz*) recently emphasised that e.g. 'exotic subjects' sharpen the specific profiles of universities and hence may increase their institutional competitiveness (Hochschulrektorenkonferenz, 2008).

[8] see `http://www.bmbf.de/en/1321.php`

class and computer rooms or libraries and laboratories equipped with machinery and other techniques. Accordingly, economies of scale can be realised by increasing the size of higher education production, that is, by establishing a large university with a high number of students and a large amount of research activities. However, such scale effects might be exhausted at a certain output level and turn into diseconomies of scale as a result of cost rising congestion effects. Moreover, economies of scope in higher education production can arise from the joint usage of inputs, such as central unit personnel, departmental administrative personnel, and facilities like libraries and laboratories. Such cost saving scope effects can particularly arise from using academic personnel and departmental administrative staff for the joint production of teaching and research, for the joint production of undergraduate, graduate and doctoral education or for multidisciplinary teaching of students enrolled in different subjects (e.g. statistics lectures for social and natural science students). They can also appear from using common facilities for research in different disciplines (libraries, laboratories, technical equipment, computer networks and servers). However, for some output combinations such scope effects may not exist and the joint production of these outputs may lead to diseconomies of scope. In this case, HEIs should decide to focus on specialisation in terms of concentrating on their promising outputs rather than on joint production of all outputs.

Depending on the presence of economies or diseconomies of scale and scope for higher education production, a common assumption is that HEIs specifically position themselves in different market segments according to their strengths and their institutional missions. In particular, if economies of scale and scope do exist, HEIs would increase their efficiency by positioning themselves as a large-scale, full university that provides a broad range of subjects and concentrates on both teaching and research. If diseconomies of scale and scope exist, HEIs would realise efficiency gains either by specialising in size, subject mix, programme range or teaching and research activities.

3 Previous research on scale and scope effects in higher education production

A variety of studies have investigated economies of scale and scope in higher education production via a cost functions approach. An exemplary overview of previous empirical research is given in Table 1. A considerable contribution referring to HEIs as multi-product organisations comes from Cohn et al. (1989). Their pioneering study is the first, in which economies of scale and scope regarding teaching and research are estimated based on the concept of the multiple-product cost functions introduced by Baumol et al. (1988). Several other studies contributed to the work of Cohn et al. (1989) and provide further empirical evidence on the cost structure of HEIs in the US (see e.g. Dundar and Lewis, 1995; De Groot et al., 1991; Koshal and Koshal, 1999; Laband and Lentz, 2003). In particular, their studies' results indicate that research is the most expensive output, undergraduate education is less expensive than graduate education, and HEIs with a medical school are more expensive than HEIs without a medical school. Further, the studies provide evidence of the presence of economies of scale and scope. Overall, the authors find economies of scale for both public and private average-sized HEIs. In most instances, economies of scope exist between undergraduate education, graduate education and research.

One of the first studies that accounts for the heterogeneity of scientific fields is the work of Dundar and Lewis (1995). They investigated the existence of economies of scale and scope for teaching and research by differentiating between disciplines, that is, social, physical, and engineering sciences. Their results for 18 US public research universities indicate that of the fields they examined, the social sciences generally have the lowest costs across almost all output categories, compared to engineering, which generally has the highest costs. Moreover, the findings of Dundar and Lewis (1995) suggest that at the level of disciplines, economies of scale and economies of scope do exist for all outputs, undergraduate, graduate and doctoral education as well as research, but at differing levels. In other words, synergy effects in terms of cost advantages due to economies of scope arise from the joint utilisation of faculty, administrators, support staff, equipment, and services for production of both teaching and research outputs.

In more recent studies on higher education production for different European countries, the authors based their analyses on frontier analysis techniques (Agasisti and Johnes, 2010; Bonaccorsi et al., 2006; Izadi et al., 2002; Johnes and Salas-Valesco, 2007; Johnes and Schwarzenberger, 2011). Following this approach, entities of interests are benchmarked relative to each other and the best-practice frontier. Within the framework of frontier analysis, different techniques are applied: Non-parametric estimation techniques, such as Data Envelopment Analysis, Free Disposable Hull or Order-m, and parametric estimation techniques, such as Stochastic Frontier Analysis.[9] Furthermore, the majority of the studies differentiate between disciplines, e.g. the non-sciences and the sciences.

The results of those studies particularly indicate considerable cost differences between the disciplines. That is, non-science undergraduate education is cheaper than science undergraduate education. Further, among all teaching activities postgraduate education is the most expensive one. However, referring to economies of scale the empirical findings are ambiguous. Some authors find economies of scale while others find diseconomies of scale. As for scope economies, the majority of the findings point to diseconomies of scope between teaching activities in different disciplines as well as between teaching activities as a whole and research activities.

Focusing on Germany, the related empirical literature is limited to only one noteworthy study by Johnes and Schwarzenberger (2011). To analyse the cost structure and measure economies of scale and scope in higher education, the authors estimate a multiple-product cost function based on Stochastic Frontier Analysis and apply a random parameter model for 72 public German universities for the periods of 2002-03 throughout 2004-05. They use undergraduate education divided into two scientific areas

[9] A review of the advantages and shortcomings of different frontier analysis techniques is beyond the scope of this paper. A detailed overview on this topic can be found e.g. in Fried et al. (2008).

Table 1: Selection of studies estimating scale and scope effects in higher education production

Study	Sample, level and estimation approach	Variables of interest	Selected results
Cohn et al. (1989)	- 1195 public and 692 private US colleges and universities (1981-1982) - university-level - flexible fixed cost quadratic function (FFCQ) - Ordinary Least Squares	**inputs** - total educational expenditures and transfers - average faculty salary is used as an input price **outputs** - undergraduate and graduate full-time equivalent (FTE) enrolment, amount of research funds	**cost structure** - significant cost structure differences between public and private HEIs **scale and scope effects** - economies of scale for public and private HEIs at the output means - diseconomies of scale for public HEIs, but economies of scale for private HEIs with output expansion beyond the output means - economies of scope for private HEIs, but diseconomies of scope for public HEIs at the output means - economies of scope for private and public HEIs with output expansion beyond the output means → complex HEIs with teaching and research are less costly than specialised HEIs → very small HEIs are more costly than average-sized HEIs
De Groot et al. (1991)	- 147 US doctorate granting universities (1982-1983) - university-level - translog variable cost function - Ordinary Least Squares	**inputs** - current educational and general expenditures minus income transfers and expenditures on public service **outputs** - undergraduate and graduate FTE enrolment, number of research publications	**cost structure** - HEIs with a medical a school are more costly than HEIs without a medical school - no cost effect of ownership type (public/private) and state-specific regulation **scale and scope effects** - economies of scale for the average HEI - economies of scale with output expansion beyond the output means - economies of scope between undergraduate and graduate education
Dundar and Lewis (1995)	- 18 US public research universities (1985-1986) - discipline-level (social sciences, physical sciences, and engineering sciences) - quadratic cost function - Ordinary Least Squares	**inputs** - total annual wages and fringe benefits of faculty and support staff, annual expenditure for services, supplies, and equipment **outputs** - number of undergraduate, master, and doctoral student-credit hours, number of journal publications	**cost structure** - social sciences is the cheapest scientific field and engineering sciences is the most expensive - research is the most expensive output and undergraduate education is the cheapest **scale and scope effects** - economies of scale for all three scientific fields - economies of scope between teaching and research in all three scientific fields

Table 1: continued

Study	**Sample, level and estimation approach**	**Variables of interest**	**Selected results**
Johnes (1997)	- 99 British and Northern Ireland universities (1994-1995) - university-level (typical universities, arts based universities, and science based universities) - CES cost function - Non-linear Least Squares	**inputs** - total university expenditures **outputs** - undergraduate student load in the arts and sciences, postgraduate student load, amount of research funds	**cost structure** - arts undergraduate education is cheaper than science undergraduate education - postgraduate education is the most expensive output **scale and scope effects** - economies of scale for typical and arts based universities, no scale effects for science based universities - diseconomies of scope between undergraduate education, postgraduate education and research for all types of universities
Koshal and Koshal (1999)	- 158 private and 171 public comprehensive US universities (1990-1991) - university-level - flexible fixed cost quadratic function - Ordinary Least Squares	**inputs** - current university expenditures - the average total score on the Scholastic Aptitude Test (SAT) is used as a quality measure **outputs** - undergraduate and graduate FTE enrolment, amount of research funds	**cost structure** - undergraduate education is cheaper than graduate education at both public and private HEIs - research, undergraduate and graduate education is more costly at private than at public HEIs **scale and scope effects** - economies of scale for both private and public HEIs - economies of scope between undergraduate education, graduate education and research for both private and public HEIs → comprehensive US universities can realise benefits from both scale and scope economies
Izadi et al. (2002)	- 99 British and Northern Ireland universities (1994-1995) - university-level (typical universities, arts based universities, and science based universities) - CES cost function - Stochastic Frontier Analysis	**inputs** - total university expenditures **outputs** - undergraduate student load in the arts and sciences, postgraduate student load, amount of research funds	**cost structure** - arts undergraduate education is cheaper than science undergraduate education - postgraduate education is the most expensive output **scale and scope effects** - economies of scale for typical and arts based universities, diseconomies of scale for science based universities - diseconomies of scope between undergraduate education, postgraduate education and research for all types of universities

Table 1: continued

Study	Sample, level and estimation approach	Variables of interest	Selected results
Laband and Lentz (2003)	- 1492 private and 1450 public US HEIs (1995-1996) - university-level - flexible fixed cost quadratic function - Ordinary Least Squares	**inputs** - total university expenditures - average faculty salary is used as an input price **outputs** - undergraduate and graduate FTE enrolment, amount of research funds	**cost structure** - undergraduate education is cheaper than graduate education at public HEIs, while it is more costly at private HEIs - research is more costly at private HEIs **scale and scope effects** - economies of scale for public and private HEIs at all output levels - economies of scope between teaching and research for public HEIs at all output levels - economies of scope between teaching and research for private HEIs at the output means - diseconomies of scope between graduate education and the other outputs for private HEIs with output expansion beyond the output means, and between all outputs for very large private HEIs
Bonaccorsi et al. (2006)	- 45 Italian universities (1995-1999) - university-level - Order-m (non-parametric frontier analysis technique)	**inputs** - total university expenditures, number of places in the lecture-halls, sum of professors and researchers, number of administrative and technical staff **outputs** - total number of graduates, number of publications and citations based on Information-Science-Institute (ISI) data	**scale and scope effects** - no scale effects for research efficiency - no scope effects for teaching efficiency → being big and diversified is not necessarily good at the university level → economies of scale and scope are not the most important drivers of efficiency in HEIs
Johnes and Salas-Valesco (2007)	- 26 Spanish universities (1998, 2000, 2002, 2004) - discipline-level (non-sciences and sciences) - quadratic cost function - Stochastic Frontier Analysis	**inputs** - expenditure per undergraduate student multiplied by the number of undergraduate students **outputs** - number of non-science and science undergraduate students, number of postgraduate students, amount of research funds	**cost structure** - non-science undergraduate education is cheaper than science undergraduate education - postgraduate education is the most expensive output **scale and scope effects** - economies of scale at the output means - diseconomies of scope at the output means → cost savings can be realised by increasing the degree of specialisation of Spanish universities

Table 1: continued

Study	**Sample, level and estimation approach**	**Variables of interest**	**Selected results**
Agasisti and Johnes (2010)	- 57 public Italian universities (2001-2002 through 2003-2004) - discipline-level (non-sciences and sciences) - quadratic cost function - Stochastic Frontier Analysis	**inputs** - current annual university expenditures excl. capital costs and depreciation **outputs** - number of non-science and science undergraduate students, number of doctoral students, amount of research funds	**cost structure** - non-science undergraduate education is cheaper than science undergraduate education - doctoral education is the most expensive output - teaching is more costly than research **scale and scope effects** - diseconomies of scale at the output means and with output expansion beyond the output means - economies of scope for all outputs, but product-specific diseconomies of scope for each output at all output levels → Italian universities are too big: cost savings can be realised by splitting (some of) them up into smaller units and by increasing the degree of specialisation
Johnes and Schwarzenberger (2011)	- 72 public German universities (2002-03 through 2004-05) - discipline-level (non-sciences and sciences) - quadratic cost function - Stochastic Frontier Analysis	**inputs** - sum of annual personnel and other current university expenditures **outputs** - number of non-science and science students, number of doctoral students, amount of third-party funding	**cost structure** - considerable differences in the cost structure between the universities - non-science education is cheaper than science education - doctoral education is the most expensive teaching output **scale and scope effects** - product-specific economies of scale for each output at the output means - diseconomies of scope for all outputs at the output means → cost savings can be realised by increasing the degree of specialisation of German universities

(the non-sciences and the sciences), and doctoral education as proxies for the teaching output and the total amount of third-party funding as a proxy for the research output. Their findings indicate that (i) German universities are relatively efficient, but there are considerable differences in their cost structures; (ii) it is more costly to deliver science subjects than other subjects; (iii) doctoral education costs more than lower levels of higher education; (iv) there remain unexhausted economies of scale for all outputs; and (v) there are diseconomies of scope for all outputs. Johnes and Schwarzenberger (2011) thus conclude that cost savings can be realised by a greater degree of specialisation within the German higher education sector.

Given this overview on previous research three important issues for our analysis of scale and scope economies in German HEIs arise. The first and the most notable issue is that except for Bonaccorsi et al. (2006) all studies have employed a cost function approach, which relies on the assumption of cost-minimisation on the basis of observed market input prices. As publicly financed higher education is non-profit by its very nature, there is most often a lack of available price information on many of its inputs and outputs. But most crucially, it seems questionable whether such a market-based cost-minimising behaviour actually holds true for the largely publicly funded and governmentally controlled German higher education sector (see e.g. Bowen, 1980; Deming, 2005; Ehrenberg, 2000). Following the strand of Stochastic Frontier Analysis, we therefore estimate an input distance function approach that does not use this assumption to measure economies of scale and scope for German HEIs.

Second, previous studies have shown the scale and scope effects vary across disciplines (e.g. Agasisti and Johnes, 2010; Dundar and Lewis, 1995; Johnes, 1997). In any case, disciplines substantially do differ from each other with respect to their resource endowment and major output targets, and thus, any analysis of scale and scope effects at the university level may lead to biased results. To account for this heterogeneity in higher education production, we use data at the discipline level and incorporate a broader range of inputs and outputs into our estimations.

Third, the German higher education system is quite diversified, comprising more than 400 officially recognised HEIs. Among them are universities, universities of applied sciences, and colleges of arts and music. Universities and the universities of applied sciences constitute the biggest percentage with more than 300 institutions and a total of 2.1 million student enrolments (for Winter semester 2010/2011, Federal Statistical Office, 2011). Universities usually offer a broad range of programmes in all subjects and have always been expected to teach methodological and theoretical knowledge and conduct basic research, both venues closely interlinked and following the Humboldtian principal. By contrast, German universities of applied sciences were established in 1968 as a new type of university with the institutional mission of more praxis-oriented teaching and research that has strong links to industry. They mainly offer subjects in engineering and social sciences and, opposed to the universities, place a much stronger emphasis on teaching and cannot award doctoral degrees (Federal Ministry of Education and Research, 2004).

Recently, the German Council of Science and Humanities, however, pointed out that the clear distinction between the missions of universities and the universities of applied sciences—a distinction originally mandated by the German Federal Legislature—is increasingly disappearing (Wissenschaftsrat, 2010*a*). The council instead emphasised the harmonisation of these HEIs and argued that both types of universities were obliged to follow the Bologna agreement of 1999 and to create new bachelors and masters degrees. As a result, German universities and universities of applied sciences now offer formally equalised degrees for professionally qualifying bachelors programmes and also research-oriented and research-applied masters programmes. Further, the enlargement of autonomy has affected both types of universities in the same way; universities and universities of applied sciences have become more autonomous in terms of determining their own specific teaching and research profiles (Wissenschaftsrat, 2010*a*).

Moreover, it is questionable to adhere to the historic view that universities of applied sciences are mostly involved in teaching. In fact, universities of applied sciences are increasingly mandated by the *Länder* legislations to conduct research (Wissenschaftsrat, 2010*b*). The German Federal Ministry of Education and Research affirms that applied research has become a second outstanding feature of German universities of applied sciences over the past 15 years, alongside their practice-based teaching (Federal Ministry of Education and Research, 2011). Nevertheless, the total amount of third-party funding required by universities of applied sciences is still less than those of their counterparts (Wissenschaftsrat, 2010*b*).

Given the recent developments in the German higher education sector, we argue that today both universities and universities of applied sciences act in a common higher education market, competing for students, academic personnel and research funding in the same manner. As Johnes and Schwarzenberger (2011) limit their analyses only to publicly financed German universities, we extend the previous research on Germany and include not only universities, but also universities of applied sciences, in the following analysis.

4 Methodology

To analyse the efficiency and the economies of scale and scope in German HEIs, we apply an input distance function approach. In contrast to a traditional cost function approach, the input distance function approach does not rely on a cost-minimisation assumption on the basis of observed market input prices. Rather, the input distance function approach assumes a shadow cost-minimising behaviour, where the decision-making units minimise their costs relative to unobserved input shadow prices. This approach is particularly suitable for industries or sectors where market input prices are difficult to obtain and market-based cost-minimisation behaviour is likely to be violated as in the governmentally controlled and largely publicly funded German higher education sector (Hajargasht et al., 2008).

By modelling a production technology as an input distance function, we investigate how much the input vector can be proportionally reduced while holding the output vector fixed. Following Coelli et al. (2005), we thus define the input distance function as:

$$D_I(x,y) = \max\{\theta : (x/\theta) \in L(y)\}, \tag{1}$$

where $L(y)$ represents the set of all non-negative input vectors $x = (x_1, ..., x_K) \in \mathbb{R}^K_+$ that can produce the non-negative output vector $y = (y_1, ..., y_M) \in \mathbb{R}^M_+$; and θ measures the proportional reduction of the input vector x. The function is homogeneous of degree one in inputs and satisfies the economic regularity conditions of monotonicity, concavity and quasi-concavity, that is, the function is non-decreasing and concave in inputs and non-increasing and quasi-concave in outputs (Färe and Primont, 1995).

From $x \in L(y)$, $D_I(x,y) \geq 1$ follows. A value equal to 1 identifies the respective input vector x as being fully efficient and located on the frontier of the input set. Values greater than 1 belong to inefficient input vectors above the frontier. This concept is closely related to Farell's (1957) measure of input-oriented technical efficiency, which can be calculated by the reciprocal of the input distance function:

$$TE(x,y) = 1/D_I(x,y) \leq 1. \tag{2}$$

Technical efficiency values equal to 1 identify efficient universities using an input vector located on the production frontier. Technical efficiency values between 0 and 1 belong to inefficient universities using an input vector above the frontier.

To estimate the input distance function we adopt a translog (transcendental-logarithmic) functional form. Unlike a Cobb-Douglas form, which assumes the same production elasticities, the same scale elasticities, and a substitution elasticity equal to 1 for all universities, the translog does not impose such restrictions, so it is more flexible (Coelli et al., 2005).

The translog input distance function for K $(k = 1, ..., K)$ inputs and M $(m = 1, ..., M)$ outputs can be written as

$$\begin{aligned} ln\, D^I_{it} = \alpha &+ \sum_{k=1}^{K} \alpha_k\, ln\, x_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \alpha_{kl}\, ln\, x_{kit}\, ln\, x_{lit} + \sum_{m=1}^{M} \beta_m\, ln\, y_{mit} \\ &+ \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \beta_{mn}\, ln\, y_{mit}\, ln\, y_{nit} + \sum_{k=1}^{K}\sum_{m=1}^{M} \gamma_{km}\, ln\, x_{kit}\, ln\, y_{mit} \\ &+ \theta_t\, t + \frac{1}{2}\theta_{tt}\, t^2 \end{aligned} \tag{3}$$

where the subscripts i and t denote the university and year, respectively; D^I_{it} is the input distance term; x_{kit} and y_{mit} denote the input and output quantity, respectively; $t = 1, ..., T$ is a time trend; and $\alpha, \beta, \gamma, \theta$ are unknown parameters to be estimated.

For the theoretical conditions of symmetry and linear homogeneity in inputs to be guaranteed, several linear restrictions must hold for the input distance function. Symmetry requires the restrictions

$$\alpha_{kl} = \alpha_{lk}, (k, l = 1, 2, ..., K) \quad \text{and} \quad \beta_{mn} = \beta_{nm}, (m, n = 1, 2, ..., M), \tag{4}$$

and linear homogeneity in inputs is given if

$$\sum_{k=1}^{K} \alpha_k = 1, \quad \sum_{l=1}^{K} \alpha_{kl} = 0, \quad \text{and} \quad \sum_{k=1}^{K} \gamma_{km} = 0. \tag{5}$$

In order to estimate the translog input distance function, we apply Stochastic Frontier Analysis. Compared to other benchmarking methods, such as Data Envelopment Analysis, the main advantage of Stochastic Frontier Analysis is that it accounts for measurement errors and other random factors by using a two-part error term that allows the separation of statistical noise from university-specific inefficiency. In particular, we employ the true random effects (TRE) model that Greene (2005*a*,*b*) proposes. In contrast to conventional stochastic frontier models for panel data, the TRE model accounts for unobserved heterogeneity by adding a random term that both captures and separates the time-invariant university-specific unobserved heterogeneity from time-varying inefficiency.

Imposing the homogeneity restrictions in Equation 5 by normalising the translog input distance function in Equation 3 by one of the inputs (Lovell et al., 1994), we define the TRE model as

$$\begin{aligned} -ln\, x_{Kit} = \alpha_i &+ \sum_{k=1}^{K-1} \alpha_k\, ln \left(\frac{x_{kit}}{x_{Kit}}\right) \\ &+ \frac{1}{2} \sum_{k=1}^{K-1} \sum_{l=1}^{K-1} \alpha_{kl}\, ln \left(\frac{x_{kit}}{x_{Kit}}\right) ln \left(\frac{x_{lit}}{x_{Kit}}\right) \\ &+ \sum_{m=1}^{M} \beta_m\, ln\, y_{mit} + \frac{1}{2} \sum_{m=1}^{M} \sum_{n=1}^{M} \beta_{mn}\, ln\, y_{mit}\, ln\, y_{nit} \\ &+ \sum_{k=1}^{K-1} \sum_{m=1}^{M} \gamma_{km}\, ln \left(\frac{x_{kit}}{x_{Kit}}\right) ln\, y_{mit} + \theta_t\, t + \frac{1}{2}\theta_{tt}\, t^2 \\ &+ v_{it} - u_{it}, \end{aligned} \tag{6}$$

where $\alpha_i = \alpha + w_i$ represents a normally distributed university-specific random term that accounts for university-specific characteristics not captured by the included variables ($w_i \sim iid\, N\,(0, \sigma_w^2)$); v_{it} is a normally distributed random error term ($v_{it} \sim iid\, N(0, \sigma_v^2)$); and $u_{it} = -ln\, D_{it}^I$ is a half-normally distributed random term assumed to represent time-varying university-specific inefficiency ($u_i \sim iid\, N^+\,(0, \sigma_u^2)$).

The parameter estimates of the TRE model are obtained by applying Bayesian estimation techniques. Introduced by Van den Broeck et al. (1994), Bayesian estimation of stochastic frontier models allows to impose the regularity conditions of monotonicity, concavity and quasi-concavity directly in the estimation process and provides estimated standard deviations of the scale and scope economies (Hajargasht et al., 2008).[10]

[10] A more comprehensive Bayesian stochastic frontier model with both a random intercept and random slope parameters was introduced by Tsionas (2002). However, this random coefficient model requires

To build a Bayesian structure for the TRE model defined in Equation 6 we need to define prior distributions for all unknown parameters α, β, γ, θ, σ_w^{-2}, σ_v^{-2}, and σ_u^{-2}. We assume α, β, γ, and θ to be normally distributed with mean zero and diffuse Gamma(0.001,0.001) priors for their precisions σ^{-2}. The regularity conditions of monotonicity and concavity are imposed by adding indicator functions to the prior distributions of α, β, and γ that equal 1 if the estimates meet the conditions and 0 otherwise.[11] The precisions of the university-specific random term (σ_w^{-2}) and the random error term (σ_v^{-2}) are defined through diffuse gamma distributions with small values for the scale and shape parameters, Gamma(0.001,0.001). For the prior distribution of the inefficiency precision (σ_u^{-2}) we choose a gamma distribution (a_0, a_1) with $a_0 = 5$ and $a_1 = 5 \times \log(r^*)^2$, where r^* represents a prior median efficiency (cp. Widmer et al., 2010; Griffin and Steel, 2007). The prior median efficiency is set at 0.94, based on the efficiency results of a preceding classical maximum-likelihood estimation of the model. Finally, the annual university-specific technical efficiency is calculated from the inefficiency terms, $r_{it} = exp(-u_{it})$.

We obtain the posterior statistics of the parameters by using the Markov chain Monte Carlo (MCMC) simulation methods. All model estimates are obtained by using WinBUGS and are based on WinBUGS codes provided by Griffin and Steel (2007). A total number of 30,000 MCMC iterations is used, with the first 10,000 discarded as burn-in iterations and a thinning factor of 2.

Once the input distance function has been estimated, we can use the parameter estimates to calculate economies of scale and scope. Expressed in terms of returns to scale (RTS), scale economies measure the responsiveness of cost to a proportional increase in all outputs. As Färe and Primont (1995) show, RTS can be calculated from the first-order derivatives of the translog input distance function with respect to outputs. That is, RTS are equal to the negative of the inverse of the sum of the output elasticities (ε_m):

$$RTS = -\left(1 \Big/ \sum_{m=1}^{M} \varepsilon_m\right) = -\left(1 \Big/ \sum_{m=1}^{M} \partial\, ln\, D^I / \partial\, ln\, y_m\right). \qquad (7)$$

Increasing RTS (economies of scale) are indicated by values greater than 1, whereas values lower than 1 indicate decreasing RTS (diseconomies of scale).

Economies of scope arise when the costs of producing a specific output vector Y jointly are lower than the costs of producing the same output vector separately (Baumol et al., 1988). In order to calculate economies of scope in an input distance function framework, we follow Hajargasht et al. (2008). By using duality theory, the authors show that based

a large dataset to deliver meaningful results. For our dataset a random coefficient specification results in some rather unreliable parameter estimates. Therefore, we stick to the simpler TRE specification with just the intercept being randomised. See, for example, Schmidt et al. (2009) or Yan et al. (2009) for other applications of the TRE model within a Bayesian framework.

[11] The inclusion of additional constraints to impose quasi-concavity in outputs has led to difficulties in model convergence (see Griffin and Steel, 2007). Therefore, we did not include these constraints directly in the estimation process.

on the first- and second-order derivatives of an input distance function, a measure for scope economies between two outputs i and j can be defined as

$$Scope_{ij} = \frac{\partial D}{\partial y_i}\frac{\partial D}{\partial y_j} - \frac{\partial^2 D}{\partial y_i \partial y_j} + \begin{bmatrix} \frac{\partial^2 D}{\partial y_i \partial x_1} & \cdots & \frac{\partial^2 D}{\partial y_i \partial x_n} \end{bmatrix} \times$$
$$\begin{bmatrix} \frac{\partial^2 D}{\partial x_1^2} + \frac{\partial D}{\partial x_1}\frac{\partial D}{\partial x_1} & \cdots & \frac{\partial^2 D}{\partial x_1 \partial_n} + \frac{\partial D}{\partial x_1}\frac{\partial D}{\partial x_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial^2 D}{\partial x_n \partial x_1} + \frac{\partial D}{\partial x_n}\frac{\partial D}{\partial x_1} & \cdots & \frac{\partial^2 D}{\partial x_n^2} + \frac{\partial D}{\partial x_n}\frac{\partial D}{\partial x_n} \end{bmatrix}^{-1} \times \begin{bmatrix} \frac{\partial^2 D}{\partial x_1 \partial y_j} \\ \vdots \\ \frac{\partial^2 D}{\partial x_n \partial y_j} \end{bmatrix}. \tag{8}$$

Negative values indicate economies of scope and positive values indicate diseconomies of scope.

5 Data

The dataset used is an unbalanced panel based on several higher education statistics from the Federal Statistical Office in Germany. It comprises detailed information on 74 public German universities and 80 public German universities of applied sciences (*Fachhochschulen*) on the level of scientific fields for 2001, 2003, 2005 and 2007.[12]

In common with previous efficiency studies on higher education (see Table 1 in Section 3), we use the following input and output variables for our analysis.[13] We use two input measures, that is, the operating expenditures and the personal expenditures. The operating expenditures cover e.g. rentals and leases, building and property maintenance, consumables and technical equipment. Personal expenditures include current expenditures, for both academic personnel (professors, assistant and associate professors, research assistants) and non-academic personnel (technical and administrative staff); pension payments are not included.

As stated in Section 2, universities are multi-output organisations producing a variety of different outputs. To represent the teaching output of HEIs, we use the number of undergraduate and graduate students enroled in bachelors and masters programmes as well as those enroled in diploma programmes, the former German degree that is comparable to a masters degree. As the number of students being educated is what influences costs (Agasisti and Johnes, 2010), we prefer using this measure rather than the number of graduates. Moreover, using the number of graduates would ignore the fact that in general student human capital already increases during the studies before degree completion (Carrington et al., 2004). Thus, only counting the number of graduates does not reflect the outcome of the teaching effort at large, but neglects any human capital

[12]We excluded all HEIs offering human and veterinary medicine due to a lack of clear statistical classification. We also excluded all HEIs that are exclusively oriented to theology and administrative sciences or to the fine arts and music.

[13]A detailed discussion on appropriate input and output measures in the higher education sector is given e.g. by Carrington et al. (2004) and Abbott and Doucouliagos (2003).

gains of students without a final degree completion. Finally, when using graduates as an output measure one has to control for student quality, because the success of degree completion heavily depends on each individual student's beginning knowledge and individual effort. A relatively good quality indicator for this is a tertiary entrance test score often used in analyses of HEIs in Anglo-Saxon countries (Carrington et al., 2004). Unfortunately, similar to other inputs and outputs, such quality indicators are highly rare or even totally unavailable for the German higher education sector.

Referring to research activities, the total amount of external third-party funds is used as an indicator of research output.[14] We consider the funds granted by research funding organisations such as the German Research Foundation (*Deutsche Forschungsgemeinschaft*), the European Union, other non-profit organisations, private foundations and the business and industry sectors. This output measure is preferable to data on publications, e.g. the number of publications or the number of citations, for two reasons: First, third-party funding is assumed to be a good measure of the 'market value' of a HEI's research activities, that is, the signalling of reputation and quality in the field of scientific research (see e.g. Harman, 2000; Johnes, 1997). The acquisition of external third-party funds follows a successful researcher's track record, and may, therefore, be considered as a 'quality adjusted measure' of the actual research conducted (Johnes and Salas-Valesco, 2007). Second, in Germany, the amount of acquired third-party funding is one of the most important performance measure for research activities used by the *Länder*'s and the universities' resource allocation mechanisms. In fact, publications or citations are only rarely included in German funding models (Broemel et al., 2010).[15] [16]

Given the empirical evidence that higher education production differs across disciplines (see Table 1 in Section 3), the usage of corresponding output measures at the university-level would yield biased results. To account for any discipline-related heterogeneity, we therefore differentiate between output measures for teaching and research in the non-sciences and the sciences.[17] We aggregate the data on linguistics, cultural sciences, arts, sport and legal, economic and social sciences to non-science disciplines, and mathematics and natural sciences, engineering, agricultural, forestry and food sciences to science disciplines. This procedure results in four output variables that reflect both teaching and research activities: The total number of non-science students, the total number of science students, the research funding for the non-sciences, and the research funding for the sciences.

[14]Because the data on the personal expenditures includes also expenditures for doctoral (PhD) students employed as teaching and research assistants, we did not consider the number of doctoral students as a proxy for the research output to avoid any biases due to double counting as both input and output.

[15]For more details on using the number of publications or the number of citations as output variables and its related problems, see e.g. Carrington et al. (2004).

[16]In addition to teaching and research activities HEIs also conduct third-mission activities such as entrepreneurial and political consultancy. Unfortunately, as there is no data available on this output category for German HEIs, we can not include third-mission activities in our analysis.

[17]A lower disaggregation level probably causes problems of multicollinearity between the input and output variables for different subjects (Johnes and Salas-Valesco, 2007).

The unbalanced panel dataset used for our estimations contains 288 observations for 72 universities and 300 observations for 80 universities of applied sciences for 2001, 2003, 2005 and 2007. Table 2 summarises the descriptive statistics of our input and output measures, differentiated between universities and the universities of applied sciences. All monetary values are displayed in thousand EURO and are deflated using the Consumer Price Index for Germany based on the benchmark year 2000 (German Council of Academic Experts, 2010).

Table 2: Descriptive statistics of input and output measures

Variable description	Variable	Mean	Median	Std.dev.	Min	Max
Universities (288 observations)						
Operating expenses (€'000)	X_{opex}	39,296	31,890	28,074	577	139,699
Personnel expenses (€'000)	X_{emp}	105,189	91,703	61,169	1,764	265,851
No. of non-science students	Y_{st_nsc}	10,985	9,514	8,368	152	46,441
No. of science students	Y_{st_sc}	5,924	4,948	4,229	6	19,561
Research funds (non-sciences) (€'000)	Y_{res_nsc}	5,160	3,880	4,426	1	23,484
Research funds (sciences) (€'000)	Y_{res_sc}	21,695	15,202	21,894	1	121,155
Universities of applied sciences (300 observations)						
Operating expenses (€'000)	X_{opex}	6,211	4,447	5,798	641	57,959
Personnel expenses (€'000)	X_{emp}	18,207	16,601	10,061	2,884	53,762
No. of non-science students	Y_{st_nsc}	2,318	1,915	1,408	316	7,933
No. of science students	Y_{st_sc}	2,781	2,437	1,962	172	10,148
Research funds (non-sciences) (€'000)	Y_{res_nsc}	318	185	362	1	2,486
Research funds (sciences) (€'000)	Y_{res_sc}	939	626	956	0.5	7,471

Source: German Federal Statistical Office (2001-2007).

Despite the trend of harmonisation between universities and universities of applied sciences observed in the higher education sector during the last decade, some fairly institutional heterogeneity yet exists. The descriptive statistics on the input and output variables, reported in Table 2, reveal marked differences both between and within the universities and the universities of applied sciences, as indicated by the standard deviation and minimum and maximum values. On average, the amount of personal expenditures is more than five times higher for universities than for universities of applied sciences. Proportionately, the difference in average operating expenditures is even higher. The amount of third-party funds also differs considerably with an essentially higher amount for universities than for their counterparts. However, for both types of universities, the average third-party funds are higher for the sciences than for the non-sciences, which reflect the fact that research in science disciplines due to equipment needs is more costly than it is in non-science disciplines.[18]

[18]For example, with more than 20,000,000 €, Humboldt University of Berlin along with Freie University Berlin belong to those HEIs with the highest amount of third-party funding in the non-sciences.

Reviewing the descriptive statistics on student enrolments presented in Table 2, the average number of students enrolled in the non-sciences (sciences) emerge as four (two) times higher for universities than the respective average number for the universities of applied sciences.[19] In addition, whereas the average number of non-science and science students is nearly equal for the universities of applied sciences, the average student enrolment in non-science disciplines is nearly twice as high as for the science disciplines at universities. This observation is not surprising because the majority of non-science disciplines are offered by universities.

6 Results

The estimated posterior means and standard deviations for the parameters of the input distance function are presented in Table 3. As each variable is normalised by its sample median, the estimates can be interpreted as elasticities at the sample median HEI. All first-order estimates are statistically significant at the 1 per cent level and have the expected signs. In other words, the estimated input distance function is decreasing in outputs and increasing in inputs. The estimated input elasticity for personnel expenses (α_1) is equal to 0.959. This value reflects the labour-intensive higher education production process. The output elasticities β_1 equal to -0.179, β_2 equal to -0.247, β_3 equal to -0.036, and β_4 equal to -0.061 indicate that teaching requires more inputs than does research.[20] Further, they show that teaching and research in the sciences require more inputs than will teaching and research in the non-sciences. Referring to the time perspective then, the first-order estimate of time (θ_t) is 0.018. This value indicates a rate of technical progress of about 1.8 per cent for the sample median HEI in the mid-year of the sample. Finally, the estimated values for λ_a, λ_v, and λ_u show that about 97 per cent of total variations in inputs is due to heterogeneity, about 2.3 per cent is due to inefficiency and only about 0.6 per cent is due to noise.

Thereby, RWTH Aachen University and the Technical University of Munich show the highest amount of science-related, third-party funding with more than of 100,000,000 €. That amount is five times higher than the respective maximum value for third-party funding in the non-sciences.

[19] The largest universities with respect to the non-sciences and the sciences, respectively, are the University of Cologne with more than 30,000 students enroled in the non-sciences and the RWTH Aachen University with more than 20,000 students enroled in the sciences. The smallest university with respect to the non-sciences is the International Graduate School (IHI) Zittau with less than 200 student enrolments in the non-sciences, while the smallest universities with respect to the sciences is the University of Erfurt with less than 30 students enrolments in the sciences. Among the universities of applied sciences the Cologne University of Applied Sciences is the biggest institution for both the non-sciences and the sciences with a student enrolment of about 8,000 in the non-sciences and nearly 10,000 in the sciences. The smallest university of applied sciences with respect to the non-sciences is the Biberach University of Applied Sciences with less than 350 students enroled in the non-sciences, while the smallest university of applied sciences with respect to the sciences is the Westcoast University of Applied Sciences with 300 students enroled in the sciences.

[20] In Germany, an essential extent of research is conducted not only at HEIs but also at non-university research institutions, such as institutions of the Max Planck Society, the Frauenhofer Society, or the Leibniz Association. This fact may explain that we find research to be less costly than teaching which is opposite to findings in the US or the UK (see Section 3).

Table 3: Bayesian estimation results of the input distance function[a,b,c]

Variable	Parameter	Mean	Std. dev.	Variable	Parameter	Mean	Std. dev.
X_{emp}	α_1	0.959	0.012	$Y_{st\_sc}Y_{res\_sc}$	β_{24}	0.003	0.005
X_{emp}^2	α_{11}	−0.002	0.005	$Y_{res\_nsc}Y_{res\_sc}$	β_{34}	−0.003	0.002
Y_{st_nsc}	β_1	−0.179	0.020	$X_{emp}Y_{st\_nsc}$	γ_{11}	0.003	0.007
Y_{st_sc}	β_2	−0.247	0.033	$X_{emp}Y_{st\_sc}$	γ_{12}	0.006	0.008
Y_{res_nsc}	β_3	−0.036	0.007	$X_{emp}Y_{res\_nsc}$	γ_{13}	−0.001	0.003
Y_{res_sc}	β_4	−0.061	0.011	$X_{emp}Y_{res\_sc}$	γ_{14}	−0.003	0.003
$Y_{st\_nsc}^2$	β_{11}	−0.040	0.014	T	θ_t	0.018	0.004
$Y_{st\_sc}^2$	β_{22}	−0.027	0.009	T^2	θ_{tt}	0.016	0.007
$Y_{res\_nsc}^2$	β_{33}	−0.003	0.002	$Sigma_a^2$	σ_a^2	0.354	0.071
$Y_{res\_sc}^2$	β_{44}	−0.007	0.002	$Sigma_v^2$	σ_v^2	0.002	0.001
$Y_{st\_nsc}Y_{st\_sc}$	β_{12}	0.075	0.014	$Sigma_u^2$	σ_u^2	0.008	0.003
$Y_{st\_nsc}Y_{res\_nsc}$	β_{13}	−0.005	0.004	$Lambda_a$	$\lambda_a = \sigma_a^2/\sigma^2$	0.971	0.008
$Y_{st\_nsc}Y_{res\_sc}$	β_{14}	0.003	0.006	$Lambda_v$	$\lambda_v = \sigma_v^2/\sigma^2$	0.006	0.009
$Y_{st\_sc}Y_{res\_nsc}$	β_{23}	0.010	0.005	$Lambda_u$	$\lambda_u = \sigma_u^2/\sigma^2$	0.023	0.003

[a]All variables are in natural logarithm and are normalized by their sample median.[b]The dependent variable is $-ln\, X_{opex}$.[c]All model estimates are obtained by using WinBUGS.

The results for scale and scope economies, differentiated by type of university and size, are presented in Table 4. The institutional heterogeneity reported by the descriptive statistics in the data section (see Section 5) indicates the usefulness of studying the scale and scope effects of German HEIs by differentiating between the types of institutions and their sizes in terms of student enrolments: First, referring to returns to scale (Column 3) the value of 1.922, which is greater than 1, indicates fairly high increasing returns to scale at the sample median HEI. The result is statistically significant at the 1 per cent level. Second, evaluating the returns to scale at the university level provides similar results. The median values of the returns to scale are 2.116 for the universities and 1.803 for the universities of applied sciences, respectively. Third, we observe that scale economies increase with size both for the universities and the universities of applied sciences. This result suggests that scale economies are not exhausted by far in the German higher education sector.

The remaining columns in Table 4 show our results for the economies of scope for (i) teaching in the non-sciences and the sciences (Column 4); (ii) research in the non-sciences and the sciences (Column 5); (iii) teaching and research within the non-sciences (Column 6); and (iv) teaching and research within the sciences (Column 7). Except for the last, all scope measures at the sample median are statistically significant at the 5 per cent level. Economies of scope are found for joint teaching in the non-sciences and the sciences, while all other measures suggest diseconomies of scope. The institutional- and size-related results show a similar pattern. The sample median value of −0.031 for joint teaching in the non-sciences and the sciences (Column 4) suggests that a 10 per cent

Table 4: Returns to scale and economies of scope[a]

	N	RTS	Teaching (Nsc/Sc)	Research (Nsc/Sc)	Non-Sciences (Teach/Res)	Sciences (Teach/Res)
At the sample median	588	1.922	−0.031	0.006	0.012	0.013
Standard deviation		0.169	0.013	0.003	0.005	0.008
Institution-related median values						
Universities	288	2.116	−0.009	0.000	0.001	0.001
Universities of appl. sciences	300	1.803	−0.066	0.065	0.083	0.048
Institution-related median values by size						
Universities						
Large	118	2.340	−0.004	0.000	0.000	0.000
Medium-sized	134	2.011	−0.013	0.000	0.002	0.002
Small	36	1.643	−0.081	0.004	0.072	0.010
Universities of applied sciences						
Large	2	2.324	−0.007	0.003	0.002	0.002
Medium-sized	118	1.963	−0.033	0.029	0.026	0.013
Small	180	1.712	−0.116	0.130	0.162	0.111

[a]Large HEIs are defined as having more than 17,250 students, medium-sized HEIs as having between 5,000 and 17,250 students and small HEIs as having fewer than 5,000 students.

increase in teaching activities in the non-sciences reduces the marginal costs of teaching in the sciences by 0.31 per cent. This value is rather low. However, for small institutions, we observe higher values for scope economies, that is, −0.081 for small universities and −0.116 for the small universities of applied sciences.

For the remaining output combinations, the relatively small positive values indicate rather marginal diseconomies of scope at the sample median (Columns 5-7). Further, for universities, the median values and many of the median values by size are close to 0, indicating neither economies of scope nor diseconomies of scope. In contrast, the median values for small and to a lesser extent the medium-sized universities of applied sciences suggest meaningful diseconomies of scope. For example, a value of 0.162 for the small universities of applied sciences regarding joint production of teaching and research in the non-sciences (Column 6) suggests that a 10 per cent increase in teaching activities increases the marginal costs of research activities by 1.6 per cent. The respective median value of 0.130 indicates a similar effect for the joint production of research in the non-sciences and the sciences (Column 5).

Finally, Table 5 presents the estimated efficiency scores for German HEIs. As a value of 1 implies 100% efficiency, high average and median efficiency values of around 0.94 for both universities and the universities of applied sciences indicate that German HEIs are relatively efficient. Nevertheless, there are potentials for efficiency improvements. On average, the same output quantity could have been produced with a reduced input usage of about 6 per cent. Further, the minimum values of 0.829 for universities and 0.695 for the universities of applied sciences show that for some institutions, a considerable input reduction of up to 30 per cent is necessary for them to become efficient.

Table 5: Efficiency scores[a]

	N	Mean	Median	Std. dev.	Min	Max
Institutional related efficiency values						
Universities	288	0.935	0.943	0.030	0.829	0.983
Universities of applied sciences	300	0.933	0.943	0.039	0.695	0.987
Institutional related efficiency values by size						
Universities						
Large	118	0.937	0.946	0.030	0.829	0.983
Medium-sized	134	0.934	0.941	0.027	0.841	0.977
Small	36	0.929	0.938	0.037	0.836	0.975
Universities of applied sciences						
Large	2	0.957	0.957	0.007	0.952	0.962
Medium-sized	118	0.931	0.945	0.042	0.750	0.987
Small	180	0.934	0.941	0.036	0.695	0.983

[a]Large HEIs are defined as having more than 17,250 students, medium-sized HEIs as having between 5,000 and 17,250 students and small HEIs as having fewer than 5,000 students.

7 Concluding discussion

This study is the first to apply a multi-product input distance function approach to explore the existence of economies of scale and scope in higher education production. We used a unique panel dataset of public 74 public German universities and 80 public German universities of applied sciences covering 2001-2007. During this period, the German higher education sector faced several major national and international reforms aimed at improvement of efficiency and enhancement of higher education competitiveness in Europe with the result that more autonomous HEIs increasingly developed strategies to differentiate themselves from their competitors. Thereby, one issue of differentiation, economically speaking, relates to the fact that HEIs as multi-product organisations can realise efficiency gains by exploiting economies of scale and scope in their production processes. To investigate the scale and scope effects in German HEIs, we based our estimations on a Bayesian stochastic frontier approach and used a TRE model that controls for unobserved heterogeneity.

For our analysis, we considered three main issues. First, we used a distance function approach instead of the more common cost function approach. The distance function approach is more appropriate for modelling the higher education production process because it does not require the pre-imposed assumption of cost-minimisation on the basis of observed market prices. Second, as financial endowment and major output targets are presumed to differ across disciplines, we accounted for the heterogeneity of disciplines. For our analysis, we differentiated between non-science and science disciplines. Third, given the recent reform processes taking place in the German higher education sector, the clear distinction between the two types of German HEIs is increasingly disappearing. For this reason, our analysis included both universities and universities of applied sciences.

Our results show the presence of increasing returns to scale for both types of institutions. This finding suggests that German HEIs are too small and that consolidation of these institutions would enhance the efficiency of higher education production in Germany. This result is reflected by a statement made by the German Council of Science and Humanities recently. The council highlighted the benefits of co-operations, networks, alliances, and mergers between universities and universities of applied sciences or other institutions as instruments to use to continuously differentiate themselves in the market (Wissenschaftsrat, 2010*b*).[21] However, while the council's experts admitted to the potential of consolidation processes for improving the overall performance of an institution, they also were concerned with the governability of large institutions and hence recommended consolidation processes in terms of co-operation and networks rather than actual mergers.

Referring to the scope effects, our results suggest slight economies of scope for joint teaching in the non-sciences and the sciences: HEIs can improve their efficiency by e.g., providing joint lectures, such as lectures in applied statistics or mathematics, and using facilities, such as libraries or personnel, jointly for both non-science and science students. However, the values for the estimated scope economies except those for small institutions are relatively small.

By contrast, especially for small and to a lesser extent for medium-sized universities of applied sciences, we observe meaningful diseconomies of scope for joint research activities in the non-sciences and the sciences, joint teaching and research activities in the non-sciences and joint teaching and research activities in the sciences. These results indicate especially for the small universities of applied sciences a potential to improve efficiency by specialising in higher education production. Referring to joint teaching and research in both scientific fields, small universities of applied sciences should specialise either in teaching or research rather than in a mixture of teaching and research activities. Further, if they conduct research activities, they should concentrate on a single scientific field, either in the non-sciences or the sciences. These findings generally support the recommendation of the German Council of Science and Humanities, which has encouraged universities of applied sciences to strengthen their institutional profile through more specialisation (Wissenschaftsrat, 2010*b*).

Opposed to the findings for especially small universities of applied sciences, our results for the large universities show no diseconomies of scope between any mixture of teaching and research activities in the non-sciences and the sciences, thus supporting the strategy of being a full university with a combination of teaching and research activities across a broad field of subjects. Again, this finding is in line with the recommendations of the German Council of Science and Humanities. The council generally emphasises the German model of unity of teaching and research and militates against the model of a 'world class university' only oriented toward excellence in research. Instead of splitting up the university sector into purely teaching and research institutions, the stratification of the university sector should likewise include internal differentiation, that is, a prioritisation in teaching, postgraduate education, knowledge transfer, or internationalisation in each case, depending on the unique institutional profile (Wissenschaftsrat, 2010*b*). In

[21] Corresponding examples are the Karlsruhe Institute of Technology, Leuphana University Lüneburg and Hafen City University of Hamburg.

other words, the council acknowledges that some of the universities will become leading institutions in research, while others become leaders according to other specific internal differentiation aspects, and the majority of universities follow the Humboldtian principal of the unity of teaching and research.

Furthermore, although the efficiency values reveal differences across the German HEIs, the estimates confirm that both universities and the universities of applied sciences operate quite efficiently. However, there is still room to improve their efficiency in the production process.

Overall, this analysis empirically fortifies some of the main recommendations recently formulated by the German Council of Science and Humanities with respect to the differentiation of the higher education sector in Germany. Our results suggest that German HEIs should try to increase their scale of operations. Hereby, large universities should follow the concept of a full university, taking on both teaching and research activities in a broad field of subjects, whereas in particular small universities of applied sciences should specialise in the teaching or research activities they conduct. However, our analysis also reveals a still existing institutional heterogeneity between universities and the universities of applied sciences.

Given the relatively short period of our analysis, further research based on more recent data for German HEIs may reflect more current developments in the German higher education sector, such as the convergence of the universities and the universities of applied sciences. Further, it should be kept in mind that our analysis is solely based on the view of technical efficiency in higher education production and hence does not provide any information on the relationship between efficiency and quality. Due to a lack of that data, we were not able to incorporate the issue of quality into our analysis. Therefore, further research would benefit from including variables that address the quality aspect in higher education production. Given the multi-product characteristic of higher education and the increasing effort of HEIs to horizontally or vertically differentiate themselves in the market, further research on German HEIs could shed more light on other potential economies of scope by considering additional outputs, such as undergraduate, graduate and doctoral education or third- mission activities. Finally, this study could be transferred to other European countries to provide more encompassing evidence for scale and scope effects in the entire European higher education sector.

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Leuphana Universität Lüneburg
Institut für Volkswirtschaftslehre
Postfach 2440
D-21314 Lüneburg
Tel.: ++49 4131 677 2321
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