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The Journal on Efficiency and Responsibility in Education and Science publishes papers of the following categories: full research papers, short communications, review studies and book reviews (on invitation only).

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# EDITORIAL

We are glad that we can present you the second issue of the year 2017 (vol. 10, no. 2). In this second issue, which you hold in your hands, we are glad to introduce four articles from diverse group of authors covering following institutions: Karel Englis College in Brno, Czech Republic; Simon Fraser University, Canada; University of Debrecen, Hungary; and University of Economics, Prague, Czech Republic. We are grateful that ERIES Journal has again attracted diverse authors from different higher education institutions. It is a commitment for the Editorial board to keep improving the journal quality and being the leading journal in the education research in the Czech Republic. During the last couple of weeks, the Technical editors along with the Executive editors have been testing a new editorial system. We hope to introduce the new editorial system at the end of August this year. In addition, the Editorial team seeks to extend the indexation of ERIES Journal. We also hope to announce new indexation in the next published issue.

The first article "Higher education for higher competitiveness", from authors Jaroslav Komárek, Jaroslav Dočkal, Petr Markovič, Barbora Novotná Březovska and Filip Rigel, provides a comparative analysis of Czech and German study programs in the area of Economics. The objective is to analyse whether Business economics programs at German universities differ in ways that can boost competitiveness. For this purpose, the authors selected eight Czech and eight German faculties of Economics and their relevant bachelor degree study programs. To find out the differences, non-hierarchical cluster analysis by one variable was used. The analysis of the bachelor degree programs justifies the validity of the research hypothesis such that German study programs are more focused on practical application in a work environment.

The second article "Bayesian diagnostics for test design and analysis" from authors Rajitha M. Silva, Yuping Guan and Tim B. Swartz demonstrates that the familiar and popular statistics used in classical test theory can be translated into a Bayesian framework, where all of the advantages of the Bayesian paradigm can be realized. In the proposed approach, analogous "statistics" are constructed from the output of simulation from the posterior distribution. This leads to population-based inferences which focus on the properties of the test rather than the performance of specific subjects.

In the third article "The effectiveness of the e-learning applications: assessment of the service quality using binominal logistic regression" the authors Peter Lengyel, Miklós Herdon, János Pancsira, Gergely Ráthonyi and István Füzesi propose a questionnaire to evaluate an e-Learning application at Faculty of Economics and Business of the University of Debrecen and the Corvinus University of Budapest. The aim objective of the research was to develop a questionnaire, which would be suitable for evaluating the e-Learning quality. The basis of the e-Learning quality questions was a multi-dimensional model for assessing e-learning systems success. The research survey was designed from predetermined group of users. The authors created 4 factors from the 27 variables by factor analysis. Moreover, the authors used binominal logistic regression to determine the importance of a given factor for the users. The results show that it is more effective and better to operate the e-Learning system under organized circumstances.

The last article "Measuring the efficiency of the Czech public higher education institutions: An application of DEA" from Pavla Mikušová presents an analysis to measure an efficiency of Czech public higher education institutions (HEIs). The author measures the efficiency using Data Envelopment Analysis based on data from the Ministry of Education, Youth and Sports in the Czech Republic. In the first part of the analysis, the author compares all the HEIs with each other. The results show that specialization of each HEI should be considered as HEIs of Arts are disadvantaged. Therefore, in the second part, HEIs are divided into three groups using coefficients of economic difficulties related to study programs. This division eliminated large differences in inputs and outputs among HEIs and increase correctness of the efficiency results.

We would like to thank to all reviewers who contributed to this second issue of 2017, as well as we would also like to thank all the authors who have submitted their manuscripts to ERIES Journal. We hope that all our readers will find this issue interesting, and we also hope that ERIES Journal will contribute to the field of efficiency and responsibility in education as it has contributed so far.

Sincerly,

Martin Flégl

*Executive Editor*

ERIES Journal

# HIGHER EDUCATION FOR HIGHER COMPETITIVENESS

**Jaroslav Komárek[1✉], Jaroslav Dočkal[2], Peter Markovič[3], Barbora Novotná Březovská[4], Filip Rigel[5]**

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*Highlights*

- *The higher education is criticized that does not match the needs of practice*
- *The economic study programs of Czech and German universities were analysed*
- *The analysis justified that German study programs are more focused on practice*

**Abstract**

The current criticism of higher education is that the education offered does not match the needs of practice. In terms of competitiveness, Germany is about the forefront in Europe, and logically the question of whether higher education is the source from which leads to this result. The objective of this paper is to compare the corresponding study programs of Czech and German universities in the area of Economics by identifying the relevant differences and to confirm or dismiss the validity of the research hypothesis „Business Economics programs at German universities differ in ways that can boost competitiveness". In order to compare the study programs between Czech and German universities, the eight faculties of Economics geared towards Business and Economics and Bachelor degree program were selected. As an introductory information, the structure of the programs was compared in terms of course load and which courses being compulsory, elective, and various forms of actual work practice and Bachelor thesis. The portfolio analysis of compulsory courses was organized into more general course groups and the percentage share of the total extent of compulsory courses was evaluated and the percentage of the active part. The analysis of Bachelor's degree programs justifies the validity of the research hypothesis such that German study programs are more focused on practical application in a work environment. To that, contribute significantly the German specific institutions, the universities of applied sciences, which are strongly geared towards the needs of actual practice. The reflection of findings may apply in the context of the forthcoming implementation of amendment to the Higher Education Act.

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Bachelor study program, competitiveness, Economics, Higher Education Act, managerial skills, practices

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## Introduction

The general impact of higher education on international competitiveness is accepted universally, it is included as the fifth pillar (Higher Education and Training) of the world-renowned international competitiveness assessment through Global Competitiveness Index (World Economic Forum, 2017), and a statistically significant correlation of the both ratings has been identified (Sekuloska, 2014). Similarly the International Institute for Management Development (IMD, 2017) uses four main criteria, which in turn include a number of sub criteria, one of them Education. World Economic Forum has provided the competitiveness ranking for nearly half century, but during the past decades, the international competitiveness environment has changed radically. 'Throughout the 1990s, many countries recognized and began to imitate the U.S. model of economic growth by improving access to higher education, increasing government investment in R&D, and lowering barriers to trade and investment. At the same time, multinational corporations accelerated their globalization, both to gain access to the enormous and rapidly growing consumer markets in emerging economies and to tap into overseas talent pools. America's unique advantage is no longer so unique. China has pulled ahead of the United States in high-technology exports, graduates nearly three times as many four-year degrees in engineering, computer science, and IT and it is projected to graduate more PhDs in science and engineering' (Attis, 2007). The topic of competitiveness was found important also in the European Union. Europe's Heads of Governments met in Lisbon and signed a common declaration where they announced their intention to make the EU "the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion" (Council of the European Union, 2000). Following its principle to measure competitiveness through a multicriteria index, the WEF has developed Lisbon Review Index for assessing the strategy followed by the EU. The measurement comprises eight distinct dimensions that capture the areas highlighted critical for reaching the goal of becoming the world's most competitive economy, but the Lisbon Review Index does not have any distinctive HE aspects (Blanke and Geiger, 2008).

It is obvious that global indexes or policy challenges can be used only as a frame for to address the actual impact of higher education on competitiveness. Therefore, an attention has been drawn to the assessing importance of the higher education systematically. For example, R. H. Mattoon (2006) demonstrated that growth is more pronounced in countries where there are well-developed higher education systems. Other researchers have been concerned about the link between the various specializations offered by higher education and economic growth. T.S. Sequeira (2007) has shown that there is a direct link between the rate of enrollment to engineering, mathematics and computing studies and the economic growth. M.G. Colombo and L. Grilli (2005) have shown that in the case of the growth of firms, the number of graduates of scientific and technical studies have a significant positive effect. C. L. Tsai, M. C Hung and K. Harriott (2010) have revealed that the percentage of graduates in science, engineering, mathematics, and computer science is an important indicator for determining the quality of the workforce. Such results confirm the influence of higher education still generally, but with very limited value for any qualitative changes in the content of higher education. The deeper insight could offer the analysis of study programs, which represent the starting knowledge for further professional development and potential contribution to the national competitiveness.

Concerning the higher education in the Czech Republic, there is a lot of criticism that the education offered does not match the needs when it comes to the job market (Co nejvíc trápí české manažery, 2013). This may be a limited, subjective opinion of employers; however, research has shown this to be a more objective view. For example, in the study, "Needs of Employers and Preparedness of School Graduates" (Úlovec, 2014) we see a result of thousands of questionnaires completed by employers in various sectors of the labour market. In the category of higher education the consensus was rather negative, claiming that universities inadequately develop the skills necessary for employment, focusing primarily more so on the areas of problem solving and decision-making.

Where the heart of the problem is, illustrates the following quote most aptly: "Transformation of higher education is especially needed when research and regular exchanges between practitioners and academicians are not commonplace and traditional education replicates outdated practices. Change and innovation in competitive products and production processes can easily outpace academics' ability to update the content of their coursework. More importantly, many undergraduate and graduate programs do not provide opportunities to develop the process skills so urgently needed in today's evolving economies and dynamic societies. The mismatch between what higher education provides and what is needed to grow the economy lies in part in outdated content knowledge but the wider and more urgent gap is in mastering the necessary process skills to effectively lead economic growth, such as reasoning, problem solving, team work, effective communication, creativity, and risk taking" (Hergnyan and Williams, 2017).

How then are university students prepared in the decisive areas for entrance into the work place, especially in facets of management functions or even for entrepreneurs are just starting out? Typically, the program of study would be a Bachelor degree study program in Economics and Management, in which the accredited course outline includes various fields of study in Business Economics. But this applies only to the practical implementation of the Higher Education Act no. 137/2016 Coll. (ČR, 2016a), which represents a fundamental change in the accreditation of higher education programs in the Czech Republic. A key change cannot be considered in the administrative areas of the accreditation process as a mandatory delimitation of the content in the study programs in what is defined as areas of education. Up to now, the content of what to be included in a study program has been assessed only by the vague provision of the Higher education act, and has been more specifically connected with the historically derived consensus of the Accreditation Commission. The defining areas of education should be a reflection on the actual development of educational disciplines and equally to the practical needs of a work place. Routine implementation of the accreditation of curricula according to the amendment can still foresee a long road ahead and should be open to suggestions for further improvement.

Bachelor's programs in Business Administration are offered in Europe in thousands (BachelorsPortal.eu) and it would be counterproductive to compare them due to the different conditions and traditions. Therefore, focusing on one country for two reasons. Concerning competitiveness, Germany is about the forefront in Europe (World Economic Forum, 2017), and logically the question of whether higher education is one of the sources from which leads to this result. The second reason is some proximity of study programs due to the influence of Wöhe's enterprise functions oriented approach (Wöhe, 1995). An answer to this question may be found by analysing and comparing the corresponding Bachelor degree programs from both German and Czech universities with a specific focus on scope, content and form. The objective of this research is to compare the study programs of Czech and German universities in the area of Economics by identifying the relevant differences and to confirm or dismiss the validity of the current research hypothesis that „Business Economics programs at German universities differ in ways that can boost competitiveness". Corresponding recommendation for the study programs in Economics and Management to support the competitiveness of the Czech economy should follow.

## Materials and methods

In order to compare the study programs between Czech and German universities, eight faculties of Economics geared towards Business and Economics with a relevant (according to the criteria of at least 2,000 students) impact on business practice and with corresponding Bachelor degree program were selected (Tab. 1, 2).

| University or Institution | Study Program |
|---|---|
| The Faculty of Business Administration at the University of Economics Prague | Business Economics and Management (University of Economics Prague, 2016) |
| Faculty of Business and Economics, Mendel University in Brno | Managerial-economic program (Mendel University in Brno, 2016) |
| Faculty of Economics and Management, Czech University of Life Science in Prague | Operation and Economics (Czech University of Life Science in Prague, 2016) |
| Faculty of Management and Economics, Tomas Bata University in Zlin | Management and Economics (Tomas Bata University in Zlin, 2016) |
| Faculty of Economics and Administration, Masaryk University Brno | Business Economics and Management (Masaryk University Brno, 2016) |
| Faculty of Economics and Administration, University of Pardubice | Management in Business (University of Pardubice, 2016) |
| Faculty of Economics, VŠB - Technical University of Ostrava | Management (VŠB - Technical University of Ostrava, 2016) |
| Faculty of Entrepreneurship, Brno University of Technology | Business Economics (Brno University of Technology, 2016) |

**Table 1: Sample of Economic faculties from universities in the Czech Republic**

The comparison of the study programs in relation to study courses such objects will be implemented through a non-hierarchical cluster analysis by one variable (proportional number of hours per course).

| University or Institution | Study Program |
|---|---|
| Ludwig-Maximilian-Universität München | Business Economics (Ludwig-Maximilian-Universität München, 2016) |
| Rheinisch-Westfälischen Technischen Hochschule Aachen | Business Economics (RWTH, 2016) |
| Frankfurt School of Finance & Management | Business Economics (Frankfurt School of Finance & Management, 2016) |
| Technische Universität Berlin | Business Economics and Management (Technische Universität Berlin, 2016) |
| Technische Universität München | Business Economics, Technology- and Management oriented (Technische Universität München, 2016) |
| Goethe-Universität Frankfurt am Main | Economics (Goethe-Universität Frankfurt am Main, 2016) |
| Universität zu Köln | Business Economics (Universität zu Köln, 2016) |
| Universität Mannheim | Business Economics (Universität Mannheim, 2016) |

**Table 2: Sample of Economic faculties from universities in Germany**

## Results

### Analysis of curricula with the standard course model

As a starting point and an introductory information the structure of the programs was compared in terms of course load for the program and based on which courses were compulsory, elective, various forms of actual work practice (internships), and the final Bachelor thesis (tab. 3). The number of elective courses in the overall course load in the German sample of universities was more than double (2.31 times) and testified to the greater flexibility of study programs due to the differentiated needs in the workplace. The organization of elective courses into optional modules replaces the need for further division into accredited fields of study thus increasing the effectiveness of learning and even its administration.

There were significant differences in the assessment of the workload for actual work practice (internships) in several German institutions, and, it must be noted that these internships are also included as a graded part of the Bachelor thesis. The differences between the assessment of the Czech Bachelor thesis can be seen as problematic as there should be a set standard of quality and quantity for the criteria in the Bachelor thesis (are the requirements among the individual Czech universities so different?).

In the first stages, the analysis was examined from the content of the framework curricula in relation to the generally accepted "body of knowledge", which was not exactly defined in the Czech higher education system, but was already established in practice by accreditation committee. The inspiration stemmed also from the practice of the Slovak Ministry of Education, which like the Czech one, administrates the system of study programs providing higher education (Ministerstvo školstva, 2016). The Accreditation Commission (educational advisory body to the Slovak Republic government), with the approval of the Ministry of Education, adopted detailed descriptions of revised programs, prepared and amended by experts at universities (Akreditačná komísia, 2016) as recommended material for school information and also for assessing applications. Each program is defined in terms of acquired competencies of the graduate and recommended courses categorized by each year of study, as well as, the subjects necessary for the culminating exams in the final year.

| Country | Higher Institution (university) | School Code | Type of course | | | |
|---|---|---|---|---|---|---|
| | | | compulsory | elective | internship | Bachelor thesis |
| Czech Republic | The Faculty of Business Administration VŠE | CZ1 | 140 | 34 | 0 | 6 |
| | Faculty of Business and Economics, Mendel University | CZ2 | 139 | 31 | 2 | 8 |
| | Faculty of Economics and Management, ČZU | CZ3 | 135 | 20 | 5 | 20 |
| | Faculty of Management and Economics UTB | CZ4 | 158 | 19 | 0 | 3 |
| | Faculty of Economics and Administration MU | CZ5 | 148 | 24 | 0 | 8 |
| | Faculty of Economics and Administration UP | CZ6 | 139 | 25 | 3 | 13 |
| | Faculty of Economics, University of Ostrava | CZ7 | 134 | 26 | 0 | 20 |
| | Faculty of Entrepreneurship BUT | CZ8 | 152 | 11 | 5 | 12 |
| Federal Republic of Germany | LMU München | GE1 | 102 | 54 | 0 | 24 |
| | RWTH Aachen | GE2 | 138 | 18 | 12 | 12 |
| | School of Finance and Management | GE3 | 76 | 74 | 18 | 12 |
| | TU Berlin | GE4 | 78 | 90 | 0 | 12 |
| | TU München | GE5 | 114 | 54 | 0 | 12 |
| | Uni Frankfurt am Main | GE6 | 120 | 40 | 0 | 20 |
| | Uni Köln | GE7 | 108 | 60 | 0 | 12 |
| | Uni Mannheim | GE8 | 131 | 37 | 0 | 12 |

**Table 3: Overview of the study course workload (credits)**

For comparing the study programs to "body of knowledge" (tab. 4, 5) has been adopted point of view, to what extent are the courses included in the study plans by content, not by name. If the content is in more courses, there is a summation of credits and hours, but objects extending or deepening "body of knowledge" are not included in the assessment. The analysis considered the samples in relation to the workload (tab. 4, 5) and to the total number of hours of the study program, shows the differences in the representation of the various courses only within their extreme value and overall, and, the content overlaps both samples in quality, but not in quantity.

The average share of "body of knowledge" has in the programs of German universities in comparison with Czech universities a greater result in the terms of workload (44.87/31.80), as well as the number of hours (50.47/33.91), and indicates a greater concentration on the focus of the study. Analysis of study programs in relation to the "body of knowledge" affected only part of the courses, focusing largely on theoretical preparation. Therefore, it was further deepened by including courses of applied nature assuming there to be a greater impact on preparation for actual practice in a work environment, and therefore, does influence competitiveness.

| Course | CZ 1 | CZ 2 | CZ 3 | CZ 4 | CZ 5 | CZ 6 | CZ 7 | CZ 8 |
|---|---|---|---|---|---|---|---|---|
| Informatics | 5.5 | 4.4 | 0.0 | 1.6 | 0.0 | 0.0 | 5.0 | 2.7 |
| Macroeco-nomics | 3.3 | 3.3 | 0.0 | 3.3 | 4.4 | 2.7 | 3.3 | 3.3 |
| Management | 3.3 | 2.7 | 2.7 | 2.7 | 4.4 | 2.7 | 2.2 | 2.7 |
| Marketing | 1.6 | 2.7 | 0.0 | 3.3 | 4.4 | 2.2 | 2.7 | 2.7 |
| Mathematics | 3.3 | 6.1 | 2.7 | 6.1 | 3.3 | 6.1 | 5.5 | 6.6 |
| Microeco-nomics | 3.3 | 3.3 | 0.0 | 3.3 | 4.4 | 2.7 | 3.3 | 3.3 |
| Business Economics | 3.3 | 2.7 | 2.7 | 6.6 | 4.4 | 2.7 | 2.7 | 3.3 |
| Finance | 3.3 | 2.7 | 0.0 | 3.3 | 0.0 | 0.0 | 0.0 | 3.3 |
| Law | 2.7 | 2.2 | 2.7 | 2.7 | 2.2 | 3.8 | 1.6 | 2.2 |
| Statistics | 3.3 | 3.3 | 5.5 | 2.7 | 5.5 | 2.7 | 2.7 | 3.3 |
| Accounting | 2.7 | 0.0 | 2.7 | 0.0 | 0.0 | 4.4 | 2.7 | 2.2 |
| Total | 36.11 | 33.89 | 19.44 | 32.77 | 33.33 | 30.56 | 32.22 | 36.11 |

**Table 4: A breakdown of courses in proportion to the total work load (credits per course / 180) %.**

| Course | GE1 | GE2 | GE3 | GE4 | GE5 | GE6 | GE7 | GE8 |
|---|---|---|---|---|---|---|---|---|
| Informatics | 3.3 | 3.3 | 3.3 | 6.6 | 0.0 | 6.1 | 3.3 | 6.6 |
| Macroeco-nomics | 3.3 | 3.3 | 3.3 | 2.2 | 6.6 | 10.0 | 5.0 | 4.4 |
| Management | 5.0 | 0.0 | 0.0 | 3.3 | 3.3 | 3.3 | 0.0 | 6.6 |
| Marketing | 1.6 | 0.0 | 3.3 | 3.3 | 3.3 | 2.7 | 5.0 | 6.6 |
| Mathematics | 1.6 | 6.6 | 3.3 | 6.6 | 3.3 | 5.5 | 3.3 | 0.0 |
| Microeco-nomics | 3.3 | 6.6 | 3.3 | 2.2 | 0.0 | 10.0 | 5.0 | 4.4 |
| Business Economics | 5.0 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 5.0 | 4.4 |
| Finance | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 9.4 | 5.0 | 6.6 |
| Law | 3.3 | 5.0 | 3.3 | 3.3 | 6.6 | 2.7 | 3.3 | 7.7 |
| Statistics | 6.6 | 3.3 | 0.0 | 6.6 | 3.3 | 8.3 | 6.6 | 4.4 |
| Accounting | 5.0 | 6.6 | 3.3 | 3.3 | 3.3 | 6.1 | 10.0 | 3.3 |
| Total | 41.67 | 41.66 | 30.67 | 44.44 | 36.66 | 67.77 | 51.67 | 44.44 |

**Table 5: A breakdown of courses in proportion to the total work load (credits per course / 180) %.**

## Analysis of courses portfolio

For the analysis of courses portfolio, it was necessary to limit the courses to compulsory courses because the elective courses pose too wide and heterogeneous spectrum. What is important to note is that elective courses in the sample of German universities are organized into specialized modules and the detailed data of courses are not publicly available. The portfolio analysis of compulsory courses was further organized into more general course groups (Humanities, Natural Sciences, Informatics, Economics, Management, and Law) so that the portfolio balance could be assessed. For courses occurring in at least half of the schools, the percentage share of the total extent of compulsory courses was evaluated and then its arithmetic mean and standard deviation for the sample of schools as a basis for comparison. Similarly, for each course the percentage of the active part (such as tutorials, seminars, and projects).

### Humanities in the curricula in Czech and German universities

Analysis of the curricula of the Czech universities showed that social sciences were reflected in the curriculum in some capacity (through compulsory and elective subjects). Courses titles, their content and scope were not identical in any way and therefore we categorized them by theme. For example, Psychology encompassed courses titled, Psychology for Economics, Psychology of Personality Traits, Social Psychology, and Managerial Psychology. Course titles under the subject of Philosophy included, Basics of Philosophy, Social Sciences in Management, among others. The greater number of courses in the curricula in comparison with other areas of Humanities subjects are Psychology and Foreign Languages (tab. 6). The question is whether the representation of these subjects affect the aforementioned competencies that employers feel they lack in the workforce in the Czech Republic.

| Course | Sample of Czech schools | | | | Sample of German schools | | | |
|---|---|---|---|---|---|---|---|---|
| | Share (%) | | Active part % | | Share (%) | | Active part % | |
| | μ | σ | μ | σ | μ | σ | μ | σ |
| Psychology | 3.07 | 1.62 | 36.24 | 15.50 | 0 | 0 | 0 | 0 |
| Philosophy | 1.10 | 1.45 | 28.33 | 14.42 | 0 | 0 | 0 | 0 |
| Political Sci-ence | 0.45 | 1.18 | 34.16 | 11.01 | 0 | 0 | 0 | 0 |
| Sociology | 0.75 | 1.33 | 28.33 | 14.42 | 0 | 0 | 0 | 0 |
| Foreign Language | 10.71 | 3.47 | 40.71 | 13.47 | 0 | 0 | 0 | 0 |

**Table 6: Humanities courses in the study plans**

The analysis of the curricula of German universities discovered only at one school a comparable course within the compulsory framework. A closer comparison with such a low manifestation did not seem useful. It also seems plausible to state that the German universities offer elective courses, which strengthen the soft skills of their students and do not consider these skills as the essential part of the curricula. Another factor may be the fact that the foundations of Humanities are already being taught in secondary schools to some degree, and these skills are only strengthened at the university level. The issue of soft skills is but often criticized in terms that German universities do not produce graduates with flexible profiles for employment. In 2007 the authors of "Abschied von Humboldt?: Reformprozesse an deutschen Hochschulen" pointed out that the curricula of university education will have to adapt to the Bologna Process in order to increase the employability skills of students (Behrens, 2007:21). However, no courses can be found within the curricula that strengthen and train soft skills. The same universities on the other end mention that, and it is often stated: '*Soft skills are an essential success factor for the career; they are regarded as key qualifications in the working world. They include all skills that go beyond professional competences.* ' (Absolventa, 2016).

When it comes to languages, Germany has a natural advantage as German is considered a world language. Learning a foreign language in German universities is focused only on prerequisite course for elective semester abroad. It can be presumed that their secondary level knowledge of a foreign language is sufficient prior to entering the university setting. However, in Czech universities, the opposite is seen, as the education of a foreign language is lacking and Czech students need to be "reequipped" with the competencies which are standard to the framework of the foreign language requirement. A relatively high proportion of this education reduces the "core of knowledge" significantly and it should be replaced by partial teaching in English. However, after a strict assessment of the student's pre-existing knowledge during the admissions process. Given the importance of language skills for international competitiveness, universities should also offer elective courses in other languages, as well.

### Natural Sciences in the curricula in Czech and German universities

The problem of this subchapter is the preparation of students in mathematics before entering university. The Czech secondary school system is comparable in terms of quantity (13 years), but in terms of quality in the subject teaching area of mathematics is very different (Walterová, 2016). The graduation requirements at a German Gymnasium (Abitur) is the only prerequisite for admission to all types of German universities. If graduates from a secondary school in Germany (Realschule) want to study at university, they have to undertake a supplementary program. For other types of secondary educations (e.g. Hauptschule), there is no transition to Gymnasium or even studying at university. Generally, Mathematics is taught in the same format in both the Czech and German universities (tab. 7), the difference being quality and that in Germany there is more of a focus on practical exercise, done in smaller groups (Walterová, 2016).

| Course | Sample of Czech schools ($V_1$) | | | | Sample of German schools ($V_2$) | | | | Ratio $V_2$/ $V_1$ (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Share (%) | | Active part (%) | | Share (%) | | Active part (%) | | Share | Active part |
| | μ | σ | μ | σ | μ | σ | μ | σ | | |
| Mathematics | 3.60 | 1.65 | 44.9 | 14.4 | 3.61 | 0.95 | 50 | 0 | 91.16 | 111.36 |
| Statistics | 3.47 | 1.52 | 52.1 | 5.51 | 4.10 | 1.63 | 50 | 0 | 118.15 | 95.96 |

**Table 7: Mathematics and Statistics in the study plans**

The course of Statistics in Germany is given an overall higher level of educational, which can be applied within the professional level of students' works; the difference in active teaching between Statistics and Mathematics is slightly lower.

## Informatics in the curricula in Czech and German universities

When comparing the teaching of Informatics in the Czech Republic with Germany, Germany has a lower percentage (tab. 8). It is quite common that in Germany, the educational system is quite conservative, however when it comes to Applied Informatics, there are many purchasing options for software related to the field. Course Catalog „Betriebswirtschaftslehre" at the University of Manheim (Universität Mannheim, 2016) offers a numerous course details which include the term Software (e.g. Financial Accounting, Unternehmensbesteuerung, or Service Operations Management), which evidences that the Informatics is an integral part of the university education. Another difference can be noted in the context of the interpretation of Table 8 where we can see a higher proportion of practical teaching of classes. One can conclude that this is due to better teaching conditions such as fully equipped laboratories and a lower number of students working in those conditions.

| Course | Sample of Czech schools ($V_1$) | | | | Sample of German schools ($V_2$) | | | | Ratio $V_2$/ $V_1$ (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Share (%) | | Active part (%) | | Share (%) | | Active part (%) | | Share μ | Active part σ |
| | μ | σ | μ | σ | μ | σ | μ | σ | | |
| Informatics | 4.58 | 2.29 | 40.6 | 18.8 | 2.81 | 1.44 | 50 | 0 | 61.35 | 123.00 |

**Table 8: Informatics in the study plans**

German universities from this point of view are ultra-conservative: all universities in this sample teach Informatics only, however one in particular (Technical University Berlin) offers moreover an additional course Databank Systems. Czech universities offer a more diverse range of additional IT courses (Database Systems, E-Technology, Introduction to the study of systems, and many others).

## Economics in the curricula in Czech and German universities

Analysis of the economic courses (tab. 9) in the sample of universities did not show any principle differences within the content framework for Economics in terms of compulsory and even elective courses. In the terms of basic economic courses, it can be stated that, in German

| Course | Sample of Czech schools ($V_1$) | | | | Sample of German schools ($V_2$) | | | | Ratio $V_2$/ $V_1$ (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Share (%) | | Active part (%) | | Share (%) | | Active part (%) | | Share | Active part |
| | μ | σ | μ | σ | μ | σ | μ | σ | | |
| Macroeco-nomics | 3.0 | 1.2 | 40.6 | 18.6 | 5.2 | 2.0 | 45.4 | 6.6 | 171.3 | 111.7 |
| Marketing | 2.6 | 1.2 | 35.4 | 16.5 | 3.4 | 2.2 | 42.3 | 18.3 | 131.9 | 119.6 |
| Microeconom-ics | 3.0 | 1.2 | 43.7 | 17.6 | 4.7 | 2.8 | 39.1 | 17.1 | 157.4 | 89.9 |
| Business Economics | 3.6 | 1.3 | 43.7 | 8.6 | 4.4 | 0.9 | 54.1 | 19.4 | 122.2 | 123.8 |
| Business Finance | 1.5 | 1.6 | 20.8 | 23.1 | 4.9 | 2.4 | 49.4 | 1.6 | 324.8 | 237.0 |
| Accounting | 2.0 | 1.8 | 27.1 | 23.4 | 5.8 | 2.0 | 47.2 | 10.7 | 277.5 | 174.4 |

**Table 9: Economics in the study plans**

universities, the evidence shows that there is a higher regard of more active forms of teaching, with more lectures offering a more interactive aspect, and students needing to resolve situations involving a problem-solving tasks actively, rather than through passive lectures. The absence of certain courses is not because they have been omitted, but rather from the system of study from the German institutions. It appears that there is an implementation of a course outline, or block of modules, clustered under categories, for example, Betriebswirtschaftslehre is the name of a module, whereas in Czech institutions courses are labelled under individual course names, such as Business Economics. The shift within the understanding of courses also takes place in German universities, which rather promotes managerial topics and a background to get the original Woehe's (1960) enterprise administration approach. This trend can be justified by the fact that the sample of selected German schools are among the top schools in the field of Economics and the schools sampled are in the process of applying for international accreditation and certification (mostly from the USA) or are already accredited.

## Management in the curricula in Czech and German universities

From the analysis of study plans in the research sample of universities in the area of Management, it was revealed that a broad spectrum of management courses are offered in both Czech and German institutions. Relative to the traditional enterprise administration approach (control functions as a part of enterprise functions), an anticipated absence of the term of management in German Economic universities was not evident. When comparing the content and scope of courses in the sample (tab. 10), it is evident that the course, Management, which is a general introduction to the study of management (General Management) is essential for all Czech schools as well as, six of the German schools.

Another result was the evidence of the course, Human Resources Management, although in German institutions, it was seen in combination with Organization. Important is as well the course Operational Management (along with its analogs Production, Logistic or Supply Chain Management) and various courses characteristic as Managerial Competencies with a higher proportion of active teaching in the sample of Czech universities. In the half of the Czech universities sampled, a course of Quality Management was evidenced, which was absent in the German sample. Representation of Strategic management in both samples was very sporadic, with more to be expected in a Master's program. The reliability of the results is adversely affected by various occurrence of courses within the sample, where the coefficient of variation does not exceed 50% only in the generally accepted course of Management.

| Course | Sample of Czech schools ($V_1$) | | | | Sample of German schools ($V_2$) | | | | Ratio $V_2$/ $V_1$ (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Share (%) | | Active part % | | Share (%) | | Active part % | | Share | Active part |
| | μ | σ | μ | σ | μ | σ | μ | σ | | |
| General Management | 3.21 | 0.9 | 33.1 | 14.4 | 3.59 | 2.9 | 50 | 0 | 111.8 | 151.5 |
| Operational (Production, SCM) Management | 1.65 | 1.6 | 37.2 | 7.36 | 3.45 | 2.8 | 50 | 0 | 209.1 | 134.4 |
| HR Management | 2.57 | 1.7 | 43.2 | 8.33 | - | - | - | - | 135.0 | 115.7 |
| Organizing and HR | - | - | - | - | 3.47 | 2.8 | 50 | 0 | | |
| Managerial Competences | 1.49 | 1.5 | 49.7 | 11.6 | 2.80 | 3.7 | 50 | 0 | 187.9 | 100.6 |

**Table 10: Management in the study plans**

In relation to the given hypothesis ("Business Economics programs at German universities differ in ways that can boost competitiveness"), the analysis shows that in German universities there is a higher proportion of compulsory courses related to managerial processes and with a higher concentration on active learning. The difference is particularly evident among courses with a direct connection to management of production processes and interacting with subordinates, which thus leads to the inference of having a greater impact on competitiveness. That was less evident by the courses with more factographic content, such as General Management or Human Resource Management, which do not have a direct link to actual business processes. It can be assumed, they have a smaller impact on competitiveness. The inability to access information about the content of elective subjects in the sample of German schools has emerged as a major limitation for further enhancing the analysis.

## Law in the curricula in Czech and German universities

Czech universities only offer courses generally aimed at law under a diverse listing of course titles such as (Law, Basics of Legal Systems, Basics of Law, Law for Economists, etc.). As far as other legal courses are concerned, it is more often the case that courses available are aimed at Business Law, respectively its sector - business corporations' law. Commercial law is considered marginal in the overall number of course hours (tab. 11). Elective legal courses are offered sporadically and in most cases, are geared towards Labour Law, in most cases, EU Labour Law. During the course, there is more of an emphasis on lectures and seminars and overall, are offered to a lesser extent, if at all. For these reasons, legal courses were itemized into one single column in the framework of examined subjects.

| Course | Sample of Czech schools ($V_1$) | | | | Sample of German schools ($V_2$) | | | | Ratio $V_2$/ $V_1$ (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Share (%) | | Active part% | | Share (%) | | Active part % | | Share | Active part |
| | μ | σ | μ | σ | μ | σ | μ | σ | | |
| Courses with a legal basis | 2.27 | 0.67 | 25.21 | 17.98 | 6.77 | 2.3 | 50 | 0 | 298.24 | 198.33 |

**Table 11: Law in the study plans**

For the legal courses at German universities, it is evident that law is given more magnitude in the area of courses, lectures and practical exercises. The ratio of seminars to lectures is 1:1, whereas in the Czech Republic it was significantly less, if at all. The courses at the German institutions are geared less towards the Theory of Law and Jurisprudence and courses on Public Law are not evident in the framework. Courses appear to be focused solely on Private Law, more concretely, Business Law for Corporations and Civil Law. On the other hand, however, Labour Law was not evident in the sampled framework, nor was EU Law.

In terms of the focus of this article, we assume that the cooperation between universities and practice, as one of the soft indicators of competitiveness (Klvačová 2005: 31), is perhaps where there are programs linked with practice. Such links naturally excludes too theoretically oriented teaching that we are much more experienced by the programs realized by Czech universities. Conversely, greater specialization, which manifests itself at German universities, allows specific connection with practice.

## Comparison with the study program of the University of Applied Sciences

The source of a quality workforce for German economy are not only universities, but also the universities of applied sciences (Fachhochschule) primarily oriented to practical requirements. In 2014 there were 108 662 university Bachelor degree graduates but the university of applied sciences graduated 113 523 (HRK, 2016). The study programs of the universities of applied sciences are more focused on practice. Similar in content as the Czech universities, but with more of an emphasis on the practical application of a theoretical background including training in managerial skills. As an example can be noted the three-year Bachelor program, Business Administration (with the focus on management positions in small and middle level enterprises) offered by the Business School Berlin Potsdam (Business, 2014). If it is compared with the program of Business Economics and Management offered by the Prague University of Economics, Faculty of Business Administration (Fakulta podnikohospodářská, 2014), significant differences are evident (Komárek, 2015). The structure of these programs as a whole is not easily comparable (e.g. foreign languages, projects), but it is obvious there exists a greater workload for theoretical courses in the Prague program (141 credits / 110 credits). The program from Berlin includes courses focused in more detail on practical application and especially on two projects (30 credits!) for real contracting authority, solved partially in the workplace of contractor and thereafter realized. Predominantly there is more of a theoretical focus in the Prague program and this is even more apparent with how the courses are being taught. The courses overall, such as Management, Marketing, Consumer Behaviour, and Psychology and Sociology are in lecture form only and taught without any practical exercises (Fakulta podnikohospodářská, 2014).

## Study programs for the Applied Management

Competitiveness of the economy do not affect only the study programs of Business Economics, but as well production oriented study programs, which graduates are in just about the same numbers (MŠMT, 2016b). Within these programs, it is possible to divide them further for creative and service-oriented positions, for which it is necessary as a prerequisite to have a certain level of economic and managerial competence provided just in the fields of Applied Management. In this context, it would be necessary to emphasize that every managerial personal position needs in most cases to be filled with someone who has a university degree (more often required in the public administration) and even professional staff needs to have some skills necessary to plan and organize as well as communicate effectively.

The reasoning behind study programs of Applied Management illustrates its current state. If we apply Cluster Analysis on a study program such as Economics and Management, we come to the interesting result that the term, Economics can be seen in the database of accredited study programs (MŠMT, 2016a) 145 times and the term Management occurs 339 times. What is the cause of this significant difference indicates further analysis - only 152 fields containing the name of "management" belong to the economic programs, majority of other notably to the engineering programs. Because Management is considered in enterprise administration approach as a part of Economic Science, study programs such as Economics and Management include an obligatory quota of mainly theoretical economic courses. To make this approach more consistently applied, the Accreditation Commission (Akreditační komise, 2014) approved standards for study programs in the field of Applied Management in the interpretation*: 'Applied management means degree studies that combine specific professional disciplines (Engineering, Agriculture, Arts etc.) with the education of experts in the (Economics and) Management. In addition to Management on a certain theoretical level supplemented with methods and techniques of management, Human Resources Management, Management skills and the Basics of Psychology and Sociology must also be included as well as other economic sources - Principles of Economics, Marketing, Law (as the Basics of Law) or Statistics'.* Nevertheless, Law and Statistics are not Economics subjects and Principles of Economics are Microeconomics and Macroeconomics. The question is, how is memorizing dozens of macroeconomic graphs going to contribute to the success of the business? But if in all non-economic fields of study there existed the inclusion of Basics of Business Economics, it would most likely, contribute to an increase in international competitiveness more than ten thousand partial projects of the Operational Program Education for Competitiveness (MŠMT, 2016c).

Analysis of non-economics related study programs corresponding to Applied Management exceeds the extent of this paper, however a preliminary analysis of a sample of 120 Bachelor degree programs offered in Germany aimed at Engineering and Technology (Bachelorsportal, 2016) resulted in the following findings:

- All of the study programs include compulsory courses of Management or Business Economics;
- A small portion of study programs shares an interdisciplinary trait (e.g. Engineering and Management, Industrial Engineering) and they include compulsory courses namely Fundamentals of Economics (or Business Economics), Accounting and Financing;
- Focus on operation (corresponding to the concept of Applied Management) is addressed in the study program curriculum through elective specialized modules (for example, Production-, Quality-, Project-, SCM Management), but no further expansion in Economics.

Study programs, which do not contain economic courses, are reflective influences from overseas concepts of Management outside the framework of Economics and are typical for modern universities of applied sciences. Both Business Economics and Management have undergone divergent evolution over the last fifty years. Business Economics as a description of the enterprise functions has remained essentially unchanged (Wöhe and Döring, 2013), and Management has developed from ambiguously defined conceptions into independent teaching with the number of separate disciplines. The new status as a higher education course and even as a study program include Strategic, Human Resources, Crisis, Risk, Change, Knowledge, Project, Information, Business Process, Operational, Safety, Environmental, Quality and of course Business Management. An economic foundation may have, in addition to Business Management, also Strategic, Crisis, and Risk Managements (if oriented on business) courses, whereas others are based largely on the Humanities, Systems and Technical Sciences.

In this context, it is interesting that in the System of study programs of the Slovak Ministry of Education the study program Management is listed separately from the program of Business Economics and Management with the following explanation. '*The current study courses are not engaged exclusively in management with the aim of educating the general manager primarily for a line management position. They combine the profession of manager with the enterprise economist's profession. They gear graduation on the values of business processes and suppress comprehensive and integrated perception of an enterprise. A universal manager such as integrator and coordinator is a separate control profession by itself'* (Akreditačná komísia, 2016). It should be noted that the basic condition of existence of humankind is material production and its distribution. In them has decisive share the mass production and worldwide distribution, which require a mass of line managers, not entrepreneurs.

## Discussion

The analysis of Bachelor's degree programs selected for the sample of Economics faculties in Czech and German universities resulted in fundamental knowledge in relation to the impact on competitiveness:

- The proportion of elective courses in the overall study workload in the sample of German universities was more than double (2.31 times) and testifies to the greater flexibility of study programs due to the differentiated needs of the workplace; organizing elective courses into elective modules replaces dividing program into separately accredited fields and increases the effectiveness of learning and even, its administration;
- The "core of knowledge" of the compared study programs Economics and Management (Czech) and Business Economics (German) in compulsory courses does not differ substantively, after all, both programs are based on the same methodological basis - Wöhe's approach to the enterprise functions; at German universities but manifests itself approaching the overseas conception of Management outside the Doctrine of Business Economics;
- A greater proportion of "core knowledge" in the overall study workload in a sample of German universities shows a greater concentration on the essence of the subject of study, especially absent Humanities, but for example Physical Education;
- The fundamental difference is significantly higher proportion of active forms of teaching in a sample of German universities, both in the courses (always 50%) and the inclusion of practice (part of the Bachelor thesis, internship in a workplace);
- A detailed analysis of study programs according to the fundamental teachings (Humanities, Science, Informatics, Economics, Management, and Law) shows that in a sample of German universities are more applied application oriented courses. The reliability of the results is adversely affected by various occurrence of courses

within the sample, where the coefficient of variation exceeds 50% in the most cases.

- Study programs in German universities do not include compulsory foreign language courses and it can be assumed that the level of foreign language attained in secondary schools is already sufficient. However, programs in Czech universities include at least one compulsory foreign language. The high proportion of language instruction reduces the course load of "core of knowledge" and that should be replaced by teaching courses in English. Given the importance of language skills for international competitiveness, Czech universities would benefit from offering elective studies in other languages.
- Czech universities are unlike German forced to focus more on teaching Mathematics and Informatics to catch up shortages of secondary schools and reducing differences in input assumptions.
- Completion of studies in German universities is associated to the delivery of a Bachelor thesis, whereas the Czech model is linked with a defence of a thesis before a state examination board, the major difference being the absence of oral exam in German universities, long-term knowledge and skills are favoured over one-time performance.

The related data justifies the validity of the hypothesis "Business Economics programs at German universities differ in ways that can boost competitiveness" such that German study programs are more focused on practical application in a work environment. It is important to note that in this context we can consider only the possible effect (tendencies) on competitiveness of the economy, among many other relevant factors. However, even in Germany the preparation of graduates for practice is not always considered as satisfactory (Behrens, 2007: 21).

A specific factor of tertiary education in Germany is equal representation for Bachelor's and Master's degrees at the universities of applied sciences, which are strongly geared towards the needs of actual practice. In this context, it is necessary to consider the current marginal status of higher vocational schools (tertiary professional schools) in the Czech Republic as a missed opportunity (originally expected also orientation on the Bachelor study). An indicative analysis of non-economic Bachelor study programs in Germany illustrates the problematic concept of standards by Accreditation Commission for study programs in Applied Management and warns of the possible threat it may pose by being taken over by a National Accreditation Office.

## Conclusion

Reflection of the findings from a comparison of curricula Czech and German universities may apply especially in the context of the forthcoming implementation of the amendment to the Higher Education Act. The current state of Regulation No. 275 (ČR, 2016b), particularly regarding the Areas of Education cannot be considered as satisfactory. The skills of graduates described in the Area of Education "Economics" correspond more to the position of the macroeconomist of central bank but in the examples of positions for graduates, an entrepreneur is absent. Furthermore, there are not differentiated requirements for professionally oriented or academic study programs. The content of each Area of Education is not formally unified, even though its structure (educational descriptors), was unambiguously defined in the research project Q-Ram (Černikovský, Hnilica and Pasáčková, 2012). When from the practice point of view are paramount importance given the "soft skills", so that the content of Areas of Education is completely unresponsive. Practically in each of the 37 Areas of Education is stated (or can be assumed) the ability to obtain a leadership position, but nowhere is mentioned the requirement of adequate managerial skills. The problem is not so much in search of "soft skills" in the individual Areas of Education, but the lack of general managerial requirements for graduates at all.

However, what is most alarming that in every Area of Education is first mentioned in the example of graduate employment "in academia." It may be an unintentional misunderstanding of priorities, but also a reflection of existing development. Higher study for the current practice requires a corresponding knowledge, of that is still less in the domestic academic environment, because the results achieved in practice are not counted due to the "hunt for impacts". As a result, there is an increasing share of academic staff with qualification obtained exclusively within the continuous studies Bachelor-Master-Doctor. It seems that still a long way can be expected to increasing the efficiency of higher education for to support competitiveness of the current and especially future Czech economy.

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# BAYESIAN DIAGNOSTICS FOR TEST DESIGN AND ANALYSIS

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*Highlights*

- *This paper extends Classical Test Theory statistics to the Bayesian framework and admits inference*

**Abstract**

This paper attempts to bridge the gap between classical test theory and item response theory. It is demonstrated that the familiar and popular statistics used in classical test theory can be translated into a Bayesian framework where all of the advantages of the Bayesian paradigm can be realized. In particular, prior opinion can be introduced and inferences can be obtained using posterior distributions. In classical test theory, inferential decisions are based on the values of statistics that are calculated from the responses of subjects over various test questions. In the proposed approach, analogous "statistics" are constructed from the output of simulation from the posterior distribution. This leads to population- based inferences which focus on the properties of the test rather than the performance of specific subjects. The use of the JAGS programming language facilitates extensions to more complex scenarios involving the assessment of tests and questionnaires.

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## Introduction

The important problems of test/questionnaire design and analysis have historically been ap- proached from either the perspective of *classical test theory* (CTT) or *item response theory* (IRT). Both of these research areas have an extensive literature where numerous comparative studies have been carried out (e.g. Hambleton and Jones 1993, Fan 1998, Guler, Uyanik and Teker 2014, Kohli, Koran and Henn 2015, Raykov and Marcoulides 2016).

As research developments have progressed, the distinction between classical test theory and item response theory has narrowed. However, in a very brief and perhaps oversimplified com- parison of the two approaches, CTT is the original testing framework and essentially concerns the results of test questions on a specific sample of respondents and has few (if any) modeling assumptions. One of the appealing aspects of CTT is that the corresponding statistics are relatively simple and guidelines have been introduced for the assessment of these statistics. In the IRT framework, more complex models are considered where these models have components (i.e. parameters) that distinguish particular aspects of tests and are generalizable to a population of respondents. IRT relies more on statistical theory and is less accessible to some practioners. IRT has grown in many directions where various models have been proposed. Most notably, Bayesian implementations of IRT now exist (Fox 2010, Levy and Mislevy 2016), and these require another level of statistical sophistication on the part of thepractitioner.

In this paper, we demonstrate how some of the very simple and still popular statistics of CTT can be directly translated into a Bayesian IRT framework. The advantage to the practitioner is that they may continue using familiar measures but simultaneously take advantage of the utility of the Bayesian paradigm. For example, they can introduce subjective prior opinion (if deemed necessary) and they can view their familiar measures from the perspective of populations (using posterior distributions). In addition, the use of the JAGS programming language (Plummer 2015) facilitates extensions to more complex scenarios involving the assessment of tests and questionnaires.

In Section 2, we provide the background for the typical testing framework involving dichotomous responses arising from test questions. In this context, some of the common statistics used in CTT are provided. This scenario is then imbedded into a Bayesian framework and it is demonstrated how the familiar testing measures can be easily translated into Bayesian diagnostics. Initially, a very simple prior distribution is introduced. In this section, we emphasize the ad- vantages of the proposed approach over the use of the familiar statistics used in CTT. We also demonstrate how missing data pose no difficulty.

In Section 3, we examine some real data taken from the aviation industry that consists of the results of multiple-choice questions given to pilots. We compare the traditional statistics with analogous Bayesian diagnostics. We also consider several extensions to the basic model introduced in Section 2. In particular, we introduce a more realistic prior which recognizes that some questions are more/less difficult for most respondents and that some respondents are stronger/weaker across most questions. The prior is also beneficial in that it reduces the effective dimensionality of the parametrization. We also indicate how the model can be extended to account for different instructors who have an effect on the performance of their students. Finally, we provide a discussion in Section 4 and a short conclusion in Section 5.

## Materials and Methods

We consider test data presented in a $n \times k$ matrix $X = (x_{ij})$ where the $n$ rows correspond to the respondents and the $k$ columns refer to the test questions. The data are dichotomous (binary) where $x_{ij}$ = 1(0) specifies that the $i$th respondent provides a correct (incorrect) answer to the $j$th question. Therefore, the setup is applicable to true/false questions and to multiple-

choice questions. For questions with ordinal grading, it is possible to introduce a threshold that corresponds to pass (fail) so that such questions can also be analyzed within the above framework.
In CTT, there are various statistics that have been proposed to assess the characteristics of test questions and the overall test. We now review three of these statistics. The first statistic, sometimes referred to as the *P-value*, is calculated on each of the $k$ test questions. For the $j$th question, its P-value is defined as

$$p_j = \frac{1}{n}\sum\nolimits_{i=1}^{n} x_{ij} \qquad (1)$$

and is the proportion of correct responses on the $j$th question. Typically, a question is not viewed as a "good" question if its P-value is either too close to 0 (the question is difficult) or too close to 1 (the question is easy). In such cases, there is little testing taking place since most respondents have the same result.
The second statistic that is referred to as the *discrimination index* is also calculated for each of the $k$ test questions. For the $j$th question, its discrimination index is defined as

$$d_j = \frac{N_{Uj} - N_{Lj}}{n/2} \qquad (2)$$

where $N_{Uj}$ is the number of `strong' students who answered the $j$th question correctly and $N_{Lj}$ is the number of `weak' students who answered the $j$th question correctly. The subscripts $U$ and $L$ denote `upper' and `lower' respectively. The strong and weak students are categorized into two groups according to their overall test score where the test score for the $i$th student is given by $x_{i.} = \sum\nolimits_{j=1}^{k} x_{ij}$ . When $n$ is even and the order statistics $x(n/2)$ and $x(n/2+1)$ differ, then the two groups form a partition of the set of the $n$ respondents. In other cases, slight adjustments are made in forming the two groups. The discrimination index lies in the interval $(-1, 1)$ where large positive values are viewed as desirable (strong students do better on the question than weak students), values near zero indicate that the question does not differentiate between strong and weak students, and negative values are viewed as undesirable (weak students do better on the question than strong students).
The third statistic which is referred to as *Cronbach's alpha* is used to describe the *reliability* or *internal consistency* of the overall test. It is defined as

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum\nolimits_{j=1}^{k} s_j^2}{s_X^2}\right) \qquad (3)$$

where

$$s_j^2 = \sum\nolimits_{i=1}^{n} (x_{ij} - \overline{x}_j)^2 / n$$

is the variance with respect to the $j$th question and

$$s_X^2 = \sum\nolimits_{j=1}^{k} s_j^2 + 2\sum\nolimits_{j_1<j_2} \sum\nolimits_{i=1}^{n} (x_{ij_1} - \overline{x}_{j_1})(x_{ij_2} - \overline{x}_{j_2}) / n$$

is the overall test variance. Cronbach's alpha is constrained to the interval $(-\infty, 1)$ where values near the upper limit are generally preferred (DeVellis 2012). However, we note that various criticisms have been made related to the above interpretation (Sijtsma 2009). For example, if for a given subject, the $k$ questions all have the same response, then the questions are redundant, which is obviously not desirable. However, in this case, $\alpha = 1$.
Before introducing the Bayesian analogue corresponding to CTT, there are two points that we wish to emphasize. First, although IRT has overtaken CTT in various ways, the CTT statistics (1), (2) and (3) are still widely used in practice (see for example, Yuan et al. 2012, Brozova and Rydval 2014). Second, as forcibly argued in the IRT literature (e.g. Hambleton and Jones 1993), an important feature of the more complex IRT models is that *item* (question) performance is linked to respondent ability. In other words, the results on test questions vary according to the strength of the student. The models and methods introduced in this paper preserve the simplicity of the common CTT statistics yet allow for the interplay between item performance and ability.Our approach is based on simple Bernoulli models where $x_{ij} \sim \text{Bernoulli}(\theta_{ij})$. The model stipulates that the probablity of a correct answer by the $i$th respondent to the $j$th question is given by

$$\text{Prob}(x_{ij} = 1) = \theta_{ij}. \qquad (4)$$

An immediate reaction to (4) may be that the model is problematic since there are as many parameters $nk$ as there are data values. However, in a Bayesian approach, prior information is available and parameters may "borrow" from one another such that the effective parameterization is reduced.
Under (4), the development of measures comparable to the statistics (1), (2) and (3) is straight- forward. Instead of calculating (1), (2) and (3) based on the data matrix $X$, the calculations are carried out on the parameter matrix $\Theta = (\theta_{ij})$. And herein lies a possible second reaction - the $\theta_{ij}$ 's are unknown. How can one calculate "statistics" based on $\Theta$? The answer again relies on the Bayesian formulation. Under a simulation-based Bayesian approach, $\Theta$'s are generated from the posterior distribution, and each simulated sample gives rise to the analogous measures. An important added benefit is that we do not have a single observed statistic ($p$, $d$, $\alpha$) as in CTT, but rather, we have a posterior distribution corresponding to our new measures and this facilitates the assessment of variability. These features and other features are emphasized in the real data example presented in Section 4.
There is another attractive aspect of the Bayesian formulation. Whereas the statistics (1), (2) and (3) refer to the observed $X$ values, the Bayesian measures refer to theprobabilities associated with the questions and the respondents. And we suggest that this corresponds to the real problem of interest where the properties of the questions/respondents is more important to practitioners than the particular sample. The idea of focusing on population quantities (i.e. parameters) rather than statistics (i.e. data) has been previously explored; see for example Swartz (2011) in the context of clustering. We also mention that there is great flexibility in the approach. Not only can the statistics (1), (2) and (3) be translated to Bayesian versions, we can do likewise with any CTT statistic. The only additional ingredient that is required for the Bayesian implementation is the specification of a prior distribution on the parameters. Initially, we consider a somewhat unrealistic prior where we assume that the $\theta_{ij}$ are independent and identically distributed (iid) Uniform $(0, 1)$ random variables. The Uniform distribution is sometimes referred to as a reference prior; it is flat and has the required domain $\theta_{ij} \in (0, 1)$.
Above, we alluded to simulation-based Bayesian software. Accordingly, we use the JAGS programming language which is relatively simple to use and avoids the need of special purpose Markov chain Monte Carlo code. JAGS is open source software (www.mcmc-jags.sourceforge.net) which is very similar to WinBUGS. Details on WinBUGS and an introduction to the Bayesian approach are given by Lunn et al. (2013).

### Relationship of approach to IRT

Various models have been proposed in IRT. In a three-parameter logistic IRT model, we retain the notation above and express

$$\theta_{ij} = \frac{1-c_j}{1+\exp\left(-a_j\left(p_i-b_j\right)\right)} \quad (5)$$

where $p_i$ is the ability parameter for the $i$th respondent and $a_j$, $b_j$ and $c_j$ are characteristics of the $j$th test question.
The relationship (5) is known as an item response function (IRF). The IRF is an important feature of IRT and is typically plotted as a function of the ability $p_i$ for estimated test characteristics $\hat{a}_j$, $\hat{b}_j$ and $\hat{c}_j$. One of the notable differences between our approach and IRT is that we allow more freedom in the $\theta_{ij}$ parameters since the $\theta_{ij}$ are assigned a prior probability distribution. In IRT, the functional relationship is fixed according to (5) or by some alternative IRT model. Accordingly, in our framework, measures such as the Bayesian P-value and the Bayesian discrimination are not constrained by functional relationships.

### Missing data

The Bayesian model is appealing in its simplicity. Via the simulated parameters $\theta_{ij}$, researchers are able to investigate questions involving both respondents and test questions.
One of the added advantages of a Bayesian approach is the elegance and ease with which missing data can be handled. For example, there are exams where test questions are randomly generated from a databank for each student or subsets of students. In these situations, individual students answer only some of the questions. In this sense, there is missing data. We therefore distinguish between the observed data $x_{obs}$ and the missing data $x_{mis}$. Letting $[A \mid B]$ denote the generic conditional density of $A$ given $B$, the relevant posterior distribution in this case is

$$\begin{aligned}\left[\Theta, x_{mis} \mid x_{obs}\right] &\propto \left[x_{mis}, x_{obs}\right] \\ &= \left[x_{obs}, x_{mis} \mid \Theta\right]\left[\Theta\right].\end{aligned} \quad (6)$$

The key observation from (6) is that $\left[x_{obs}, x_{mis} \mid \Theta\right]\left[\Theta\right]$ is the unnormalized posterior density that one would obtain if $x$mis were actually observed. Therefore, one simulates as before except that $x$mis takes the role of a random parameter rather than a fixed data value. To handle missing data in JAGS, we need only code the unobserved data values with the NA symbol. We emphasize that this is incredibly easy to do.

## Results

We consider the results of a multiple-choice exam given to pilots where there are $n = 307$ respondents (pilots) and $k = 10$ test questions. In the aviation industry, safety is of paramount importance, and therefore, the proportion of correct answers must be very high. We first calculate various CTT statistics. For this dataset the vector of P-values is

$$p = (0.925, 0.837, 0.990, 0.967, 0.971, 0.932, 0.977, 0.993, 0.896, 0.951)'.$$

The vector for the discrimination index is

$$d = (0.150, 0.326, 0.020, 0.065, 0.059, 0.137, 0.046, 0.013, 0.208, 0.098)'$$

which indicates that all questions are answered better by the stronger students than by the weaker students. Cronbach's alpha is $\alpha = 0.492$ which (for many researchers) indicates that the test is reliable.
Since the P-value and discrimination index provide properties of the same test, they are sometimes interpreted jointly. In Table 1, we provide guidelines (Skoda, Doulik and Hajerova- Mullerova 2006) that have been proposed for a suitable test and have been endorsed by Brozova and Rydval (2014). Although practitioners may have alternative guidelines for a particular application, here we illustrate the utility of the proposed Bayesian with respect to the guidelines provided in Table 1.
We now present some results based on 1000 simulations from the posterior distribution. For

| P-value | [0.20,0.30] | [0.30,0.70] | [0.70,0.80] |
|---|---|---|---|
| Discrimination | ≥0.15 | ≥0.25 | ≥0.15 |

**Table 1: Recommended values for the P-value and discrimination index for a test question (Skoda, Doulik and Hajerova-Mullerova 2006).**

each simulation, the Bayesian P-value, the discrimination index and Cronbach's alpha were calcu- lated. In Figure 1, we provide the joint distribution of the Bayesian P-value and the discrimination index for questions 1 and 2. In contrast to the single paired observations ($p_1 = 0.925$, $d_1 = 0.612$) and ($p_2 = 0.837$, $d_2 = 0.788$), Figure 1 highlights that there is variability associated with each measure and uncertainty is expressed via the posterior distribution. In each of the plots, we have provided bars according to the guidelines in Table 1 which allows us to assess the suitability of the test questions. We observe a difference between the properties of question 1 and question 2. For example, question 2 is more difficult (i.e. the cloud of points is slightly shifted to the left). We also observe that there is more variability in the discrimination index than in the P-value.
We also observe in Figure 1 that the generated P-values are smaller than the traditional CTT statistics $p_1 = 0.925$ and $p_2 = 0.837$. This is due to the unrealistic $\theta_{ij} \sim$ Uniform(0, 1) prior distribution which shrinks the posterior distribution of $\theta_{ij}$ towards 0.5. In a particular application, we may have specific knowledge concerning the $\theta_{ij}$ values, and this knowledge can be incorporated into the prior distribution. We illustrate this flexibility in Section 4.
In Figure 2, we provide a density plot of the posterior distribution of the Bayesian version of Cronbach's alpha. Again, the figure highlights that there is variability associated with the measure. One of the frequent discussion points concerning the use of Cronbach's alpha is that its
interpretation is subject to the dimension of the $n \times k$ data matrix $X$. With the Bayesian version
of Cronbach's alpha, the observed variability depends on the dimension of $X$. We note that the posterior mean 0.075 in Figure 2 differs from the traditional CTT statistics $\alpha = 0.492$. In Section 4, we vary the prior and observe changes in the resultant posterior mean.

### A more realistic prior

We now turn our attention to the development of a more realistic prior, one which recognizes that some questions are more/ less difficult for most respondents and that some respondents are stronger/weaker across most questions. The intention is to introduce a prior distribution that leads to Bayesian CTT statistics that are more in line with the traditional CTT statistics. This allows practitioners to use the same calibration scales with which they are comfortable.

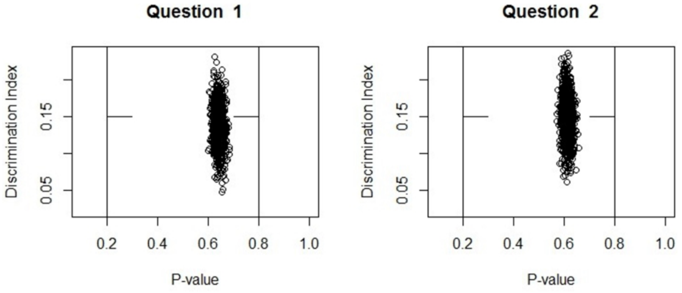


**Figure 1: Posterior simulations of the Bayesian P-value and discrimination index for questions 1 and 2 using the iid uniform prior. Horizontal lines are drawn to delineate the recommendations from Table 1.**

The suggested prior has the following assumed structure

$$[\Theta] = \prod_{ij} [\theta_{ij}]$$

where

$$[\Theta] \sim \text{truncated} - \text{Normal}\left(\mu_{ij}, \sigma_{ij}^2\right). \qquad (7)$$

In (7), the truncation corresponds to the interval (0, 1) and the parameters $\mu_{ij}$ and $\sigma_{ij}^2$ are specified according to an empirical Bayes procedure. The procedure first requires logistic regression involving the original data *X* where

$$\text{logit}\left(\theta_{ij} \middle| \beta_0, \alpha_i, \gamma_j\right) = \beta_0 + \alpha_i + \gamma_j. \qquad (8)$$

Logistic regression provides us with parameter estimates $\hat{\beta}_0, \hat{\alpha}_i$ and $\hat{\gamma}_j$. We then invert the logistic function and set

$$\mu_{ij} = \frac{\exp\left(\hat{\beta}_0 + \hat{\alpha}_i + \hat{\gamma}_j\right)}{1 + \exp\left(\hat{\beta}_0 + \hat{\alpha}_i + \hat{\gamma}_j\right)}$$

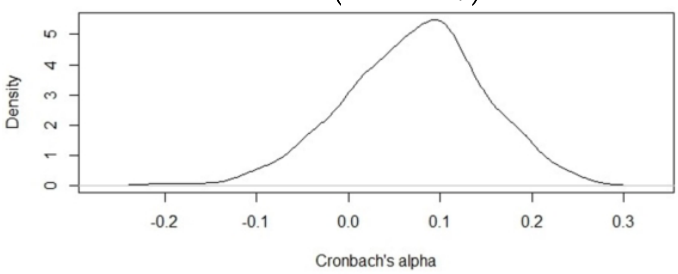


**Figure 2: Posterior density plot of the Bayesian version of Cronbach's alpha using the iid uniform prior.**

To set $\sigma_{ij}^2$, we make use of the Delta method applied to (8). After some calculations, this yields

$$\sigma_{ij}^2 = \frac{\exp\left(2\left(\hat{\beta}_0 + \hat{\alpha}_i + \hat{\gamma}_j\right)\right)\hat{\upsilon}}{\left(1 + \exp\left(\hat{\beta}_0 + \hat{\alpha}_i + \hat{\gamma}_j\right)\right)^4}$$

where $\hat{\nu}$ is the sum of the entries in the variance-covariance matrix corresponding to the parameter estimates.

Whereas the calculation of $\mu_{ij}$ and $\sigma_{ij}^2$ may appear daunting for some practitioners, we note that the *predict* function can be used on a *glm* object in R to provide the values. This is most convenient when running the *rjags* package since it provides an interface from R to the JAGS library. In the Appendix, we see that the empirical Bayes procedure requires only three statements of code.

To check the impact of the empirical Bayes prior specification (7), we repeat the Bayesian analysis on the aviation dataset. Recall for question 1, the CTT P-value was 0.925 and the posterior mean of the Bayesian P-value was 0.642. With the new prior that takes into account student ability and test difficulty, the posterior mean of the Bayesian P-value is 0.912. We therefore see that the new value has moved towards the CTT value. Similarly, with Cronbach's alpha, the CTT value was 0.492, the posterior mean of the Bayesian α was 0.075, and the posterior mean of the Bayesian α based on the empirical Bayes prior specification (7) is 0.201.

In Figure 3, we provide the joint distribution of the Bayesian P-value and the discrimination index for questions 1 and 2 based on the empirical Bayes prior of Section 4.2. The distribution of values are more in line with the CTT diagnostics. In Figure 4, we provide a density plot of the posterior distribution of the Bayesian version of Cronbach's alpha based on the empirical Bayes prior of Section 4.2. Again, the distribution of values are more in line with the CTT diagnostic. We repeat that a main advantage of the empirical Bayes procedure is that it takes into account the difficulty of questions and the strength of the respondent.

The prior specification in (7) provides only a template of what can be done. For example, one could introduce alternative distributions. One could also introduce more knowledge about students and test questions by modifying the truncated-Normal distribution. In the Appendix, we see that the specification of the prior in JAGS is straightforward (e.g. one line involving the dnorm function).

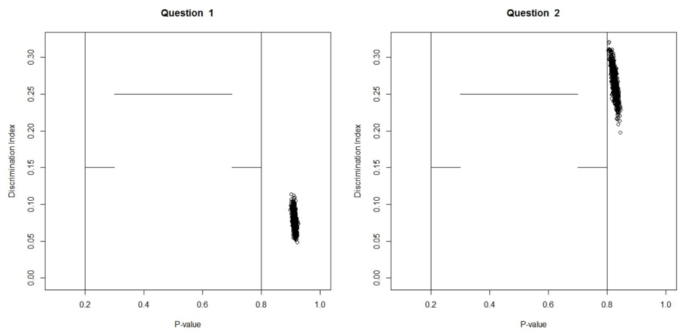


**Figure 3: Posterior simulations of the Bayesian P-value and discrimination index for questions 1 and 2 using the empirical Bayes prior of Section 4.2. Horizontal lines are drawn to delineate the recommendations from Table 1.**

## Generalizing with respect to instructors

We now demonstrate that the Bayesian framework provides advantages that are not available in the classical CTT framework.

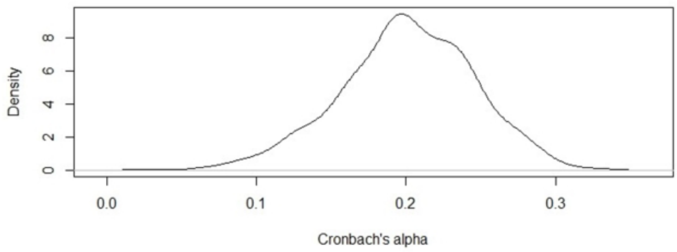


**Figure 4: Posterior density plot of the Bayesian version of Cronbach's alpha using the empirical Bayes prior of Section 4.2.**

A possible application is the assessment of instructors. For example, we may have *L* instructors who are each responsible for a cohort of students. In this case, every observation $x_{ij}$ has an added subscript such that $x_{ijl}$ = 1(0) denotes that the *i* student has a correct (incorrect) response to the *j*th question and that this student received instruction on this question by instructor *l*. We similarly extend the notation for the parameters leading to terms $\theta_{ijl}$. The above setup is also applicable to other situations.

For example, a comparison of different groups of students may be of interest where the groups are designated by the index $l$.
Using either the simple uniform prior or the more realistic prior given by (7) and (8), posterior realizations of $\theta_{ijl}$ are generated as before. Let $S_l = \{\theta_{ijm}: m = l\}$ and let $nl$ be the number of terms in the set $S_l$. Then an analysis of instructors in the spirit of the CTT Bayesian framework can be based by calculating

$$\bar{\theta}_{..l} = \frac{1}{n_l}\sum_{S_l}\theta_{ijl} \qquad (9)$$

which can be interpreted as the average probability of a correct answer for instructor $l$. One can compare the $\bar{\theta}_{..l}$ values, $l = 1,\ldots, L$, and assess their relative magnitudes by also calculating their corresponding posterior standard deviations.

## Discussion

The two main approaches to questionnaire design and analysis are IRT and CTT. Methods based on IRT require the specification of statistical models and permit the inferential benefits associated with the models. IRT is the dominant approach used in major educational testing initiatives (An and Yung 2014) and IRT software is now widely accessible including popular statistical packages such as SAS (Choi 2017). Much recent research has been carried out under the IRT umbrella and there are now many IRT models that can be considered for a given application (Cai et al. 2016).
However, despite the popularity of IRT, there are two main drawbacks involving IRT. First, sometimes the existing statistical models do not adequately characterize the special features of an application and the models need to be modified (if possible) to account for these features. In comparison to CTT, Hambleton and Jones (1993) describe the assumptions related to IRT as `strong'. Second, the sophistication of the IRT models in terms of model fitting and interpretation is sometimes beyond the technical scope of practitioners. For example, even the simple IRF given in (5) often poses a challenge for a non-technical audience.
On the other hand, CTT approaches consist of few assumptions and are easily adopted by practitioners. These appealing features have led to the continuation of the use of CTT despite the lack of inferential capabilities under CTT. For example, in clinical psychology when there are fewer than 20 test items, Jabrayilov, Emons and Sijtsma (2016) recommend CTT over IRT for detecting change in individuals. In discussing CTT, Hambleton and Jones (1993) write that the dependence of the methodology on the particular test and examinees `limit the utility of the person and item statistics in practical test development work and complicate any analyses'.
The methods proposed in this paper allow practitioners to work under the familiar CTT approach, yet benefit from inferential capabilities. This is accomplished by imbedding the CTT structure within a Bayesian framework. The inferential component is accomplished via simulation from posterior distributions where simulated values provide population-level descriptions of questionnaires.
However, the greatest advantage of the proposed approach is its flexibility. We have seen that we can vary the prior to take into account subjective beliefs concerning students and test questions. In addition, the flexibility of applications is facilitated through the availability of the simulated $\theta_{ij}$ values (something that is not immediately available in IRT). For example, we have shown in Section 3 how the introduction of a new subscript can extend an investigation to take into account the effect of instructors. As another example, suppose that a researcher is interested in the performance of students on test questions 6, 7 and 8. Then, for the $i$th student, the researcher needs only keep track of the simulated outcomes $T_i = \theta_{i6} + \theta_{i7} + \theta_{i8}$. Essentially, with the $\theta_{ij}$ values, the researcher can investigate any aspect of interest regarding students and test questions.
Finally, we have used an empirical Bayes procedure based on fitting a logistic regression model according to (8). Nothing prevents us from using a similar procedure based on an alternative parametrization. For example, we could fit a logistic regression model according to three-parameter IRF (5). This would further tighten the relationship between our Bayesian CTT approach and IRT.

## Conclusion

We have made the case that the approach developed in this paper may help bridge the gap between CTT and IRT, by retaining the simplicity of CTT and by providing the inferential advantages of IRT. In particular, when compared to traditional CTT, the proposed approach does not rely on the interpretation of summary statistics. Rather, variability can be assessed via posterior distributions.

## Acknowledgements

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## Appendix

Here we provide the JAGS code used in the analysis in Section 4.2. We see that the code is straightforward and is easily adaptable to more complex testing problems.

```
# The following code reads in a test matrix and obtains
# posterior means of various test parameters using Just
# Another Gibbs Sampler (JAGS) through the R library
# 'rjags'. Here we assume the realistic independent
# truncated normal prior.

sink(file.path(tempdir(),"model.txt"))
cat("
    model
{
for (i in 1:n)
{
for( j in 1:k)
{
x[i,j]    ~ dbern(theta[i,j])
theta[i,j] ~ dnorm(mu_ij[i,j],1/pow(se.fit[i,j],2))T(0,1)
}
}
for(j in 1:k)
{
theta_dotj [ j ] <- sum(theta[, j ])
}
for( i in 1:n)
{
thetai_dot [ i ] <- sum(theta[ i, ])
}
for( j in 1:k)
{
Pvalue[ j ] <- theta_dotj [ j ] / n
}
thetai_dotbar <- mean(thetai_dot[]) mid <- (n+1)/2
Index <- rank(thetai_dot[])
for(i in  1:n)
{
for(j in 1:k)
{
G[i,j]   <- step(Index[i] - mid)*theta[i, j] G_dash[i,j] <-
step(mid - Index[i])*theta[i, j]
}
}
for(j in 1:k)
{
Nu[j] <- sum(G[, j])
Nl[j] <- sum(G_dash[, j])
discrim[j] <- 2*(Nu[j] -  Nl[j])/n
}
for(i in  1:n)
{
for(j in 1:k)
{
tmp[i,j] <- theta[i,j] - Pvalue[j]
}
}
covari[1:k,1:k] <- t(tmp[,]) %*% tmp[,]
for(j in 1:k)
{
covi[j] <- sum(covari[j,])
}
```

```
sum.cov <- sum(covi[1:k]) for(j in 1:k)
{
vari[j] <- covari[j,j]
}
sum.var <- sum(vari[1:k])

# To calculate kron = k*(1 - sum(diag(cov[,]))/sum(cov[,]))/(k-

1) eps <- pow(10,-50)
A <- (sum.var)/(sum.cov+eps) kron <- k*(1 -A)/(k-1)
}
        ", fill = TRUE) sink()
data0 <- read.csv("data123.csv", header=T,row.names =
"UserID") x <- data0[complete.cases(data0),]
long_format = matrix(ncol=3, nrow=nrow(x)*ncol(x))
for(i in1:nrow(x))
{
for(j in 1:ncol(x))
{
k = j + (i-1)*ncol(x)
long_format[k,1] = x[i,j] long_format[k,2] = row.names(x)[i]
long_format[k,3] = names(x)[j]
}
}
long_format = data.frame(long_format)
names(long_format) = c("Correct","Respondent","Question")
long_format$Respondent = as.character(sort(as.
numeric(levels(long_format$Respondent))))
# Empirical Bayes procedure
mod = glm(Correct ~ Respondent + Question,data=long_
format,family="binomial")
mu_ij = matrix(predict(mod,type="response",data=long_forma
t),ncol=ncol(x),nrow=nrow(x), byrow=TRUE)
se.fit_ij = matrix(predict(mod,type="response",data=long_
format,se.fit=TRUE)$se.fit, ncol=ncol(x),nrow=nrow(x),byrow
=TRUE)
n <- nrow(x) k <- ncol(x)
linedata <- list("n" = n, "k"=k, "x" = x, "mu_ij"=mu_ij,
"se.fit_ij"=se.fit_ij) parameters <- c("Pvalue","discrim","theta
","kron")
# We call the model above into JAGS
mult.sim <- jags.Model(file = file.path(tempdir(),"model.txt"),
                  data = linedata,
                  inits = NULL, n.chains = 1,
                  n.adapt = 1000)
# We update the MCMC chains 1000 times for burn-in
update(mult.sim, n.iter = 1000)
# Sampling phase
mcmc.out <- coda.samples(mult.sim,
              variable.names = parameters,
              thin = 1,
              n.iter = 1000)
# To get the output
output <- as.data.frame(as.matrix(mcmc.out, chains = TRUE))
```

# THE EFFECTIVENESS OF THE E-LEARNING APPLICATIONS: ASSESSMENT OF THE SERVICE QUALITY USING BINOMINAL LOGISTIC REGRESSION

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*Highlights*

- *Our research objectives include the quality of e-Learning establishment of our institution*
- *We used statistic methods to examine the quality evaluation of the e-Learning usage*
- *It is more effective and better to operate the e-Learning system under organized circumstances*

**Abstract**

The success and the efficiency of e-Learning should be measured by a reliable method in order to use it effectively. Although, there are several studies about the success of e-Learning systems, only a few of them deal with the measurement of this success within the institutions.

We made a questionnaire to evaluate the e-Learning application. The aim was to develop such questionnaire which is suitable to evaluate e-Learning quality. The basis of the e-Learning quality questions was a multi-dimensional model for assessing e-learning systems success (ELSS).

The aim of the questionnaire were to compare the opinions of the students and the teachers and also to evaluate the Faculty of Economics and Business (FEB) of the University of Debrecen and the Corvinus University of Budapest (CUB) regarding the application of e-Learning. The role of the questionnaire for quality development is to give guidance for the FEB in implementing and using e-Learning. E-Learning in the CUB is applied under certain organized institutional circumstances. The e-Learning application of CUB works with an organization defined extended several faculties of the University, which can be a good example for FEB.

We have used factor analysis and binominal logistic regression. We have examined whether the background variables manipulating the variables are possible to be developed on the basis of the answers. We used factor analysis to demonstrate this since it contracts the coherent factors into one common factor.

Finally we used logistic regression to determine the importance of a given factor for the users of both faculties.

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## Introduction

The number of educational institutions, companies and other users who applying e-Learning systems has grown significantly in the last decade, therefore they have become as important means and resources as other information systems of the institutions (Szilágyi, 2012). However, there are several conditions and components to use these systems in the educational institutions successfully. Important issues for example what kind of system is chosen, how it is implemented and introduced. The availability of the system and services are also important for the users (teachers, students) (Lengyel et al, 2016).

Probably the most significant question is how teachers and students can profit from the system. What is the advantage of using it? How does it help the process of teaching and learning to become more effective and transparent? Does it support the management of institutional education? If it does so, what extent? Naturally, the organizational and economical aspects of the usage of e-Learning systems are also important. The application of the e-Learning systems is gradually becoming more essential for those institutions, organizations and companies have distance learning and also useful for the improvement of human resources.

The Learning Management System (LMS) is often used with a virtual learning environment (VLE) interchangeably. A VLE refers to an operating system and specialized learning management software that allows students and the instructor to plan, organize, monitor, coordinate, and control the learning activities to facilitate the learning process and to optimize the desired learning outcomes.

The DeLone and McLean (D&M) model is one of the widely recognized information system (IS) success models based on a systematic review of 180 studies with over 100 measures. The DM model theorized that system quality and information quality singularly and jointly affect both use and user satisfaction, which in turn, are direct antecedents of system effectiveness (DeLone and McLean, 1992). To extend the DM model into the e-learning area, a number of studies empirically tested the D&M model of information systems success model in a university e-learning context using structural equation modeling. Eom and others (Eom et al, 2012) presented empirical test of the D&M model of IS success in a university e-learning context, which is strictly involuntary use. Their study reached several useful conclusions. Perceived system quality and perceived information quality are very strong (high path coefficient) predictor of user satisfaction. Perceived user satisfaction is a very strong predictor of individual impact. Perceived system quality is an insignificant predictor of system use or relatively weak predictor of system use. The direct influence of system use on user satisfaction is weak even though it is statistically significant. In order for e-learning students to be successful, they must be provided with e-learning system that provides information they need and user-friendly.

Although system quality has not directly contributed to predict individual impact, its impact is indirect. System quality and information quality have positive effects on user satisfaction. Information quality has also positive effects on system use, which in turn positively contributes to user satisfaction. Therefore, all the antecedent variables are positively affecting e-learning outcomes either indirectly or directly. System quality and information quality are necessary conditions for e-learning success and students' satisfaction with LMS, but not sufficient conditions (Eom, 2015).

Our research objectives include the quality of e-Learning establishment and the support of our institution. Accordingly, tasks were set for the examination of e-Learning opportunities for quality improvement in education, improvements in this regard, proposals and recommendations for application development. The course structure recommended for the application of e-Learning for institutional quality improvement together with other functions reachable as a module of the system, can ensure an integrated and comprehensive e-Learning quality service. The strategy and implementation of quality improvement is only possible by providing qualified human resources. The basic objective of the introduced LMS (Learning Management System) is to improve the quality of education, which is one way where the students and instructors receive ongoing feedback about their experiences with the system (Wang, Wang and Shee, 2007). Corresponding objective is to compile a questionnaire, which was a result of useful information about the students and teachers e-Learning system and application views (Lengyel and Herdon, 2012).

The aim of the questionnaires were to compare the opinions of the students and the teachers and also to evaluate the Faculty of Economics and Business (FEB) of the University of Debrecen and the Corvinus University of Budapest (CUB) regarding the e-Learning applications. The role of the questionnaire for quality development is to give guidance for the FEB in the application of e-Learning. E-Learning in the CUB is applied under certain organized institutional circumstances. The e-Learning application of CUB works with an organization defined extended several faculties of the University, which can be a good example for our faculty.

The following hypotheses was defined: The quality development of e-Learning should be ensured under organized circumstances.

## Matherials and methods

### Questionnaire survey

There is an on-line way of response, which is a quantitative online CAWI (Computer Assisted Web Interviews) survey over the Internet. Usually rapid market surveys are made by this method. Our questionnaire was accessible through Limesurvey system (Figure 1), which is a free and open source on-line survey application written in PHP based on a MySQL database. As a web server-based software it enables users using a web interface to develop and publish on-line surveys, collect responses, create statistics, and export the resulting data to other applications (Bocarnea, Reynolds and Baker, 2012).

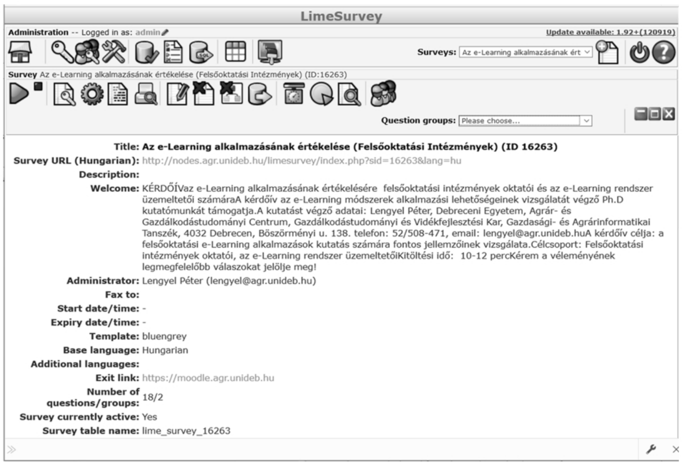


**Figure 1: Administration interface of Limesurvey system (source: http://nodes.agr.unideb.hu/limesurvey/index.php?sid=16263&lang=hu, 2016)**

The research survey designed from the predetermined group of users to get answers to important research questions. The SPSS (Statistical Package for the Social Sciences) program was used to evaluate the questionnaires. The questionnaire responses from LimeSurvey were exported to the files that we imported into SPSS.

### The applied statistical methods

A statistically significant t-test result is one in which a difference between two groups is unlikely to have occurred because the sample happened to be atypical. Statistical significance is determined by the size of the difference between the group averages, the sample size, and the standard deviations of the groups. For practical purposes statistical significance suggests that the two larger populations from which we sample are "actually" different.

We used factor analysis and binominal logistic regression too. We examined whether the background variables manipulating the variables are possible to be developed on the basis of the answers. We used factor analysis to demonstrate this since it contracts the coherent factors into one common factor. Factor analysis is used to compress data and explore data structure (Szakály et al, 2014, Balogh et al, 2015). This method contracts the basic variables into so called factor variables which cannot be directly observed. In most cases, factor analysis is used foremost in order to filter out multicollinearity (Field, 2009).

Logistic regression quantifies the probability of occurrence of the category of a doubtful, category like dependent variable under the condition of the known outcomes of other explanatory variables. Logistic regression is a non-linear classification method that does not suppose the continuity of explanatory variables neither the normality of multivariables. The decision-maker can construct a decision-making rule relying on the hypothetical probability value in order to classify the given observation unit into a predetermined result like category (Gal et al, 2013). If the number of the dependent variables' outcome is two, then the method is called a binomial logistic regression.

### The applied model

The success and the efficiency of e-Learning should be measured by a reliable method in order to use it effectively. Although, there are several studies about the success of e-Learning systems, only a few of them is about the measurement of this success within the institutions (Karima and Mostafa, 2016, Li, Fu and Duan, 2013, Silambannan and Srinath, 2013). It is a study by Wang, Wang and Shee (2007), in which they measured the success of the e-Learning systems with e-Learning System Success (ELSS) model based on DeLone and McLean (2003) Information System Success Model.

## Results

The aim was to develop such questionnaires which are suitable both for the evaluation of the e-Learning's quality. The basis of the e-Learning's quality questions was the ELSS model. The questions of the students and the lecturers were the same.
The groups of questions were the following:

- System quality (1-7)
- Information quality (8-12)
- Service quality (13-17)
- Benefits of the e-Learning system (18-24)
- Conclusions (25-27)

The questionnaire involving 27 questions is shown in the Appendix. There were 273 students and 50 lecturers from the CUB and 288 students and 46 teachers from the UD FEB who properly filled out the questionnaires. We examined the answers about the e-Learning quality in this research on the basis of two criterion (student-teacher, CUB - FEB). The basis of the answers' comparability was that both institutions applied the Moodle frame system. We tried to find out what extent they exploit the facilities of the system.
The 27 questions could be answered in a scale of 10. Figure 2 represents a diagram that indicates the means of the answers of the two institutions' students and teachers.

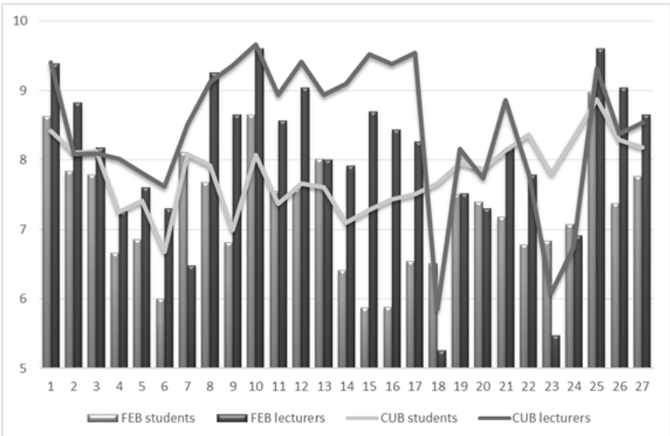


**Figure 2: Comparison of the students and teachers responses at FEB and CUB (source: own calculation)**

We can see on Figure 2 that generally, according to the e-Learning users of the CUB, the quality of the e-Learning application is better. The answers are demonstrating significant differences based on the results of t-tests, therefore we find significant differences in the answers.
The significant differences in the lecturers' answers is illustrated by Table 1 and Table 2 naming the difference indicator issues. All results were higher at Benchmark excepting for the question 2 and 26. Before t-test we calculated descriptive statistics with SPSS (Appendix 2). Within the results for t-test for Equality of Means, the results were displayed into Equal Variances assumed (E.v.a.) and not assumed (E.v. not a.).

| question | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | |
|---|---|---|---|---|---|---|---|---|
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| 2. | E.v.a. | 2.704 | 0.103 | 3.341 | 94 | 0.001 | 0.7461 | 0.2233 |
| | E.v. not a. | | | 3.380 | 90.657 | 0.001 | 0.7461 | 0.2207 |
| 7. | E.v.a. | 21.558 | 0.000 | -5.024 | 94 | 0.000 | -2.0417 | 0.4064 |
| | E.v. not a. | | | -4.895 | 64.022 | 0.000 | -2.0417 | 0.4171 |
| 9. | E.v.a. | 34.140 | 0.000 | -2.215 | 94 | 0.029 | -0.7078 | 0.3195 |
| | E.v. not a. | | | -2.141 | 53.624 | 0.037 | -0.7078 | 0.3306 |
| 13. | E.v.a. | 10.075 | 0.002 | -2.625 | 94 | 0.010 | -0.9400 | 0.3581 |
| | E.v. not a. | | | -2.539 | 54.687 | 0.014 | -0.9400 | 0.3702 |
| 14. | E.v.a. | 8.619 | 0.004 | -4.479 | 94 | 0.000 | -1.1870 | 0.2650 |
| | E.v. not a. | | | -4.342 | 57.460 | 0.000 | -1.1870 | 0.2733 |
| 15. | E.v.a. | 47.302 | 0.000 | -3.510 | 94 | 0.001 | -0.8243 | 0.2349 |
| | E.v. not a. | | | -3.413 | 61.405 | 0.001 | -0.8243 | 0.2415 |
| 16. | E.v.a. | 18.063 | 0.000 | -4.011 | 94 | 0.000 | -0.9452 | 0.2357 |
| | E.v. not a. | | | -3.908 | 64.075 | 0.000 | -0.9452 | 0.2419 |
| 17. | E.v.a. | 56.573 | 0.000 | -3.957 | 94 | 0.000 | -1.2791 | 0.3232 |
| | E.v. not a. | | | -3.817 | 51.447 | 0.000 | -1.2791 | 0.3351 |
| 26. | E.v.a. | 2.879 | 0.093 | 2.927 | 94 | 0.004 | 0.6635 | 0.2267 |
| | E.v. not a. | | | 2.974 | 86.273 | 0.004 | 0.6635 | 0.2231 |

**Table 1: Significant differences in teachers' answers (source: own calculation)**

Regarding the result it can be said that the e-Learning application of the CUB is more successful than the FEB according to the students' and the lecturers' evaluation. It is also obvious that the quality of the system's operation of the CUB is higher than the FEB. This result supports our hypothesis according to which the FEB can evolve in the quality of e-Learning application by ensuring the institutional frames for the system.
After that we examined whether background variables influencing the variables are possible to be formed. We analyzed the whole database used factor analysis to demonstrate this contracts the coherent factors into one common factor. We examined the variables on the basis of the Kaiser-Meyer-Olkin (KMO) criteria to determine whether they are suitable for factor analysis (Várallyai, Botos and Péntek, 2015). The value of the KMO is 0.886 (Table 3), which means that the variables are suitable for factor analysis.
The table also indicates the null hypothesis of the Bartlett test, which means that there is no correlation between the basic variables because the level of significance (Sig.) is smaller than 0.05. Consequently the basic condition of the factor analysis, according to which the variables must correlate is fulfilled (Sajtos and Mitev, 2007).

| question | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | |
|---|---|---|---|---|---|---|---|---|
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| 3. | E.v.a. | 45.561 | 0.000 | -2.873 | 559 | 0.004 | -0.3402 | 0.1184 |
| | E.v. not a. | | | -2.849 | 496.230 | 0.005 | -0.3402 | 0.1194 |
| 4. | E.v.a. | 6.349 | 0.012 | -4.544 | 559 | 0.000 | -0.5861 | 0.1290 |
| | E.v. not a. | | | -4.530 | 544.646 | 0.000 | -0.5861 | 0.1294 |
| 5. | E.v.a. | 3.602 | 0.058 | -3.351 | 559 | 0.001 | -0.5634 | 0.1681 |
| | E.v. not a. | | | -3.357 | 558.955 | 0.001 | -0.5634 | 0.1678 |
| 6. | E.v.a. | 16.211 | 0.000 | -3.773 | 559 | 0.000 | -0.6813 | 0.1806 |
| | E.v. not a. | | | -3.785 | 556.557 | 0.000 | -0.6813 | 0.1800 |
| 10. | E.v.a. | 74.275 | 0.000 | 5.026 | 556 | 0.000 | 0.5785 | 0.1151 |
| | E.v. not a. | | | 4.938 | 408.564 | 0.000 | 0.5785 | 0.1171 |
| 13. | E.v.a. | 7.834 | 0.005 | 2.735 | 556 | 0.006 | 0.3993 | 0.1460 |
| | E.v. not a. | | | 2.721 | 528.765 | 0.007 | 0.3993 | 0.1468 |
| 14. | E.v.a. | 27.860 | 0.000 | -3.443 | 556 | 0.001 | -0.6833 | 0.1985 |
| | E.v. not a. | | | -3.468 | 541.585 | 0.001 | -0.6833 | 0.1970 |
| 15. | E.v.a. | 6.775 | 0.009 | -7.322 | 556 | 0.000 | -1.4139 | 0.1931 |
| | E.v. not a. | | | -7.378 | 540.316 | 0.000 | -1.4139 | 0.1916 |
| 16. | E.v.a. | 0.412 | 0.521 | -8.667 | 556 | 0.000 | -1.5479 | 0.1786 |
| | E.v. not a. | | | -8.686 | 555.987 | 0.000 | -1.5479 | 0.1782 |
| 17. | E.v.a. | 0.729 | 0.394 | -5.305 | 556 | 0.000 | -0.9694 | 0.1827 |
| | E.v. not a. | | | -5.318 | 555.973 | 0.000 | -0.9694 | 0.1823 |
| 18. | E.v.a. | 36.219 | 0.000 | -6.286 | 559 | 0.000 | -1.1489 | 0.1828 |
| | E.v. not a. | | | -6.330 | 535.017 | 0.000 | -1.1489 | 0.1815 |
| 19. | E.v.a. | 31.714 | 0.000 | -2.462 | 559 | 0.014 | -0.4456 | 0.1810 |
| | E.v. not a. | | | -2.474 | 548.737 | 0.014 | -0.4456 | 0.1801 |
| 20. | E.v.a. | 1.128 | 0.289 | -2.631 | 559 | 0.009 | -0.4723 | 0.1795 |
| | E.v. not a. | | | -2.633 | 558.579 | 0.009 | -0.4723 | 0.1794 |
| 21. | E.v.a. | 22.547 | 0.000 | -5.664 | 559 | 0.000 | -0.9658 | 0.1705 |
| | E.v. not a. | | | -5.714 | 519.901 | 0.000 | -0.9658 | 0.1690 |
| 22. | E.v.a. | 56.671 | 0.000 | -7.659 | 559 | 0.000 | -1.5814 | 0.2065 |
| | E.v. not a. | | | -7.747 | 489.119 | 0.000 | -1.5814 | 0.2041 |
| 23. | E.v.a. | 25.634 | 0.000 | -5.080 | 559 | 0.000 | -0.9689 | 0.1907 |
| | E.v. not a. | | | -5.114 | 538.851 | 0.000 | -0.9689 | 0.1895 |
| 24. | E.v.a. | 12.750 | 0.000 | -7.956 | 559 | 0.000 | -1.2458 | 0.1566 |
| | E.v. not a. | | | -8.006 | 541.488 | 0.000 | -1.2458 | 0.1556 |
| 25. | E.v.a. | 6.600 | 0.010 | -6.810 | 559 | 0.000 | -0.9107 | 0.1337 |
| | E.v. not a. | | | -6.801 | 553.257 | 0.000 | -0.9107 | 0.1339 |
| 27. | E.v.a. | 59.530 | 0.000 | -3.166 | 559 | 0.002 | -0.4160 | 0.1314 |
| | E.v. not a. | | | -3.139 | 491.741 | 0.002 | -0.4160 | 0.1325 |

**Table 2: Significant differences in students' answers (source: own calculation)**

| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | 0.886 |
|---|---|---|
| Bartlett's Test of Sphericity | Approx. Chi-Square | 17 114.773 |
| | df | 351 |
| | Sig. | 0.000 |

**Table 3: The results of KMO and Bartlett test (source: own calculation)**

We used two methods to determine the number of the factors. One of them is the percentage of variance, which determines the number of the factors on the basis of the cumulated percentage of the variance, which means that it is necessary to establish such number of the factors which makes it possible to reach a cumulated minimal level of variance. The Table 4 indicates the variance explained by the factors.

| Factor | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 11.526 | 42.690 | 42.690 | 11.192 | 41.452 | 41.452 | 6.140 | 22.740 | 22.740 |
| 2 | 3.621 | 13.410 | 56.100 | 3.317 | 12.285 | 53.737 | 5.893 | 21.825 | 44.565 |
| 3 | 1.944 | 7.201 | 63.301 | 1.566 | 5.800 | 59.538 | 3.105 | 11.501 | 56.066 |
| 4 | 1.500 | 5.554 | 68.855 | 1.264 | 4.681 | 64.219 | 2.201 | 8.153 | 64.219 |
| 5 | 1.090 | 4.037 | 72.892 | | | | | | |
| 6 | 0.953 | 3.530 | 76.423 | | | | | | |

**Table 4: Choice factors in the method variance (source: own calculation)**

The fourth row of the 'Cumulative %' shows the cumulated variance of the four factors (64.219%) which were developed by the Kaiser-criteria. It is above the necessary 60%.

The 5-factor solution would have been reasonable regarding the methods but relying on the fulfilled factor analysis there would only be one variable in the factor 5. Therefore, we used a 4-factor solution which means that we replaced 27 variables. It explains with 100% with 4 factors which explains in 64.22%. After this, we rotated the factors during their selection to filter the correlated factors without relation and also in order to get a more simple and understandable solution. We used the Varimax rotational method during which the orthogonal rotation results in correlating factors.

Finally, we reached a 4-factor solution as a result of the analysis, where the KMO = 0.886 and the explained variance is 64.22%. The names of the factors are the following:

- FACTOR1: Quality of the service
- FACTOR2: Efficiency of the system
- FACTOR3: Quality of the online material
- FACTOR4: Usability of the system

We used logistic regression for the results of the factor analysis. Our aim was to determine the importance of a given factor for the users of the CUB and the FEB. The dependent variable is the factor CUB and the independent variable is the factor of FEB.

Table 5 and 6 represent the first phase of the analysis. Table 4 shows the constant Wald-statistic in the pre-analysis phase, which is the square of the beta (B) and the standard error. It demonstrated that there is not a significance.

| | | B | S.E. | Wald | df | Sig. | Exp(B) |
|---|---|---|---|---|---|---|---|
| Step 0 | Constant | -.043 | .078 | .300 | 1 | .584 | .958 |

**Table 5: Parameter estimation based on the Wald-statistic (source: own calculation)**

Table 5 represents the individual effect of the independent variables yet not used in the analysis, according to which FACTOR1. FACTOR2 and FACTOR3 are also significant on their own, while the forth variable is not. The second part of the analysis demonstrates the final result. We used the „Enter" method, which means that we used the four independent variables in the analysis at same time.

| | | | Score | df | Sig. |
|---|---|---|---|---|---|
| Step 0 | Variables | FACTOR1 | 49.687 | 1 | .000 |
| | | FACTOR2 | 20.899 | 1 | .000 |
| | | FACTOR3 | 22.418 | 1 | .000 |
| | | FACTOR4 | .401 | 1 | .526 |
| | Overall Statistics | | 97.189 | 4 | .000 |

**Table 6. Significance of individual effects of variables (source: own calculation)**

Table 7 also applies the Wald-statistic. If the given variable is significant, then it supports the model. It is obvious that FACTOR1. FACTOR2 and FACTOR3 contributes to the model, while FACTOR4 does not. The Exp(B) indicates how each variables correct the estimation.

| | | B | S.E. | Wald | df | Sig. | Exp(B) | 95.0% C.I.for EXP(B) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Lower | Upper |
| Step 1(a) | FACTOR1 | .759 | .105 | 52.118 | 1 | .000 | 2.135 | 1.738 | 2.624 |
| | FACTOR2 | .521 | .102 | 26.021 | 1 | .000 | 1.683 | 1.378 | 2.056 |
| | FACTOR3 | -.596 | .104 | 32.805 | 1 | .000 | .551 | .449 | .676 |
| | FACTOR4 | -.115 | .087 | 1.748 | 1 | .186 | .891 | .751 | 1.057 |
| | Constant | -.108 | .087 | 1.549 | 1 | .213 | .898 | | |

**Table 7: Wald-statistic (source: own calculation)**

Regarding this, FACTOR1 corrects the estimation the most (Exp(B)=2.135) with 113.5%, while FACTOR2 corrects it with 68.3%. FACTOR3 worsens the estimation with 44.9%, which means that according to the CUB users the first factor is twice, while the second factor is 1.683 times more important than according to the FEB.

## Discussion

In our study we used the ELSS model (Wang, Wang and Shee, 2007) based on IS success model developed by DeLone and McLean (2003). We used it at both institutions. Our results of the questionnaire evaluation are the same as the main line of article by Halonen et al (2009).

System quality has a significant influence on use and user satisfaction (DeLone and McLean, 2003). In our research the system was Moodle platform and when evaluating 'System Quality' we considered Moodle's functionality and the technical support that was connected with its use.

Respondents perceived that the e-learning system operated almost without reproaches and we interpret that it describes the stability and good availability of the system.

Information quality has a significant impact on use and user satisfaction (DeLone and McLean, 2003). Information is an important factor in the e-learning system. The respondents were mainly satisfied with the organized information. The replies did not indicate if the organization of information helped the students perceive the structure of the degree.

Replies concerning 'Information Quality' highlighted three issues on 'Service Quality'. The students perceived that the plans of study blocks helped them understand the purpose of their studies. Another important information concerned students' experiment on receiving essential and needed information for their degree from the e-learning system. The third significant success factor was the instructions on giving evidence of expertise (Halonen et al, 2009).

Service quality builds on all support that is offered to its users (DeLone and McLean, 2003). In our study we measured 'Service Quality' by evaluating interaction between the students and teachers. The students replied that they were mostly satisfied with interaction. The students had received support and guidance and their questions were answered. These results tell us that the respondents were satisfied with given guidance.

Service quality is extremely important because due to bad service customers may be lost (DeLone and McLean, 2003). From the e-learning approach we could interpret that weak interaction in the e-learning system could lead to reluctance to study. Our measures showed that 'service quality' was good.

Benefits in e-learning are positive consequences and in our research they were positive consequences for studies and evidences of experience. The most important output was that the students perceived to benefit from the e-learning system when they accomplished their degrees (Halonen et al, 2009). Benefits indicated that the e-learning system supports students when they accomplish their degrees.

## Conclusion

We used statistic methods to examine the quality evaluation of the e-Learning usage among the students and the lecturers of the FEB and the CUB. We found significant differences between the CUB's and the FEB's application as well as between the students' and the lecturers' evaluation by performing a t-test. We determined relying on the result, that it is more effective and better to operate the e-Learning system under organized circumstances. This confirmed our hypothesis. We have created 4 factors from the 27 variables by factor analysis and we performed logistic regression on them. Our result shows according to the CUB users the quality of the service is more than twice as good according to the FEB users. While the efficiency of the system is 1.683 times more important. This method can be used to evaluate (compare) the quality of e-Learning services among educational institutes.

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## Appendix 1.

### Questionnaire

*System Quality (questions 1-7)*

1. The LMS provides high availability.
2. The LMS is easy to use.
3. The LMS is user friendly.
4. The LMS provides interactive features between users and system.
5. The LMS provides personalized information presentation.
6. The LMS provides charming feature to attract users.
7. The LMS provides high speed of accessing information.

*Information Quality (questions 8-13)*

8. The LMS provides information that is exactly what you need.
9. The LMS provides information you need in time.
10. The LMS provides information that is relevant to your job.
11. The LMS provides sufficient information.
1. The LMS provides up-to-date information.

Service Quality (questions 14-18)

13. The LMS provides proper level of on-line assistance and explanation.
14. The LMS developers interact with users extensively during the development of e-learning system.
15. The IS department staff provide high availability for consultation.
16. The IS department responds to your suggestion for future enhancements of e-learning system cooperatively.
17. The IS department provides satisfactory support to users using e-learning system.

Benefits (questions 18-24)

18. The LMS helps you improve your job performance.
19. The LMS helps the organization enhance competitiveness or create strategic advantage.
20. The LMS enables the organization to respond more quickly to change.
21. The LMS helps the organization provide better products or services to customers.
22. The LMS helps the organization save cost.
23. The LMS helps the organization to speed up transactions or shorten product cycles.
24. The LMS helps the organization increase return on financial assets.

*Conclusion (questions 25-27)*

25. As a whole, the performance of the e-learning system is good.
26. As a whole, the e-learning system is successful.
27. You are satisfied with the e-learning system.

## Appendix 2.

### Descriptive statistics on teachers' answers

| question number | Institution | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| 1. | FEB | 46 | 9.391 | 0.8814 | 0.1300 |
| | CUB | 50 | 9.400 | 0.6999 | 0.0990 |
| 2. | FEB | 46 | 8.826 | 0.9263 | 0.1366 |
| | CUB | 50 | 8.080 | 1.2262 | 0.1734 |
| 3. | FEB | 46 | 8.174 | 1.1016 | 0.1624 |
| | CUB | 50 | 8.100 | 1.3740 | 0.1943 |
| 4. | FEB | 46 | 7.261 | 2.3705 | 0.3495 |
| | CUB | 50 | 8.020 | 1.7437 | 0.2466 |
| 5. | FEB | 46 | 7.609 | 3.1516 | 0.4647 |
| | CUB | 50 | 7.820 | 1.6123 | 0.2280 |
| 6. | FEB | 46 | 7.304 | 3.4825 | 0.5135 |
| | CUB | 50 | 7.620 | 1.7010 | 0.2406 |
| 7. | FEB | 46 | 6.478 | 2.5625 | 0.3778 |
| | CUB | 50 | 8.520 | 1.2493 | 0.1767 |
| 8. | FEB | 46 | 9.261 | 0.9985 | 0.1472 |
| | CUB | 50 | 9.120 | 1.2720 | 0.1799 |
| 9. | FEB | 46 | 8.652 | 2.1418 | 0.3158 |
| | CUB | 50 | 9.360 | 0.6928 | 0.0980 |
| 10. | FEB | 46 | 9.609 | 0.7142 | 0.1053 |
| | CUB | 50 | 9.660 | 0.4785 | 0.0677 |
| 11. | FEB | 46 | 8.565 | 1.6553 | 0.2441 |
| | CUB | 50 | 8.940 | 1.1141 | 0.1576 |
| 12. | FEB | 46 | 9.043 | 1.4446 | 0.2130 |
| | CUB | 50 | 9.420 | 0.5746 | 0.0813 |
| 13. | FEB | 46 | 8.000 | 2.3851 | 0.3517 |
| | CUB | 50 | 8.940 | 0.8184 | 0.1157 |
| 14. | FEB | 46 | 7.913 | 1.7362 | 0.2560 |
| | CUB | 50 | 9.100 | 0.6776 | 0.0958 |
| 15. | FEB | 46 | 8.696 | 1.5036 | 0.2217 |
| | CUB | 50 | 9.520 | 0.6773 | 0.0958 |
| 16. | FEB | 46 | 8.435 | 1.4855 | 0.2190 |
| | CUB | 50 | 9.380 | 0.7253 | 0.1026 |
| 17. | FEB | 46 | 8.261 | 2.1953 | 0.3237 |
| | CUB | 50 | 9.540 | 0.6131 | 0.0867 |
| 18. | FEB | 46 | 5.261 | 3.4797 | 0.5131 |
| | CUB | 50 | 5.860 | 2.1666 | 0.3064 |
| 19. | FEB | 46 | 7.522 | 3.4237 | 0.5048 |
| | CUB | 50 | 8.160 | 1.5167 | 0.2145 |
| 20. | FEB | 46 | 7.304 | 3.2446 | 0.4784 |
| | CUB | 50 | 7.740 | 1.9878 | 0.2811 |
| 21. | FEB | 46 | 8.174 | 2.8387 | 0.4185 |
| | CUB | 50 | 8.860 | 1.4429 | 0.2041 |
| 22. | FEB | 46 | 7.783 | 2.8590 | 0.4215 |
| | CUB | 50 | 7.800 | 2.1381 | 0.3024 |
| 23. | FEB | 46 | 5.478 | 2.9645 | 0.4371 |
| | CUB | 50 | 6.080 | 3.0226 | 0.4275 |
| 24. | FEB | 46 | 6.913 | 3.5890 | 0.5292 |
| | CUB | 50 | 6.740 | 2.4974 | 0.3532 |
| 25. | FEB | 46 | 9.609 | 0.7142 | 0.1053 |
| | CUB | 50 | 9.320 | 1.3915 | 0.1968 |
| 26. | FEB | 46 | 9.043 | 0.8681 | 0.1280 |
| | CUB | 50 | 8.380 | 1.2919 | 0.1827 |
| 27. | FEB | 46 | 8.652 | 0.7664 | 0.1130 |
| | CUB | 50 | 8.540 | 1.0539 | 0.1490 |

### Descriptive statistics on students' answers

| question number | Institution | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| 1. | FEB | 288 | 8.635 | 1.0030 | 0.0591 |
| | CUB | 273 | 8.418 | 1.6938 | 0.1025 |
| 2. | FEB | 288 | 7.844 | 1.8020 | 0.1062 |
| | CUB | 273 | 8.110 | 1.6701 | 0.1011 |
| 3. | FEB | 288 | 7.792 | 1.1739 | 0.0692 |
| | CUB | 273 | 8.132 | 1.6079 | 0.0973 |
| 4. | FEB | 288 | 6.667 | 1.4435 | 0.0851 |
| | CUB | 273 | 7.253 | 1.6106 | 0.0975 |
| 5. | FEB | 288 | 6.854 | 2.0498 | 0.1208 |
| | CUB | 273 | 7.418 | 1.9254 | 0.1165 |
| 6. | FEB | 288 | 6.000 | 2.2585 | 0.1331 |
| | CUB | 273 | 6.681 | 2.0030 | 0.1212 |
| 7. | FEB | 288 | 8.115 | 1.2258 | 0.0722 |
| | CUB | 273 | 8.088 | 1.7677 | 0.1070 |
| 8. | FEB | 288 | 7.677 | 1.3447 | 0.0792 |
| | CUB | 273 | 7.923 | 1.7525 | 0.1061 |
| 9. | FEB | 288 | 6.813 | 1.8364 | 0.1082 |
| | CUB | 273 | 6.989 | 2.1343 | 0.1292 |
| 10. | FEB | 288 | 8.656 | 0.9239 | 0.0544 |
| | CUB | 270 | 8.078 | 1.7043 | 0.1037 |
| 11. | FEB | 288 | 7.552 | 1.4009 | 0.0825 |
| | CUB | 273 | 7.374 | 1.6448 | 0.0995 |
| 12. | FEB | 288 | 7.583 | 1.5483 | 0.0912 |
| | CUB | 273 | 7.659 | 1.7334 | 0.1049 |
| 13. | FEB | 288 | 8.010 | 1.5806 | 0.0931 |
| | CUB | 270 | 7.611 | 1.8635 | 0.1134 |
| 14. | FEB | 288 | 6.417 | 2.5851 | 0.1523 |
| | CUB | 270 | 7.100 | 2.0535 | 0.1250 |
| 15. | FEB | 288 | 5.875 | 2.5220 | 0.1486 |
| | CUB | 270 | 7.289 | 1.9883 | 0.1210 |
| 16. | FEB | 288 | 5.885 | 2.1778 | 0.1283 |
| | CUB | 270 | 7.433 | 2.0316 | 0.1236 |
| 17. | FEB | 288 | 6.542 | 2.2302 | 0.1314 |
| | CUB | 270 | 7.511 | 2.0761 | 0.1263 |
| 18. | FEB | 288 | 6.510 | 2.4237 | 0.1428 |
| | CUB | 273 | 7.659 | 1.8504 | 0.1120 |
| 19. | FEB | 288 | 7.510 | 2.3314 | 0.1374 |
| | CUB | 273 | 7.956 | 1.9246 | 0.1165 |
| 20. | FEB | 288 | 7.396 | 2.1518 | 0.1268 |
| | CUB | 273 | 7.868 | 2.0963 | 0.1269 |
| 21. | FEB | 288 | 7.177 | 2.3134 | 0.1363 |
| | CUB | 273 | 8.143 | 1.6510 | 0.0999 |
| 22. | FEB | 288 | 6.781 | 2.9033 | 0.1711 |
| | CUB | 273 | 8.363 | 1.8402 | 0.1114 |
| 23. | FEB | 288 | 6.833 | 2.5113 | 0.1480 |
| | CUB | 273 | 7.802 | 1.9547 | 0.1183 |
| 24. | FEB | 288 | 7.073 | 2.0511 | 0.1209 |
| | CUB | 273 | 8.319 | 1.6194 | 0.0980 |
| 25. | FEB | 288 | 8.979 | 1.0119 | 0.0596 |
| | CUB | 273 | 8.879 | 1.5134 | 0.0916 |
| 26. | FEB | 288 | 7.375 | 1.5455 | 0.0911 |
| | CUB | 273 | 8.286 | 1.6221 | 0.0982 |
| 27. | FEB | 288 | 7.771 | 1.2890 | 0.0760 |
| | CUB | 273 | 8.187 | 1.7941 | 0.1086 |

# MEASURING THE EFFICIENCY OF THE CZECH PUBLIC HIGHER EDUCATION INSTITUTIONS: AN APPLICATION OF DEA

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*Highlights*

- *The efficiency score is sensitive to the selected inputs and selected outputs*
- *Dividing the HEIs into groups give us better information about their efficiency*

**Abstract**

The Ministry of Education, Youth and Sports (MEYS) financially supports the Czech higher education institutions (HEIs). The largest amount of the MEYS's budget intended for HEIs subsidizes the public HEIs. Therefore, the aim of this paper is to measure the efficiency of the public higher education institutions. This will help us to determine which public HEIs can handle the sources (inputs) efficiently and how much the inefficient public HEIs should change their outputs to become efficient. We measure their teaching efficiency using data from 2015 and the DEA methodology. We run two analyses. The first analysis compares all the HEIs with each other. It shows that we have to consider the specialization of the HEIs. The second analysis divides the HEIs into three groups using coefficients of economic difficulties. This analysis shows that dividing the HEIs into groups helps us to eliminate the large differences in inputs and outputs. Therefore, we obtain better information about the efficiency of the HEIs.

**Keywords**

Data Envelopment Analysis, efficiency, higher education institutions, public HEIs

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## Introduction

The Czech higher education system includes three types of higher education institutions (hereafter HEIs) – 26 public HEIs, 37 private HEIs and 2 state HEIs (in 2016). Public and private HEIs are financially supported by the Ministry of Education, Youth and Sports (hereafter MEYS). The MEYS is the second-largest chapter in the state budget. Its expenses were 143 668 million CZK in 2015, representing 11.1 % of the state budget (Monitor, 2017). The planned amount of expenses of the MEYS is 156 526 million CZK for the year 2017. 21 627 million CZK (13.8 % of the MEYS's budget; for comparison the ratio was 15.9 % in 2013) is intended for the HEIs and 20 321 million (13.0 % of the MEYS's budget; the ratio was 12.0 % in 2013) is intended for research, experimental development and innovation (Act no. 475/2013 Coll. and Act no. 457/2016 Coll.).

The allowance and subsidies granted to HEIs follow the MEYS's rules (MEYS, 2015a). This budget is divided into budget headings and indicators. Budget heading I focuses on institutional financing of HEIs (indicators A and K), budget heading II combines indicators aimed at supporting students in the form of scholarships or grants (indicators C, J, S and U), budget heading III includes tools for supporting the development of HEIs (indicator I) and budget heading IV includes indicators for international cooperation and other indicators (indicators D and F). The MEYS using this methodology supports the diversification of higher education institutions in the Czech Republic, motivates HEIs to higher and better performance and to higher efficiency of the educational process.

Generally, if we want to measure the efficiency of a production unit, we compare inputs and outputs. Many methods can be used, for example parametric and non-parametric methods. Parametric methods, such as Stochastic Frontier Analysis (SFA), are stochastic and set the concrete production function, usually the cost or profit function. Non-parametric methods, for example Data Envelopment Analysis (DEA) or the Free Disposal Hull (FDH), are deterministic and in general determine the ratio of the weighted sum of inputs and the weighted sum of outputs (Polouček et al., 2006).

Data Envelopment Analysis is very common methodology used for measuring the efficiency of public higher education institutions. DEA is used to evaluate the technical efficiency of homogeneous production units. The basic model was described by Charnes, Cooper and Rhodes (1978). This model was later followed up by Banker, Charnes and Cooper (1984). This methodology treats multiple inputs and multiple outputs. In the case of measuring the efficiency of higher education institutions, the commonly used inputs are expenditure on tertiary education (Johnes, 2008; Kantabutra and Tang, 2010; Nazarko and Šaparauskas, 2014), the number of academic staff (Avkiran, 2001, Abbott and Doucouliagos, 2003) or number of students (St. Aubyn et al., 2009; Wolszczak-Derlacz and Parteka, 2011). On the other hand, the number of graduates (McMillan and Datta, 1998; Abbott and Doucouligos, 2003; Afonso and Santos, 2005; Kempkes and Pohl, 2007; Cuenca, 2011), the number of publications (Athanassopoulos and Shale, 1997; St. Aubyn et al., 2009) or the employment rate (Kantabutra and Tang, 2010) can be used as outputs.

The aim of the article is to measure the teaching efficiency of the Czech public higher education institutions (see Table 2 in Appendix) in 2015 by using DEA methodology and to find implications for improvement of its efficiency score.

## Materials and Methods

Data Envelopment Analysis evaluates the technical efficiency of homogeneous production units. Technical efficiency is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs (Flegg et al., 2003). A homogeneous production unit is referred to as a decision-making unit (DMU). Charnes, Cooper and Rhodes (1978) used the name decision-making unit to describe the units being analysed in DEA. This term emphasizes the fact that the focus is not on profits. DMUs are units that produce identical or equivalent outputs and may include banks, supermarkets, hospitals, schools, public universities, public libraries and so forth (Cooper, Seidford and Tone, 2007).

Data Envelopment Analysis is the optimization method of mathematical programming. Its aim is to divide production units into efficient and inefficient production units. DEA can measure the efficiency of DMUs with multiple inputs and multiple outputs. The inputs and outputs can be expressed in monetary and non-monetary forms (e.g. in the area of education: the number of academic staff, the number of non-academic staff or financial resources as inputs and the number of graduates or research quantum as outputs; Cunha and Rocha, 2012).

Using DEA, we are also able to design a virtual (hypothetical) unit for each inefficient unit. Virtual units are part of the efficient frontier and are calculated as a combination of selected efficient units. These selected units are called peer units or peers. Sometimes the efficient unit can be the virtual unit for the inefficient unit.

There are two basic DEA models – the CCR model assuming constant returns to scale (CRS; Charnes, Cooper and Rhodes, 1978) and the BCC model assuming variable returns to scale (VRS; Banker, Charnes and Cooper, 1984). The CCR model is used in situations in which the outputs increase proportionally to an increase in inputs. The BCC model fits situations in which the outputs do not increase proportionally to an increase in inputs. Both models can be input- or output-oriented. The choice of an input- or output-oriented model depends on the production process characterizing the production unit (i.e. minimize the use of inputs to produce a given level of outputs or maximize the level of outputs for a given level of inputs; Pascoe et al., 2003).

There is one fact that is characteristic of all linear programming models. A lot of conditions and restrictions has a negative impact on the solution of the problem. Therefore, it is recommended to use dual model of linear programming. This dual model uses the same data but with less restrictions. From this point of view, the dual model seems to be more practical (for the calculation procedure using the dual model, see Jablonský, 2011, Jablonský and Dlouhý, 2004, or the original work from Charnes, Cooper and Rhodes, 1978, and Banker, Charnes and Cooper, 1984).

Data Envelopment Analysis can be a powerful tool when used wisely. Cornuejols and Trick (1998) reported a few of the characteristics that make DEA powerful; for example, DEA can handle multiple-input and multiple-output models. It does not require an assumption of a functional form relating inputs to outputs, and DMUs are compared directly with a peer or a combination of peers.

Cornuejols and Trick (1998) warned that the same characteristics that make DEA a powerful tool can also create problems; for example, since DEA is an extreme point technique, noise (even symmetrical noise with a zero mean), such as measurement error, can cause significant problems. DEA measures relative efficiency not absolute efficiency. In other words, it can determine how well you are performing compared with your peers but not compared with a theoretical maximum. Since DEA is a non-parametric technique, statistical hypothesis tests are difficult. Since a standard formulation of DEA creates a separate linear programme for each DMU, large problems can be computationally intensive.

## Data and model specification

The Ministry of Education, Youth and Sports collect specific data from the higher education institutions. We used this data for our analysis. The data set includes data from 2015 on the number of graduates (we divided these students into two groups – the bachelor and master's graduates and the PhD graduates; MEYS, 2016a), the number of academic staff (MEYS, 2016b) and the indicators A and K (MEYS, 2015b). The bachelor and master's graduates and the PhD graduates represent the outputs of our models. On the other hand, the number of academic staff and the indicators A and K represent the inputs.

The academic staff (see Avkiran, 2001; Abbott and Doucouliagos, 2003) contains professors, associate professors, assistant professors, lecturers, assistants and teaching staff. According to the MEYS, the academic staff is involved in pedagogical or scientific activities. It is not possible to include academic staff among academics who are only scientifically active at the university and do not teach at all. The number of academic staff is calculated as the average number of full-time equivalent employees (MEYS, 2016b).

Institutional financing of higher education institutions is based on the scale and economic demands of the performance of higher education institutions and their quality – the indicators A (the number of students in study programs) and K (quality and performance). Funds are allocated in budget heading I and are provided to universities in the form of a contribution. The volume of expenditure allocated through indicators A and K under institutional funding is set at 76 % and 24 % for 2015 (MEYS, 2015a).

Using these variables, we constructed two models. The first model is CCR model with constant returns to scale. The second one is BCC model with variable returns to scale. The foreign authors usually use models with variable returns to scale – BCC models – in the case of measuring the efficiency of the public higher education institutions. It is common that they construct and compare results of CCR (constant returns to scale) and BCC (variable returns to scale) models. Therefore, we also constructed CCR and BCC models. Both models are output-oriented because we want to find out how HEIs effectively use the resources (inputs). If they do not use them efficiently, using these models we will be able to determine how these inefficient HEIs should change their outputs to become efficient.

There is a formula for dual output-oriented CCR model:

$$\begin{aligned} &\textit{maximize} && g = \phi_q + \varepsilon\,(e^T s^+ + e^T s^-) \\ &\textit{subject to} && X\lambda + s^- = x_q \\ & && Y\lambda - s^+ = \phi_q y_q \\ & && \lambda, s^+, s^- \geq 0 \end{aligned} \qquad (1)$$

where $\lambda$ is scale, $s^+$ and $s^-$ are vectors of additional variables, $e^T = (1, 1,\ldots, 1)$ and $\varepsilon$ is infinitesimal constant, which is usually chosen as $10^{-8}$. The value of $\phi_q$ expresses the need for a proportional increase in outputs to achieve efficiency (Jablonský and Dlouhý, 2004). To allow variable returns to scale in BCC model, it is necessary to add the convexity condition to the CCR model:

$$e^T \lambda = 1 \qquad (2)$$

The descriptive statistics (minimum, maximum, mean, median and standard deviation) of the data sets are presented in Table 1. The calculation was performed in the computer program DEAP Version 2.1 written by Tim Coelli (DEAP, 2011).

| Variable | Min. | Max. | Mean | Median | Std. dev. |
|---|---|---|---|---|---|
| I: Indicator A | 51 216.0 | 1 988 107.0 | 470 970.4 | 347 378.0 | 432 628.1 |
| I: Indicator K | 8 689.0 | 884 385.0 | 148 727.5 | 88 939.5 | 183 869.6 |
| I: Academic Staff | 58.0 | 3 236.2 | 587.7 | 444.5 | 617.1 |
| O: Graduates Bc and Mgr | 49.0 | 8 125.0 | 2 629.3 | 2 147.0 | 2 224.3 |
| O: Graduates PhD | 0.0 | 657.0 | 92.2 | 47.5 | 134.4 |

**Table 1: Descriptive statistics of data set of the Czech public HEIs in 2015 (source: own calculation based on the data from MEYS)**

## Results

The efficiency scores of both models using data from 2015 are presented in Table 3 (in the Appendix). The efficient public higher education institutions have the efficiency score equal to 1. Other HEIs are inefficient in teaching. According to the CCR model, there are 12 efficient public HEIs (CU, MU, UVPS, UHK, SU, ICT, BUT, TUO, UE, CULS, CPJ and ITB). The HEIs with very low efficiency score are APA, AFA, AAAD and JAMPA. All these HEIs are art HEIs. The efficiency score also determines how the HEIs should change their outputs to become efficient. AFA, the HEI with the lowest efficiency score, should increase the outputs – the number of bachelor and master's graduates and PhD graduates – by 76.3 %. It means, with the given level of inputs (the funding from MEYS and the number of academic staff), the number should be 86 bachelor and master's graduates instead of 49 and 5 PhD graduates instead of 3. The results show that AFA should produce more people skilled in art. Mathematically speaking it is correct, but this inefficiency is due to the high costs per student (see coefficients of economic difficulties, MEYS, 2012).

The same HEIs plus AFA are also efficient when we use BCC model – model with variable returns to scale. In this case, AFA belongs to the efficient HEIs. The efficiency score of AAAD also was improved. AAAD should increase the outputs by 10.9 %, instead of 64.8 %. Some HEIs (PU, OU, UWB) have efficiency score very similar in both models. It shows that the different specialization of HEIs has different returns to scale.

The efficiency score is sensitive to the selected inputs and selected outputs. Using more variables in the model decreases the sensitivity and increases the efficiency scores – for example, McMillan and Datta (1998) recommended keeping the number of variables smaller than one-third of the number of observations. This is one of the reasons why we did not use other indicators (such as C – scholarships for PhD students, J – subsidies for accommodation and boarding, U – accommodation scholarships, D – international cooperation) in our models, because when we used them, almost all HEIs were efficient. It is also important to consider factors like the specialization of the HEI. The specialization of AFA requires high costs (see coefficients of economic difficulties; MEYS, 2012). Its costs are high, and the graduates/teacher and students/teacher ratios are low. This is because art HEIs require high costs and more teachers per graduate and student than other HEIs with, for example, a specialization in economics (e.g. UE).

In accordance with this conclusion, we divided the HEIs into groups with similar specializations. Some HEIs do not have only one specialization (e.g. CU), and therefore we used coefficients of economic difficulties. The MEYS divides study programmes into seven groups according to the relative costs. The relative costs are represented by cost coefficients, which are between 1.00 (for economics and humanities) and 5.90 (for art; MEYS, 2012; see Fischer, 2015). We calculated the total coefficient of economic difficulties for each HEI as a weighted average of coefficients of economic difficulties and the number of students in study programmes.

According to the total coefficients of economic difficulties, we divided HEIs into three groups with similar coefficients. The average of the total cost coefficients of Group 1 is 1.28, of Group 2 it is 1.60 and of Group 3 it is 5.82. UE (with a total cost coefficient of 1.08), ICT (2.72) and UVPS (3.15) are not included, because they are outliers in these groups. UE is an economic HEI, the specialization of ICT is chemical technology and the specialization of UVPS is veterinary medicine and pharmaceutical sciences, and there are no other HEIs with the same or a similar specialization.

We used the same data and models as in the first analysis. The results of the second analysis are presented in Table 4 (in the Appendix). It is obvious that the efficiency scores are higher than in the first analysis. Using the total coefficients of economic difficulties and dividing the HEIs into groups, we eliminated the large differences in inputs and in outputs. We divided the HEIs into groups that are more homogeneous. On the other hand, the division into three more homogenous groups violated the recommended number of variables in DEA models (in case of Group 1 and Group 3). However, this violation can be justified for the purpose of the additional analysis. Using BCC model, there are many efficient HEIs in each model due to very low discrimination ability in the DEA models. But we can still find HEIs with a low efficiency score.

Group 1: MU, UHK, SU, UWB, CPJ and ITB represent Group 1. These HEIs are much more homogenous than the whole group of all HEIs. Only UWB is inefficient. According to the results of both models, it should increase its outputs (the number of bachelor and master's graduates and PhD graduates) by 9.6 % (CCR model; from 2 835 bachelor and master's graduates to 3 107 and from 69 PhD graduates to 76) or by 6.7 % (BCC model; from 2 835 bachelor and master's graduates to 3 025 and from 69 PhD graduates to 74). When we compared all HEIs together, they were not totally homogenous and it was the reason why we used the coefficients of economic difficulties to divide HEIs into the homogenous groups. Now the results give us better information about the efficiency of HEIs.

Group 2: Members of Group 2 are CU, USB, JEPU, PU, OU, CTU, TUL, UP, BUT, TUO, TBU, CULS and MUB – 13 HEIs. According to the CCR model, there are only 4 efficient HEIs (CU, BUT, TUO and CULS). The most inefficient HEI is OU. It should increase the outputs by 19.6 % to become efficient. The results of BCC model showed 11 efficient HEIs. Only PU and CTU are inefficient. They should increase the outputs by 11.3 % and 12.6 %.

Group 3: All HEIs in this group are art HEIs (APA, AFA, AAAD and JAMPA). These HEIs were very inefficient in the first analysis (e.g. APA 0.450 in CCR model and 0.480 in BCC model), but comparing APA only with other art HEIs, we got the results that show APA as the efficient HEI. Now we know the effectiveness was not caused by wrong management of funding or academic staff. It was caused by comparing 'wrong' HEIs together.

## Discussion

Using groups led to better comparability of HEIs. The efficiency scores showed which HEIs are efficient and which are inefficient in teaching. But it is not all what the efficiency score can tell us. It also can determine how much the inefficient DMUs should change their inputs or outputs to become efficient. In our case, when we used output-oriented model, the efficiency score determines how much the inefficient HEIs should change their outputs to become efficient.

It seems to be easy to say by how much the number bachelor and master's graduates and PhD graduates should be increased. However, we also have to consider other aspects – for example: Do the programmes require high costs and a high number of academic staff? Are we comparing chemistry vs. management programmes? Did the public procurement go wrong? Could the price and the costs be lower? Is the device/equipment fully utilized?

Dividing the HEIs into groups helped us to be more specific about the efficiency of HEIs. However there are still some aspects to consider; therefore, we recommend using faculties or departments as DMUs with the same or similar specializations for further analyses. DMUs can be divided into groups as follows: economics, philosophy, engineering, agriculture, medicine, art and so on (for a comparison see McMillan and Datta, 1998). Or we can focus only on one specialization (see Pietrzak, Pietrzak and Baran, 2016, who focused on only faculties specialized in social sciences). Faculties or departments are more homogeneous than HEIs. This can lead us to more precise results. On the other hand, the data availability for faculties and departments can be crucial.

The faculties prepare annual reports and it is possible to collect data from them, but the problem is, that this data are not standardized like the data from HEIs. There is a pattern form from MEYS that the HEIs have to fill in with data and this data are comparable. Unfortunately, there is no pattern form for faculties. When a faculty publishes the data about the academic staff per departments and the other one not, the missing data has to be collected in different way (e.g. survey). When we decide to use a survey, we have to consider what data we need. We need some data for input(s) and other for output(s). It is very important which data we choose.

When we find the data that are suitable for our analysis, we will be able to identify, which faculties or department are efficient and which are not. We will also be able to recommend to MEYS how to change the distribution of money that is used for financing the universities. Nowadays, MEYS uses the coefficient of economic difficulties, but these coefficients do not say anything about the efficiency – for example, when we compare all economic faculties or departments and some of them are inefficient, MEYS should ask why – Is this inefficiency caused by poor management of finances? Or by something else? When we are able to answer these questions, it could help MEYS effectively distribute the money (not only for teaching) among the universities.

We mentioned earlier the strengths and limitations of DEA. When we have all data that we need for our research, we have to be careful with using DEA methodology. It is necessary to use it wisely and we should try to minimize its limitations.

## Conclusion

The Czech public HEIs are financially supported by the MEYS, therefore, we measured the teaching efficiency of the public HEIs and identified the public HEIs that can handle the sources (inputs) efficiently. The results also showed how much the inefficient public HEIs should change their outputs to become efficient.

To measure the efficiency, we used the DEA methodology. We ran two analyses. The first analysis compared all the HEIs with each other. The second one divided the HEIs into three groups with similar coefficients of economic difficulties. The first analysis showed that we have to consider the specification of the HEIs. We mentioned APA as an example. The specialization of APA (the art HEI) requires high costs and therefore its efficiency score was low in the first analysis. Without considering the specific aspects, it looked like APA is very inefficient.

In the second analysis, dividing the HEIs into three groups helped us to eliminate the great differences in inputs and in outputs. The creation of groups of HEIs with similar specializations gave us better information about their efficiency. The efficiency score can also determine how much the inefficient HEIs should change their inputs to become efficient. But we should not increase the outputs only on the base of the efficiency score without considering other aspects (e.g. the costs and the academic staff requirement – compare chemistry vs. management programmes; in public procurement whether the price could be lower; device/equipment utilization).

Dividing the HEIs into groups helped us to be more specific about their efficiency, but there are still some aspects to consider; therefore, we recommend using faculties or departments as DMUs with the same or similar specializations for further analysis. Faculties or departments are more homogeneous than HEIs and can lead us to more precise results. On the other hand, the data availability for faculties and departments can be crucial.

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## Appendix

| Abbreviation | Name of the Czech public HEIs |
|---|---|
| AAAD | Academy of Arts, Architecture and Design in Prague |
| AFA | Academy of Fine Arts, Prague |
| APA | Academy of Performing Arts in Prague |
| BUT | Brno University of Technology |
| CPJ | College of Polytechnics Jihlava |
| CTU | Czech Technical University in Prague |
| CU | Charles University in Prague |
| CULS | Czech University of Life Sciences Prague |
| ICT | Institute of Chemical Technology in Prague |
| ITB | The Institute of Technology and Business |
| JAMPA | Janáček Academy of Music and Performing Arts |
| JEPU | Jan Evangelista Purkyně University in Ústí nad Labem |
| MU | Masaryk University |
| MUB | Mendel University Brno |
| OU | University of Ostrava |
| PU | Palacký University of Olomouc |
| SU | Silesian University, Opava |
| TBU | Tomas Bata University in Zlín |
| TUL | Technical University of Liberec |
| TUO | Technical University of Ostrava |
| UE | University of Economics, Prague |
| UHK | University of Hradec Králové |
| UP | University of Pardubice |
| USB | University of South Bohemia in České Budějovice |
| UVPS | University of Veterinary and Pharmaceutical Sciences, Brno |
| UWB | University of West Bohemia |

**Table 2: Definition of abbreviations of the Czech HEIs**

| HEIs | CRS | Rank | VRS | Rank |
|---|---|---|---|---|
| CU | 1.000 | 1 | 1.000 | 1 |
| USB | 0.838 | 17 | 0.864 | 19 |
| JEPU | 0.702 | 21 | 0.758 | 23 |
| MU | 1.000 | 1 | 1.000 | 1 |
| PU | 0.859 | 14 | 0.865 | 17 |
| UVPS | 1.000 | 1 | 1.000 | 1 |
| OU | 0.785 | 18 | 0.785 | 21 |
| UHK | 1.000 | 1 | 1.000 | 1 |
| SU | 1.000 | 1 | 1.000 | 1 |
| CTU | 0.843 | 16 | 0.865 | 17 |
| ICT | 1.000 | 1 | 1.000 | 1 |
| UWB | 0.766 | 19 | 0.766 | 22 |
| TUL | 0.652 | 22 | 0.701 | 24 |
| UP | 0.754 | 20 | 0.791 | 20 |
| BUT | 1.000 | 1 | 1.000 | 1 |
| TUO | 1.000 | 1 | 1.000 | 1 |
| TBU | 0.882 | 13 | 0.920 | 14 |
| UE | 1.000 | 1 | 1.000 | 1 |
| CULS | 1.000 | 1 | 1.000 | 1 |
| MUB | 0.859 | 14 | 0.881 | 16 |
| APA | 0.450 | 23 | 0.480 | 25 |
| AFA | 0.237 | 26 | 1.000 | 1 |
| AAAD | 0.352 | 24 | 0.891 | 15 |
| JAMPA | 0.309 | 25 | 0.437 | 26 |
| CPJ | 1.000 | 1 | 1.000 | 1 |
| ITB | 1.000 | 1 | 1.000 | 1 |
| *Mean* | *0.819* | | *0.885* | |
| *Std. dev.* | *0.232* | | *0.155* | |

**Table 3: The efficiency scores of the Czech public HEIs in 2015 (source: own calculation)**

| HEIs | CRS | Rank | VRS | Rank |
|---|---|---|---|---|
| GROUP 1 | | | | |
| MU | 1.000 | 1 | 1.000 | 1 |
| UHK | 1.000 | 1 | 1.000 | 1 |
| SU | 1.000 | 1 | 1.000 | 1 |
| UWB | 0.904 | 6 | 0.933 | 6 |
| CPJ | 1.000 | 1 | 1.000 | 1 |
| ITB | 1.000 | 1 | 1.000 | 1 |
| *Mean* | *0.984* | | *0.989* | |
| *Std. dev.* | *0.036* | | *0.025* | |
| GROUP 2 | | | | |
| CU | 1.000 | 1 | 1.000 | 1 |
| USB | 0.862 | 9 | 1.000 | 1 |
| JEPU | 0.821 | 10 | 1.000 | 1 |
| PU | 0.867 | 8 | 0.887 | 12 |
| OU | 0.804 | 11 | 1.000 | 1 |
| CTU | 0.872 | 6 | 0.874 | 13 |
| TUL | 0.662 | 13 | 1.000 | 1 |
| UP | 0.757 | 12 | 1.000 | 1 |
| BUT | 1.000 | 1 | 1.000 | 1 |
| TUO | 1.000 | 1 | 1.000 | 1 |
| TBU | 0.962 | 5 | 1.000 | 1 |
| CULS | 1.000 | 1 | 1.000 | 1 |
| MUB | 0.870 | 7 | 1.000 | 1 |
| *Mean* | *0.883* | | *0.982* | |
| *Std. dev.* | *0.103* | | *0.043* | |
| GROUP 3 | | | | |
| APA | 1.000 | 1 | 1.000 | 1 |
| AFA | 0.594 | 4 | 1.000 | 1 |
| AAAD | 1.000 | 1 | 1.000 | 1 |
| JAMPA | 0.981 | 3 | 0.984 | 4 |
| *Mean* | *0.894* | | *0.996* | |
| *Std. dev.* | *0.173* | | *0.007* | |

**Table 4: The efficiency scores of the Czech public HEIs divided into three groups based on coefficient of economic difficulties in 2015 (source: own calculation)**