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

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Abstract
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 (HEIs) to use their resources more efficiently. HEIs 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 HEIs, this article 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 HEIs 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 specialize in the teaching and research activities they conduct. (JEL codes: L25, I23, D24)

Keywords: higher education production, economies of scale and scope, technical efficiency, stochastic frontier analysis, input distance function

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 such as the implementation of New Public Management and the Bologna Reforms. New market– or quasi-market–like mechanisms have been introduced into the system (Teixeira et al. 2004) which fostered ‘marketization’ of the higher education sector.
European HEIs are increasingly encouraged to develop strategies that allow them to differentiate themselves horizontally or vertically from their competitors and to increase their efficiency based on their strengths and their institutional missions, for example, the provision of a broad vs. discipline-specific subject mix, provision of all vs. limited levels of undergraduate, graduate, and doctoral education, the provision of cutting-edge research vs. industry-oriented research, and in terms of ‘performance’ and ‘quality’ aspects signalling excellent teaching and research conditions (Bonaccorsi et al. 2006; Daraio et al. 2011).

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. As HEIs are multi-product organizations, an investigation of how those institutions can improve efficiency by exploiting economies of scale and scope is of high interest not only for policymakers but also for HEI managers. If such 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 improve their efficiency by concentrating on a small scale of operation and the production of only one specific output. Given economies of scale and scope, HEIs are assumed to develop specific strategies, allowing them to successfully position in different market segments by realizing efficiency gains in the production process. In other words, 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 realize efficiency gains by specializing in size, subject mix, programme range, or teaching and research activities.

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 (Cohn et al. 1989; Dundar and Lewis 1995; Johnes 1997; Koshal and Koshal 1999; Izadi et al. 2002; Agasisti and Johnes 2010). For Germany, there is only one noteworthy study by Johnes and Schwarzenberger (2011). However, these studies use a cost function approach that relies upon a cost-minimization 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-minimizing based on market prices is not an appropriate assumption in that sector.
(Bowen 1980; Ehrenberg 2000; Deming 2005), the results that rely on such an assumption should be interpreted carefully.

This article seeks to fill the gap in the previous research by analysing the efficiency and the existence of economies of scale and scope in two directions. First, we use an input distance function approach instead of the cost function approach applied in former studies. The input distance function approach is dual to a cost function approach, but it does not rely on a cost-minimization assumption on the basis of observed market input prices. Rather, this approach assumes a shadow cost-minimizing behaviour, where the decision-making units minimize their costs relative to unobserved input shadow prices.

Second, we extend the previous research for Germany by including not only universities, but also universities of applied sciences (Fachhochschulen), in our analysis. Given the recent reform processes undertaken in the German higher education sector, the historical distinction between the missions of universities and universities of applied sciences originally mandated by the German Federal Legislature is increasingly disappearing (German Council of Science and Humanities 2010b). Today, both types of universities are part of a common higher education market where they compete for students, academic personnel, and research funding in the similar manner.

For our analysis, we use an extensive and unique panel data set covering the period of 2001–2007. The data set includes 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 differentiated by disciplines, for 74 public German universities and 80 public German universities of applied sciences. Bayesian estimation techniques are applied to estimate a Stochastic Frontier Analysis input distance function model that accounts for unobserved heterogeneity and allows efficiency to vary over time.

The remainder of this article is organized as follows. Section 2 presents an overview of the previous research and discusses the critical issues to be considered for the estimation approach. Section 3 introduces the methodology, while Section 4 provides information on the data set used in this analysis. The results are presented in Section 5, followed by a concluding discussion in Section 6.

2 Previous research and estimation approach

A variety of studies have investigated economies of scale and scope in higher education production via a cost functions approach. A considerable contribution referring to HEIs as multi-product organizations 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 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 USA (De Groot et al. 1991; Dundar and Lewis 1995; Koshal and Koshal 1999; Laband and Lentz 2003). In particular, the studies’ results indicate that non-science subjects are less expensive than science subjects, undergraduate education is less expensive than graduate education, and HEIs with a medical school are more expensive than HEIs without a medical school.1 Further, the studies provide evidence on 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 are found between undergraduate education, graduate education, and research.

In more recent studies on higher education production for different European countries, the authors based their analyses on frontier analysis techniques (Izadi et al. 2002; Bonaccorsi et al. 2006; Johnes and Salas-Velasco 2007; Agasisti and Johnes 2010; Johnes and Schwarzenberger 2011). Following this approach, entities of interests are benchmarked relative to each other and the production frontier built by best-practice, that is, the HEIs using resources most efficiently. 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.2

Again, the results of those studies 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,

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1 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 A review of the advantages and shortcomings of different frontier analysis techniques is beyond the scope of this article. A detailed overview on this topic can be found e.g. in Fried et al. (2008).
such as the sciences and non-sciences, 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). 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 2002–2003 throughout 2004–2005. They use undergraduate education divided into two scientific areas (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 realized by a greater degree of specialization within the German university 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-minimization on the basis of observed market input prices. However, 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-minimizing behaviour actually holds true for the largely publicly funded and governmentally controlled German higher education sector (Bowen 1980; Ehrenberg 2000; Deming 2005). 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 that the scale and scope effects vary across disciplines (Dundar and Lewis 1995; Johnes 1997; Agasisti and Johnes 2010). In any case, disciplines substantially do differ from each other with respect to their resource endowment and major output targets. To account for this heterogeneity, we use data at the discipline level and differentiate between higher education production in the sciences and the non-sciences.

Third, the German higher education system is quite diversified, comprising more than 400 officially recognized 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; German 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 outputs closely interlinked and following the Humboldtian principle. 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 (German Council of Science and Humanities 2010a). The council instead emphasized the harmonization 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. Indeed, German universities and universities of applied sciences now offer formally equalized 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 (German Council of Science and Humanities 2010a).

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 (German Council of Science and Humanities 2010b). 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). 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 similar 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 our analysis.

3 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-minimization assumption on the basis of observed market input prices. Rather, the input distance function approach assumes a shadow cost-minimizing behaviour, where the decision-making units minimize 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-minimization 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 follows:

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

where $L(y)$ represents the set of all non-negative input vectors $x = (x_1, \ldots, x_K) \in \mathbb{R}_+^K$ that can produce the non-negative output vector $y = (y_1, \ldots, y_M) \in \mathbb{R}_+^K$; and $\theta$ 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 Farrell’s (1957) measure of input-oriented technical efficiency, which can be calculated by the reciprocal of the input distance function:

$$TE(x, y) = 1/D_I(x, y) \leq 1$$

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.
A cost function corresponding to the input distance function given in Equation (1) can be defined as follows:

\[ C(p, y) = \min_x \{ px : x \in L(y) \}, \tag{3} \]

where \( p = (p_1, \ldots, p_K) \in \mathbb{R}_+^K \) is a vector of input prices. Duality between the input distance function and the cost function can be expressed by:

\[ C(x, y) = \min_x \{ px : D_I(x, y) \} \geq 1, \tag{4} \]

since \( x \in L(y) \) if and only if \( D_I(x, y) \geq 1 \) (Atkinson et al. 2003). The Lagrangian and the first-order conditions for the minimization problem in Equation (4) are given as follows:

\[ L(x, y) = px + \lambda (1 - D_I(x, y)), \tag{5a} \]

\[ \frac{\partial L}{\partial x} = p - \lambda \frac{\partial D_I(x, y)}{\partial x} = 0, \tag{5b} \]

and

\[ \frac{\partial L}{\partial \lambda} = 1 - D_I(x, y) = 0, \tag{5c} \]

where \( \lambda \) is the Lagrangian multiplier. Following Shepard (1970) it can be shown that \( \lambda = C(x, y) \) at the optimum. In addition, applying the envelope theorem yields the following relationship between the derivatives of the input distance function with respect to inputs and the cost function (Färe and Primont 1995):

\[ \frac{\partial D_I(x, y)}{\partial x_k} = \frac{p_k}{C(p, y)} \tag{6a} \]

That is, the derivative of the input distance function with respect to a particular input \( k \) is equal to the cost-deflated shadow price of that input.

The shadow price may or may not be coincident with the market input price. Only in the case of equality between shadow and market prices the decision-making units minimize their costs relative to market prices.

Expressed in terms of log derivatives of the input distance function, Equation (6b) leads to:

\[ \varepsilon_k = \frac{\partial \ln D_I(x, y)}{\partial \ln x_k} = \frac{p_k x_k}{C(p, y)} = S_k \tag{6b} \]

where \( S_k \) denotes the cost share of the input \( k \).
Similarly, with respect to outputs, application of the envelope theorem yields the following expression for the log derivatives of the input distance function:

\[ \varepsilon_m = \frac{\partial \ln D_i(x, y)}{\partial \ln y_m} = - \frac{\partial \ln C(p, y)}{\partial \ln y_m}. \]  

(7)

Hence, the elasticity of the input distance function with respect to a particular output \( m \) is equal to the negative cost elasticity of that output (Färe and Primont 1995). 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 \( K(k = 1, \ldots, K) \) inputs and \( M(m = 1, \ldots, M) \) outputs can be written as

\[ \ln D_{it} = \alpha + \sum_{k=1}^{K} \alpha_k \ln x_{kit} + \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \alpha_k \alpha_l \ln x_{kit} \ln x_{lit} + \sum_{m=1}^{M} \beta_m \ln y_{mit} + \frac{1}{2} \sum_{m=1}^{M} \sum_{n=1}^{M} \beta_m \beta_n \ln y_{mit} \ln y_{nit} + \sum_{k=1}^{K} \sum_{m=1}^{M} \gamma_{km} \ln x_{kit} \ln y_{mit} + \theta_t t + \frac{1}{2} \theta_{tt} t^2 \]  

(8)

where the subscripts \( i \) and \( t \) denote the university and year, respectively; \( D_{it} \) is the input distance term; \( x_{kit} \) and \( y_{mit} \) denote the input and output quantity, respectively; \( t = 1, \ldots, T \) 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

\[ \alpha_{kl} = \alpha_{lk}, (k, l = 1, 2, \ldots, K) \text{ and } \beta_{mn} = \beta_{nm}, (m, n = 1, 2, \ldots, M), \]  

(9a)

and linear homogeneity in inputs is given if

\[ \sum_{k=1}^{K} \alpha_k = 1, \sum_{l=1}^{K} \alpha_{kl} = 0, \text{ and } \sum_{k=1}^{K} \gamma_{km} = 0. \]  

(9b)

3 It should be noted that a translog specification does not allow for zero values in the data. However, as the data set used in this study only includes observations with positive values for all considered inputs and outputs, this problem does not arise in our case.
In order to estimate the translog input distance function, we apply Stochastic Frontier Analysis. Compared with 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 (2005a,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 normalizing the translog input distance function in Equation (3) by one of the inputs (Lovell et al. 1994), we define the TRE model as

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

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 (\( w_i \sim iid N(0, \sigma^2_w) \)); \( v_{it} \) is a normally distributed random error term (\( v_{it} \sim iid N(0, \sigma^2_v) \)); and \( u_{it} = -\ln D_{it} \) is a half-normally distributed random term assumed to represent time-varying university-specific inefficiency (\( u_{it} \sim iid N^+(0, \sigma^2_u) \)).

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).4

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4 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 a large data set to deliver meaningful results. For our data set a random coefficient specification results in some rather unreliable parameter estimates. Therefore, we stick to the simpler TRE specification with just the intercept being
To build a Bayesian structure for the TRE model defined in Equation (6) we need to define prior distributions for all unknown parameters \( \alpha, \beta, \gamma, \theta, \sigma^{-2}_{\alpha}, \sigma^{-2}_{\beta}, \) and \( \sigma^{-2}_{\gamma}. \) We assume \( \alpha, \beta, \gamma, \) and \( \theta \) to be normally distributed with mean zero and diffuse Gamma\((0.001,0.001)\) priors for their precisions \( \sigma^{-2}. \) The regularity conditions of monotonicity and concavity are imposed by adding indicator functions to the prior distributions of \( \alpha, \beta, \) and \( \gamma \) that equal 1 if the estimates meet the conditions and 0 otherwise.\(^5\) The precisions of the university-specific random term \( \sigma^{-2}_{\omega} \) and the random error term \( \sigma^{-2}_{\nu} \) 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 \( \sigma^{-2}_{\mu} \) we choose a gamma distribution \( G(\alpha_0,\alpha_1) \) with \( \alpha_0 = 5 \) and \( \alpha_1 = 5 \times \log(r^*)^2, \) where \( r^* \) represents a prior median efficiency (cp. Griffin and Steel 2007; Widmer et al. 2010). The prior median efficiency is set at 0.94, based on the efficiency results of a preceding classical maximum-likelihood estimation 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 equi-proportional change in all outputs as a result of an equi-proportional change in all inputs. Following Baumol et al. (1988), RTS can be measured by the ratio of average to marginal cost (MC). Given Equation (7), this ratio can be calculated from the first-order derivatives of the translog input distance function with respect to outputs as follows:

\[
RTS = \frac{AC}{MC} = 1 - \sum_{m=1}^{M} \frac{\partial \ln C_{it}(p, y, t)}{\partial \ln y_{mit}} = -1 - \sum_{m=1}^{M} \frac{\partial \ln D^I_{it}(x, y, t)}{\partial \ln y_{mit}}.
\]
That is, RTS are equal to the negative of the inverse of the sum of the output elasticities. Increasing RTS (economies of scale) are indicated by values greater than 1, whereas values lower than 1 indicate decreasing RTS (diseconomies of scale).

According to Baumol et al. (1988), there are weak economies of scope if the costs of producing a specific output vector \(Y\) jointly (\(C(y)\)) are lower or equal to the costs of producing the same output vector separately (\(\sum_{m=1}^{M} C(y_m)\)). That is, if

\[
C(y) \leq \sum_{m=1}^{M} C(y_m).
\] (12)

Diseconomies of scope occur when that inequality is reversed.

Traditionally, this relationship is analysed within a cost function framework. However, as emphasized by Hajargasht et al. (2008), Equation (11) can not be verified when the cost function is defined in logarithmic terms. For such cases and for an estimation approach with an input distance function framework, Hajargasht et al. (2008) suggest analysing economies of scope via the concept of cost complementarities. As shown by Baumol et al. (1988), a sufficient condition for weak economies of scope is that the cost function exhibits weak cost complementarities. Technically, weak cost complementarities between output \(i\) and output \(j\) exist if

\[
\frac{\partial^2 C(p, y)}{\partial y_i \partial y_j} \leq 0.
\] (13)

In other words, the MCs of one output \(y_i\) decrease (weakly) if the quantity of the other output \(y_j\) increases. In the reverse case, there are diseconomies of scope (Baumol et al. 1988).

By using duality theory, Hajargasht et al. (2008) show that a measure for economies of scope in line with Equation (13) can be obtained from the first- and second-order derivatives of an input distance function:

\[
\text{Scope}_{ij} = \frac{1}{C} \frac{\partial^2 C}{\partial y_i \partial y_j} = \frac{\partial D}{\partial y_i} \frac{\partial D}{\partial y_j} - \frac{\partial^2 D}{\partial y_i \partial y_j} \frac{\partial^2 D}{\partial y_i \partial x_1} \cdots \frac{\partial^2 D}{\partial y_i \partial x_n} + \frac{\partial^2 D}{\partial y_j \partial x_1} \cdots \frac{\partial^2 D}{\partial y_j \partial x_n} \times \left[ \frac{\partial^2 D}{\partial x_1 \partial y_j} \cdots \frac{\partial^2 D}{\partial x_n \partial y_j} \right]^{-1} \times \left[ \frac{\partial^2 D}{\partial x_1 \partial y_i} \cdots \frac{\partial^2 D}{\partial x_n \partial y_i} \right].
\] (14)

Negative values indicate economies of scope, and positive values indicate diseconomies of scope.
4 Data

The data set 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 2007.6

In common with previous efficiency studies on higher education, we use the following input and output variables for our analysis.7 As done by Johnes and Schwarzenberger (2011) in their study on the German university sector, we use two input measures, that is, the operating expenditures and the personnel expenditures. The operating expenditures cover, for example, rentals and leases, building and property maintenance, consumables and technical equipment. Personnel 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 organizations producing a variety of different outputs. To represent the teaching output of HEIs, we use the number of undergraduate and graduate students enrolled in bachelors and masters programmes as well as those enrolled in diploma programmes, the former German degree that is comparable with 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 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

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6 Our initial data set included 381 HEIs. We excluded all HEIs and facilities exclusively offering human and veterinary medicine due to a lack of clear statistical classification. Furthermore, in order to concentrate our analysis on public and non-highly specialized institutions, we also excluded privately and church-funded institutions as well as all HEIs that are exclusively oriented to theology, administrative sciences, sports, or fine arts and music. This reduces the sample to 173 HEIs. Finally, as a result of missing values for some of the utilized variables, 19 institutions had to be deleted, leaving a remaining number of 154 HEIs.

7 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).
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. We consider the funds granted by research funding organizations such as the German Research Foundation (Deutsche Forschungsgemeinschaft), the European Union, other non-profit organizations, private foundations, and the business and industry sectors. This output measure is preferable to data on publications, for example, 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 (Johnes 1997; Harman 2000). 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).

Given the empirical evidence that higher education production differs across disciplines (see Section 2), 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

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8 In order to test the robustness of our results, we also run the analyses by using the number of graduates as a teaching output. We find that our results are at least qualitatively robust to this variation.

9 As opposed to Johnes and Schwarzenberger (2011), we did not consider the number of doctoral students as an additional output. First, compared with the Anglo-Saxon countries, the number of students enrolled in doctoral programmes increased just recently in Germany as a result of introducing the Bologna reforms into the German higher education system. In the period considered in this article, students who did their doctorate were generally employed at the university as teaching and research assistants and not enrolled in a doctoral programme with a specific course programme for doctoral education. Second, the available data on personnel expenditures also includes expenditures for doctoral (PhD) students employed as teaching and research assistants, which would cause a bias due to double counting these as both input and as output.

10 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).

11 In addition to teaching and research activities HEIs also conduct third-mission activities such as entrepreneurial and political consultancy. Unfortunately, as there are no data available on this output category for German HEIs, we cannot include third-mission activities in our analysis.
measures for teaching and research in the non-sciences and the sciences.\textsuperscript{12}

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.

The unbalanced panel data set 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 1 summarizes 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).

Despite the trend of harmonization between universities and universities of applied sciences observed in the higher education sector during the past decade, some institutional heterogeneity yet exists. The descriptive statistics on the input and output variables, reported in Table 1, 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 personnel 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.

Reviewing the descriptive statistics on student enrolments presented in Table 1, 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. 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

\textsuperscript{12} A lower disaggregation level probably causes problems of multicollinearity between the input and output variables for different subjects (Johnes and Salas-Valesco 2007).
science disciplines at universities. This observation is not surprising because the majority of non-science disciplines are offered by universities.

5 Results

The estimated posterior means and standard deviations for the parameters of the input distance function are presented in Table 2. As each variable is normalized 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% 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 \( (C_{11}) \) is equal to 0.961. This value reflects the labour-intensive higher education production process. The output elasticities \( (C_{12}) \) equal to 0.169, \( (C_{12}) \) equal to 0.210, \( (C_{12}) \) equal to 0.032, and \( (C_{12}) \) equal to 0.053 indicate 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 \( (\theta_t) \) is 0.014. This value indicates a rate of technical progress of about 1.4% for the sample median HEI in the mid-year of the sample. Finally, the estimated values for \( \lambda_a, \lambda_v, \) and \( \lambda_u \) show that about 97.8% of total variations in inputs is due to

Table 1 Descriptive statistics of input and output measures

<table>
<thead>
<tr>
<th>Variable description</th>
<th>Variable</th>
<th>Mean</th>
<th>Median</th>
<th>Standard deviation</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universities (288 observations)</td>
<td>Xopex</td>
<td>39,296</td>
<td>31,890</td>
<td>28,074</td>
<td>577</td>
<td>139,699</td>
</tr>
<tr>
<td>Personnel expenses (€’000)</td>
<td>Xemp</td>
<td>105,189</td>
<td>91,703</td>
<td>61,169</td>
<td>1764</td>
<td>265,854</td>
</tr>
<tr>
<td>Number of non-science students</td>
<td>Yst_nsc</td>
<td>10,476</td>
<td>8997</td>
<td>7864</td>
<td>152</td>
<td>42,454</td>
</tr>
<tr>
<td>Number of science students</td>
<td>Yst_nc</td>
<td>5496</td>
<td>4546</td>
<td>3958</td>
<td>5</td>
<td>17,580</td>
</tr>
<tr>
<td>Research funds (non-sciences) ( (€’000) )</td>
<td>Yres_nsc</td>
<td>5160</td>
<td>3880</td>
<td>4426</td>
<td>1</td>
<td>23,484</td>
</tr>
<tr>
<td>Research funds (sciences) ( (€’000) )</td>
<td>Yres_sc</td>
<td>21,695</td>
<td>15,202</td>
<td>21,894</td>
<td>1</td>
<td>121,155</td>
</tr>
<tr>
<td>Universities of applied sciences (300 observations)</td>
<td>Xopex</td>
<td>6211</td>
<td>4447</td>
<td>5798</td>
<td>641</td>
<td>57,959</td>
</tr>
<tr>
<td>Personnel expenses (€’000)</td>
<td>Xemp</td>
<td>18,207</td>
<td>16,601</td>
<td>10,061</td>
<td>2884</td>
<td>53,762</td>
</tr>
<tr>
<td>Number of non-science students</td>
<td>Yst_nsc</td>
<td>2318</td>
<td>1915</td>
<td>1408</td>
<td>316</td>
<td>7933</td>
</tr>
<tr>
<td>Number of science students</td>
<td>Yst_nc</td>
<td>2781</td>
<td>2437</td>
<td>1962</td>
<td>172</td>
<td>10,148</td>
</tr>
<tr>
<td>Research funds (non-sciences) ( (€’000) )</td>
<td>Yres_nsc</td>
<td>318</td>
<td>185</td>
<td>362</td>
<td>1</td>
<td>2486</td>
</tr>
<tr>
<td>Research funds (sciences) ( (€’000) )</td>
<td>Yres_sc</td>
<td>939</td>
<td>626</td>
<td>956</td>
<td>0.5</td>
<td>7471</td>
</tr>
</tbody>
</table>

heterogeneity, about 1.8% is due to inefficiency, and only about 0.4% is
due to noise.

Our estimates for the scale and scope economies evaluated at the sample
median are presented in Table 3. First, referring to RTS the value of 2.164,
which is greater than 1, indicates fairly high increasing RTS at the sample
median HEI. The result is statistically significant at the 1 per cent level and
suggests that a 1% increase in all inputs results in a 2.2% increase in all
outputs. Furthermore, differentiating RTS with respect to the outputs
reveals that this result is mainly driven by the teaching outputs. That is,
at the sample median, the impact of the teaching outputs on RTS is almost
three times higher than the impact of the research outputs.

The remaining values in Table 3 show our results for the economies of
scope for (i) teaching in the non-sciences and the sciences; (ii) research in
the non-sciences and the sciences; (iii) teaching and research within the
non-sciences; and (iv) teaching and research within the sciences. Except for
the last, all scope measures at the sample median are statistically signif-
ificant at least at the 10% 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 sample median value of −0.027 for

Table 2 Bayesian estimation results of the input distance function\textsuperscript{a,b,c,d,e}

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Variable</th>
<th>Parameter</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{emp}$</td>
<td>$\alpha_1$</td>
<td>0.961\textsuperscript{d}</td>
<td>0.011</td>
<td>$Y_{st_sc}$</td>
<td>$Y_{res_sc}$</td>
<td>$\beta_{24}$</td>
<td>0.007</td>
</tr>
<tr>
<td>$X_{emp}^2$</td>
<td>$\alpha_{11}$</td>
<td>−0.002</td>
<td>0.005</td>
<td>$Y_{res_nsc}$</td>
<td>$Y_{res_sc}$</td>
<td>$\beta_{34}$</td>
<td>−0.002</td>
</tr>
<tr>
<td>$Y_{st_nsc}$</td>
<td>$\beta_1$</td>
<td>−0.169\textsuperscript{d}</td>
<td>0.021</td>
<td>$X_{emp}$</td>
<td>$Y_{st_nsc}$</td>
<td>$\gamma_{11}$</td>
<td>0.003</td>
</tr>
<tr>
<td>$Y_{st_sc}$</td>
<td>$\beta_2$</td>
<td>−0.210\textsuperscript{d}</td>
<td>0.025</td>
<td>$X_{emp}$</td>
<td>$Y_{st_sc}$</td>
<td>$\gamma_{12}$</td>
<td>0.005</td>
</tr>
<tr>
<td>$Y_{res_nsc}$</td>
<td>$\beta_3$</td>
<td>−0.032\textsuperscript{d}</td>
<td>0.007</td>
<td>$X_{emp}$</td>
<td>$Y_{res_nsc}$</td>
<td>$\gamma_{13}$</td>
<td>−0.000</td>
</tr>
<tr>
<td>$Y_{res_sc}$</td>
<td>$\beta_4$</td>
<td>−0.053\textsuperscript{d}</td>
<td>0.008</td>
<td>$X_{emp}$</td>
<td>$Y_{res_sc}$</td>
<td>$\gamma_{14}$</td>
<td>−0.003</td>
</tr>
<tr>
<td>$Y_{st_nsc}^2$</td>
<td>$\beta_{11}$</td>
<td>−0.038\textsuperscript{d}</td>
<td>0.013</td>
<td>$T$</td>
<td></td>
<td>$\theta_1$</td>
<td>0.014\textsuperscript{d}</td>
</tr>
<tr>
<td>$Y_{st_sc}^2$</td>
<td>$\beta_{22}$</td>
<td>−0.027\textsuperscript{d}</td>
<td>0.008</td>
<td>$T^2$</td>
<td></td>
<td>$\theta_{11}$</td>
<td>0.018\textsuperscript{d}</td>
</tr>
<tr>
<td>$Y_{res_nsc}^2$</td>
<td>$\beta_{33}$</td>
<td>−0.002\textsuperscript{e}</td>
<td>0.001</td>
<td>$\Sigma\sigma_\sigma$</td>
<td>$\sigma_\sigma^2$</td>
<td></td>
<td>0.437\textsuperscript{d}</td>
</tr>
<tr>
<td>$Y_{res_sc}^2$</td>
<td>$\beta_{44}$</td>
<td>−0.008\textsuperscript{d}</td>
<td>0.002</td>
<td>$\Sigma\sigma_\sigma$</td>
<td>$\sigma_\sigma^2$</td>
<td></td>
<td>0.002\textsuperscript{e}</td>
</tr>
<tr>
<td>$Y_{st_nsc}Y_{st_sc}$</td>
<td>$\beta_{12}$</td>
<td>0.063\textsuperscript{d}</td>
<td>0.013</td>
<td>$\Sigma\sigma_u$</td>
<td>$\sigma_u^2$</td>
<td></td>
<td>0.008\textsuperscript{d}</td>
</tr>
<tr>
<td>$Y_{st_nsc}Y_{res_nsc}$</td>
<td>$\beta_{13}$</td>
<td>−0.004</td>
<td>0.004</td>
<td>$\Lambda\lambda_u$</td>
<td>$\lambda_u=\sigma_u^2/\sigma^2$</td>
<td></td>
<td>0.978\textsuperscript{d}</td>
</tr>
<tr>
<td>$Y_{st_sc}Y_{res_sc}$</td>
<td>$\beta_{14}$</td>
<td>0.006</td>
<td>0.005</td>
<td>$\Lambda\lambda_v$</td>
<td>$\lambda_v=\sigma_v^2/\sigma^2$</td>
<td></td>
<td>0.004\textsuperscript{d}</td>
</tr>
<tr>
<td>$Y_{st_sc}Y_{res_nsc}$</td>
<td>$\beta_{23}$</td>
<td>0.009\textsuperscript{e}</td>
<td>0.004</td>
<td>$\Lambda\lambda_u$</td>
<td>$\lambda_u=\sigma_u^2/\sigma^2$</td>
<td></td>
<td>0.018\textsuperscript{d}</td>
</tr>
</tbody>
</table>

\textit{Note.} \textsuperscript{a}All variables are in natural logarithm and are normalized by their sample median.
\textsuperscript{b}The dependent variable is $-\ln X_{opex}$.
\textsuperscript{c}All model estimates are obtained by using WinBUGS.
\textsuperscript{d}Significant at 1%.
\textsuperscript{e}Significant at 5%.
joint teaching in the non-sciences and the sciences suggests that a 10% increase in teaching activities in the non-sciences reduces the MCs of teaching in the sciences by 0.27%. This value is rather low. For the remaining output combinations, the relatively small positive values indicate rather marginal diseconomies of scope at the sample median.

It needs to be emphasized that the estimates reported in Table 3 are average values evaluated for a hypothetical institution that exhibits sample median values for each variable in the model. As our data set is characterized by a significant institutional heterogeneity, these average values may not hold true for all observations. Therefore, in a second step, we use the estimated coefficients of the input distance function and the observation-specific input and output values to calculate measures of scale and scope economies for each observation. The median values obtained from this exercise, differentiated by type of university and size, are reported in Table 4. Furthermore, in order to test whether the median values differ between institution types, we applied the Mann-Whitney-Wilcoxon test. The obtained p-values for the null hypothesis of equal median values for universities and universities of applied sciences are also shown in Table 4.

Overall, the institutional- and size-related results show a similar pattern as the results for the sample median. The median values of the RTS are 2.424 for the universities and 2.021 for the universities of applied sciences.

\textsuperscript{13} As we normalized each variable by its sample median prior to log transformation, all input and output variables of the sample median institution are equal to one. In this case, the first- and second-order derivatives of the (translog) input distance function used to calculate scale and scope economies can be simply derived from the first- and second-order coefficients of the estimated translog input distance function.
respectively. Furthermore, 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. Referring to scope economies for joint teaching in the non-sciences and the sciences, the highest value is shown for small universities ($\gamma_{0.097}$). All other values are relatively small. For the remaining output combinations, the median values for universities 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 0.129 for the small universities of applied sciences regarding joint production of teaching and research in the sciences suggests that a 10% increase in teaching activities increases the MCs of research activities by

### Table 4 Scale and scope economies differentiated by type of university and size$^{a,b}$

<table>
<thead>
<tr>
<th>Institutions</th>
<th>N</th>
<th>RTS</th>
<th>Teaching (Nsc/Sc)</th>
<th>Research (Nsc/Sc)</th>
<th>Non-sciences (Teach/Res)</th>
<th>Sciences (Teach/Res)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institution-related median values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Universities</td>
<td>288</td>
<td>2.424</td>
<td>−0.012</td>
<td>0.000</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>Universities of applied sciences</td>
<td>300</td>
<td>2.021</td>
<td>−0.017</td>
<td>0.042</td>
<td>0.083</td>
<td>0.044</td>
</tr>
<tr>
<td>p-value</td>
<td></td>
<td></td>
<td>(0.000)</td>
<td>(0.753)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Institution-related median values by size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Universities</td>
<td>102</td>
<td>2.720</td>
<td>−0.004</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Universities of applied sciences</td>
<td>2</td>
<td>2.607</td>
<td>−0.006</td>
<td>0.002</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>p-value</td>
<td></td>
<td></td>
<td>0.227</td>
<td>0.368</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>Medium-sized</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Universities</td>
<td>148</td>
<td>2.324</td>
<td>−0.018</td>
<td>0.000</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Universities of applied sciences</td>
<td>118</td>
<td>2.193</td>
<td>−0.017</td>
<td>0.018</td>
<td>0.017</td>
<td>0.013</td>
</tr>
<tr>
<td>p-value</td>
<td></td>
<td></td>
<td>0.000</td>
<td>0.817</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Universities</td>
<td>38</td>
<td>1.899</td>
<td>−0.097</td>
<td>0.002</td>
<td>0.015</td>
<td>0.005</td>
</tr>
<tr>
<td>Universities of applied sciences</td>
<td>180</td>
<td>1.903</td>
<td>−0.013</td>
<td>0.090</td>
<td>0.116</td>
<td>0.129</td>
</tr>
<tr>
<td>p-value</td>
<td></td>
<td></td>
<td>0.610</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

$^a$Large HEIs are defined as having more than 17,250 students, medium-sized HEIs as having between 5000 and 17,250 students, and small HEIs as having fewer than 5000 students.

$^b$p-values for the null hypothesis of equal median values for universities and universities of applied sciences.
1.3%. The respective median value of 0.116 indicates a similar effect for the joint production of teaching and research in the non-sciences. The estimated $p$-values for the Mann-Whitney-Wilcoxon test indicate that the median values for diseconomies of scope differ significantly between universities and universities of applied sciences.\(^\text{14}\)

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 0.93 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 7%. Further, the minimum values of 0.821 for universities and 0.686 for the universities of applied sciences show that for some institutions, a considerable input reduction of up to 30% is necessary for them to become efficient.\(^\text{15}\)

### 6 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 data set of 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 aiming 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 organizations can realize efficiency gains by exploiting economies of scale and scope in their production processes. To investigate the scale and scope effects in German

\(^\text{14}\) In order to test the robustness of our results, we also estimate a separate distance function for each institution type. We find that the majority of our results remain, at least qualitatively, robust to these variations. A notable exception is the finding of relatively high diseconomies of scope for large universities regarding joint research activities in the sciences and the non-sciences. However, for small- and medium-sized universities the respective values are similar to the ones obtained from the joint estimation.

\(^\text{15}\) The relatively high estimated efficiency scores are partly due to the estimation approach. In contrast to conventional stochastic frontier models, the applied TRE model treats all time-invariant effects as unobserved heterogeneity and separates them from time-varying inefficiency. Thus, any persistent inefficiency is not included in the efficiency scores. Consequently, as noted by Farsi et al. (2006), the TRE model tends to overestimate efficiency, while the conventional models tend to underestimate it.
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-minimization 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 RTS 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

Table 5 Efficiency scores\(^a\)

<table>
<thead>
<tr>
<th>Institutions</th>
<th>N</th>
<th>Mean</th>
<th>Median</th>
<th>Standard deviation</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institutional-related efficiency values</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Universities</td>
<td>288</td>
<td>0.937</td>
<td>0.945</td>
<td>0.029</td>
<td>0.821</td>
<td>0.983</td>
</tr>
<tr>
<td>Universities of applied sciences</td>
<td>300</td>
<td>0.934</td>
<td>0.944</td>
<td>0.038</td>
<td>0.686</td>
<td>0.987</td>
</tr>
<tr>
<td>Institutional-related efficiency values by size</td>
<td></td>
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<tr>
<td>Universities</td>
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<tr>
<td>Large</td>
<td>102</td>
<td>0.937</td>
<td>0.945</td>
<td>0.030</td>
<td>0.830</td>
<td>0.983</td>
</tr>
<tr>
<td>Medium-sized</td>
<td>148</td>
<td>0.937</td>
<td>0.946</td>
<td>0.026</td>
<td>0.846</td>
<td>0.978</td>
</tr>
<tr>
<td>Small</td>
<td>38</td>
<td>0.931</td>
<td>0.942</td>
<td>0.037</td>
<td>0.821</td>
<td>0.975</td>
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<tr>
<td>Universities of applied sciences</td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Large</td>
<td>2</td>
<td>0.957</td>
<td>0.957</td>
<td>0.007</td>
<td>0.952</td>
<td>0.962</td>
</tr>
<tr>
<td>Medium-sized</td>
<td>118</td>
<td>0.933</td>
<td>0.945</td>
<td>0.041</td>
<td>0.748</td>
<td>0.987</td>
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<tr>
<td>Small</td>
<td>180</td>
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<td>0.943</td>
<td>0.035</td>
<td>0.685</td>
<td>0.984</td>
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\(^a\)Large HEIs are defined as having more than 17,250 students, medium-sized HEIs as having between 5000 and 17,250 students, and small HEIs as having fewer than 5000 students.
mergers between universities and universities of applied sciences or other institutions as instruments to use to continuously differentiate themselves in the market (German Council of Science and Humanities, 2010a). 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, for example, 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 universities 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 specializing in higher education production. Referring to joint teaching and research in both scientific fields, small universities of applied sciences should specialize 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 specialization (German Council of Science and Humanities, 2010b).

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 emphasizes the German model of unity of teaching and research and

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16 Corresponding examples are the Karlsruhe Institute of Technology, Leuphana University Lüneburg, and Hafen City University of Hamburg.
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 prioritization in teaching, postgraduate education, knowledge transfer, or internationalization in each case, depending on the unique institutional profile (German Council of Science and Humanities, 2010a). In 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 principle 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 on both the German universities and the German universities of applied sciences over the 2001–2007 period is consistent with the results Johnes and Schwarzenberger (2011) found in their study of German universities for 2001–2004. More importantly, our 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 specialize 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. Further research would benefit from including variables that address the quality aspect in higher education production. One may think of using information from initial test scores to account for students’ intake quality or information on class-size, dropout rates, students’ success, and institutional reputation taken from university statistics, job surveys, and
university rankings to account for the quality of institutional teaching and research activities. With respect to our analysis, one hypothesis could be that higher quality may lead to lower economies or even diseconomies of scope for interdisciplinary teaching and research activities in the sciences and the non-sciences. The exploitation of interdisciplinary scope effects may be limited because high-skilled researchers may be too specialized in their fields. In addition, one may presume that a higher quality of teaching activities may lead to lower RTS given smaller class-sizes.

Moreover, 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.

Acknowledgements

We would like to thank Gary Ferrier and the participants of the XII European Workshop on Efficiency and Productivity Analysis (EWEPA 2011), Andrea Schenker-Wicki, and Mehdi Farsi for helpful comments and discussions on prior versions of this article. The views expressed herein are those of the authors and do not necessarily reflect the views of the mentioned discussants.

References


