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The Dynamics of Productivity in the Swiss and German University Sector: A Non-Parametric Analysis That Accounts for Heterogeneous Production

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THE DYNAMICS OF PRODUCTIVITY IN THE SWISS AND GERMAN UNIVERSITY SECTOR: A NON-PARAMETRIC ANALYSIS THAT ACCOUNTS FOR HETEROGENEOUS PRODUCTION

August 2012

Based on a disaggregate cross-country analysis, we investigate the performance of 10 public Swiss universities and 77 public German universities from 2001-2007. During this period the universities in both countries have faced two major reforms aimed at improving efficiency and productivity in the European higher education sector. We assess the change in productivity and its sources, that is technological change, technical efficiency change and scale effects, obtained by computing the non-parametric Malmquist productivity index by benchmarking the non-science disciplines and the science disciplines of both countries separately against a common frontier. Given the lack of statistical inference of non-parametric productivity analyses, we employ bootstrapping techniques and estimate confidence intervals, allowing us to verify the statistical significance of our results. The results indicate that improvements in technical efficiency were by far the most important driver for productivity growth, followed by gains realised through exploiting economies of scale; thereby technological change partly reduced the increases in productivity. Our findings, however, suggest reform-related differences between the Swiss and the German public university sector. Further, the results point to structural differences across the scientific disciplines, as we found divergent patterns for the development in productivity and its sources in the non-sciences and the sciences.

Keywords: Higher Education, Cross-Country Analysis, Total Factor Productivity, Non-parametric Malmquist Productivity Index

JEL-Classification: I23, I28, D24

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1. Introduction

Over the last two decades, higher education has become increasingly important to political agendas because of the growing constraints on public budgets and the recognition that education is a key driver of economic competitiveness in an increasingly knowledge-based global economy (OECD, 2008*b*). Accordingly, as in most other European countries, since the late 1990s, the Swiss and the German higher education sector has been subjected to several paradigmatic national and international reforms that have aimed at increasing competition and improving efficiency and productivity in higher education institutions (HEIs). With the reforms of New Public Management (NPM), national governmental authorities have intended to increase efficiency in higher education production by introducing more 'market-like' management and governance structures into publicly financed HEIs, thus implying more autonomy, but also more accountability for HEIs' decision-making (Teixeira et al., 2004; Pollitt and Bouckaert, 2000). In line with this aim to increase productivity in the European countries by creating the most competitive and dynamic knowledge-based economy in the world (Council of the European Union, 2000), the second major higher education reform was started by the signing of the Bologna Declaration in 1999. Known as the Bologna Reforms, this reform process particularly targeted a harmonisation of higher education across European countries (Bologna Declaration, 1999).

Given the political objectives of improving efficiency and productivity that are inherent both in the NPM reforms and the Bologna Reforms, an analysis on whether efficiency and productivity has actually improved in the Swiss and German higher education sector is of great political and economic interest. Switzerland and Germany are two countries where higher education has become a dominant element in terms of boosting high-educated and high-skilled people ready to join the labour-market, as postulated by the Swiss Science and Technology Council (2006) and the German Council of Science and Humanities (2006). Hence, evaluating the development of higher education performance will allow us to draw conclusions on how effective the deregulation processes have been in terms of enhancing both efficiency and productivity in the higher education sector.

Although a variety of studies has explored the performance of HEIs, studies on higher education productivity are overall rare, among them any analyses using the non-parametric Malmquist productivity index (see e.g. Worthington and Lee, 2008; Johnes, 2008; Flegg et al., 2004). Cross-country analyses are even scarcer. However, the few studies conducted have shown that productivity develops differently in the European countries (see e.g. Agasisti and Johnes, 2009; Agasisti and Pohl, 2012; Parteka and Wolszczak-Derlacz, 2011). As of now, there is no such analysis for Switzerland and Germany. In addition, only a very small number of studies on the performance of HEIs have been conducted on Switzerland (e.g. Bolli and Farsi, 2011; Schenker-Wicki and Olivares, 2009; Filippini and Lepori, 2007) and on Germany (e.g. Warning, 2004; Kempkes and Pohl, 2010).

From an empirical point of view, two main concerns appear when analysing the previous research. Most notably, except for Smart (2009) and Parteka and Wolszczak-Derlacz

(2011) none of the productivity studies that used the non-parametric Malmquist productivity index – which generally lacks statistical properties – assessed the statistical significance of their results. Hence, these studies should be interpreted with care. Further, only Bolli and Farsi (2011) have analysed higher education productivity at a disaggregated level, that is, the level of scientific fields. As input and output variables can vary by department and disciplines (Dundar and Lewis, 1995), any analysis on higher education productivity should account for the heterogeneous production process in HEIs and investigate the development in productivity disaggregated at the discipline level.

Filling the gap of previous productivity analyses in higher education, we provide empirical evidence for Swiss and German public universities based on a disaggregate cross-country analysis, wherein we separately benchmark the non-science disciplines and the science disciplines of the two countries against a common production frontier.[1] Further, given the lack of statistical inference with non-parametric productivity analyses, we employ bootstrapping techniques and estimate confidence intervals, thereby allowing us to verify the statistical significance of our results.

This study is the first that is (i) based on a cross-country analysis to estimate the dynamics of total factor productivity in the Swiss and the German university sector, (ii) by using the non-parametric Malmquist productivity index, while also (iii) providing statistical significance of the results. Basing our estimations on the Malmquist productivity index allows us to identify the key sources driving productivity change, that is, technological change (a shift of the production frontier due to new technologies and reorganisation), technical efficiency change (a catch up to each sector's production frontier due to learning from best practice) and scale efficiency changes (a movement along the frontier due to adjusting to the optimal scale of operation). Estimating the development of university productivity through a cross-country comparison between Switzerland and Germany can provide valuable insights for both university management to identify the best practices to learn from and policy makers to understand performance differences caused by country-specific structural differences. The data we use represents a unique panel dataset that covers micro-level information of 10 public Swiss universities and 77 public German universities over the period of 2001-2007.

The paper is structured as follows. Section 2 introduces the Swiss and German higher education landscape and discusses the higher education reforms occurring in both countries since the late 1980s. Section 3 presents an exemplary overview of previous studies on non-parametric productivity analyses of higher education. In Section 4, we introduce the theoretical background of our analyses from which we derive our hypotheses to be tested in this study. Section 5 illustrates the methodology, while Section 6 provides information on the dataset used for this analysis. The results are then presented and discussed in Section 7, followed by a conclusion in Section 8.

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[1] The term 'sciences' refers to all natural and technical disciplines and subjects, such as mathematics and the natural sciences, engineering, agronomy, forestry and nutritional sciences. To distinguish humanities and social sciences from the science disciplines, we use the term 'non-sciences', which refers to all 'non'-natural and 'non'-technical disciplines and subjects, such as linguistics, cultural sciences, arts, sport and legal, economics and social sciences.

2. The Swiss and the German higher education system and the challenges of undertaking reforms

In the following subsections, the Swiss and the German higher education systems are briefly introduced and roughly compared. In addition, we describe the main aspects of the reform processes, including considerable managerial and organisational changes at HEIs that have occurred in both countries.

2.1. An overview of the higher education landscape in Switzerland and Germany

Apart from the obvious difference in country size, the Swiss and German higher education systems display numerous similarities in their institutional aspects and the reform processes that occurred since the 1990's. In both countries, the higher education system is predominantly financed by public funding[2], and it is based on a Federal system of responsibilities at different levels, namely, the Confederation and the cantons in Switzerland and the German Federation and the Federal States (*Länder*) in Germany. In both countries, the university landscape is diversified with different types of HEIs, among these traditional universities with science-based teaching and research and universities of applied sciences offering often more praxis-oriented teaching and research.

The Swiss public higher education sector comprises traditional universities, the ten cantonal universities and the two federal institutes of technology (ETH Zurich and EPF Lausanne), seven universities of applied sciences, 18 universities for teacher education and other professional education and training institutions at the level of higher education. The majority of the cantonal universities offer study programmes across a broad range of scientific fields, except for the Universities in St. Gallen, Lucerne and Lugano which specialise more in the humanities and the social sciences. The federal institutes of technology focus on the exact sciences, technical sciences and architecture, specialising in particular in life sciences, nanotechnology and communications technology. As a result of one of the most important reforms, the Swiss universities of applied sciences were created in 1995 as a new type of university. They was developed from existing colleges of higher vocational education and training to provide study programmes in engineering, business and social sciences, applied arts and design, healthcare, and social work. In contrast to universities of applied sciences, these universities have the right to issue doctorates (State Secretariat for Education and Research and Federal Office for Professional Education and Technology, 2006; Swiss Coordination Centre for Research in Education, 2011).

Funding and responsibility for Swiss higher education is shared by the cantons and the Swiss Confederation. The Confederation supervises and funds the federal institutes of technology and provides financial contributions to the universities and universities of applied sciences. By contrast, the cantons are responsible for the cantonal universities

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[2] Moderate tuition fees have to be paid at Swiss HEIs. Tuition fees (at a moderate level) have been introduced in seven Länder, beginning in 2007. By 2012, Bavarian and Lower-Saxony were the only two Länder left, where students are charged tuition fees; in all other Länder university studies are once again tuition free.

and are their main funding source. Until the Federal Act on Funding and Coordination of the Higher Education Sector was adopted in 2012, the coordination of the different university types was handled by several different national bodies.[3] The new legal act led to considerable simplification and harmonisation regarding the coordination of these responsibilities and activities.[4]

The German higher education system is even more diversified, comprising more than 400 officially recognised HEI, thereof more than 100 universities and technical universities, about 200 universities of applied sciences, 50 colleges of arts and music, 16 colleges of theology and 6 colleges of education, (German Federal Statistical Office, 2012*a*). German universities usually offer a broad range of programmes in all subjects and have always been expected to provide science-based teaching and conduct basic research, both venues being closely interlinked and following the Humboldtian principal.[5] In contrast to their Swiss counterparts, German universities of applied sciences were already established in 1968. The German universities of applied sciences mainly offer subjects in engineering and social sciences and, opposed to the universities, place a much stronger emphasis on teaching, and they also cannot award doctoral degrees (Federal Ministry of Education and Research, 2004).

In 2006, the German Federal system faced an extensive reform that shifted educational responsibility from the Federal Government to the Länder, especially in the area of higher education. The Framework of Higher Education – until then, the respected legal Federal framework for regulating the higher education system in Germany – has been replaced by regulations established at the Länder level. Since 2006, the administrative responsibility for and the funding of public HEIs is almost exclusively set with the Länder; the respective legislation is passed in the Länder constitutions and in the Länder laws on higher education. However, the Federal Government does have the right to enact legislation on university admission and university degrees. In addition, areas of supra-regional importance, such as science and research projects and large-scale research facilities at universities, are areas of joint responsibility that can be set by agreements made between the Länder and the Federal Government (German Federal Ministry of Education and Research, 2012).[6]

Although the characteristics regarding the institutional setting and the funding mechanisms of the Swiss and German higher education system appear quite similar, there are obvious differences between the higher education systems, especially concerning financial endowment and size. Comparing the two countries' higher education systems in monetary terms, we see that the total expenditures on higher education increased in Switzerland and in Germany between 1995 and 2008 (OECD, 2011). Given the differing rates of student evolution, the total expenditures per student, however, developed differently in the two countries. From 1995 to 2008, the OECD statistics show that the

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[3] Leporie (2007) provides a detailed overview on the previous Swiss coordination bodies.

[4] Additional information on Swiss higher education can be found in the recent report of the Swiss Coordination Centre for Research in Education (2011) and in Leporie (2007).

[5] There are some specialised German universities, such as the two Universities of the Federal Armed Forces and the University of Veterinary Medicine Hannover.

[6] More information on the German higher education system can be found in e.g. Hartwig (2011).

Swiss total expenditures per students decreased during this time. In Germany, the same measure rose because the total expenditures on higher education increased at a higher rate than the number of students. However if the expenditures on higher education is considered as a percentage of the GDP, a new picture emerges. Compared to previous years in which Switzerland even topped the OECD average of 1.5% of the GDP, public spending on higher education declined to 1.3% of the GDP in 2008. In comparison, in Germany, public spending per GDP on higher education amounted to merely 1.0% of the GDP in 2008. While from 1995 to 2008 the public spending on higher education relative to the GDP increased by 0.4 percentage points in Switzerland, it stagnated at 1.0% of the GDP in Germany.

Referring to the size of the two higher education systems, in Switzerland, a total of more than 130,000 students were enroled at universities and about 75,000 students were enroled at the universities of applied sciences as of 2010/2011 (Swiss Federal Statistical Office, 2012*a*). The corresponding student enrolment for the German counterparts were essentially higher, with a total of nearly 1.5 million students enroled at universities and nearly 700,000 students enroled at the universities of applied sciences (German Federal Statistical Office, 2012*b*). The distribution of student enrolment differs over the range of scientific fields in both countries. As the statistics show, the enrolment is still essentially higher in the humanities and the social sciences as it is in the natural and technical sciences (Swiss Federal Statistical Office, 2012*b*; German Federal Statistical Office, 2012*c*).

2.2. The reformation process in the Swiss and German higher education sector

Over the last few decades, the dilemma of financial constraints of public funding, such as in the higher education sector, has become one of the overarching public debates in most European countries (Sporn, 2007). Parallel to this, another strand of political discourse appeared, emphasising the need to invest in higher education and high-level research to stay internationally competitive and to foster economic growth (OECD, 2008*b*). In fact, as shown by Aghion et al. (2008), there is still an economic growth gap between the US and Europe that the authors reflect upon against the background of differentials in the governance and performance of both US and European universities.

In line with these political discourses, higher education was subject to two major reform processes that occurred in many of the European countries over the last two decades. The first major reform process, referred to as New Public Management (NPM), began in the late 1980's and affected the entire public sector, aiming at an improvement in efficiency (Pollitt and Bouckaert, 2000). Corresponding reforms introduced in public organisations led to a paradigmatic change. In higher education, this paradigmatic change was characterised as a shift from the model of state control to a model of state supervision mechanisms (Neave and van Vught, 1994) that affected both higher education management and funding. New governance structures and managerial procedures were introduced in the higher education sector in most European countries. The HEIs gained more institutional autonomy in terms of decentralised decision-making with respect to internal governance and control mechanisms, budgeting, curricula design, study programmes, student selection and faculty employment. The newly established management processes came along with 'market-like' instruments, such as competitive and performance-oriented funding or contract management. At the same time, accountability like reporting, auditing and quality assurance were established, obliging the HEIs to demonstrate that they were using their resources efficiently (De Boer and File, 2009).

Since the 1990s, NPM reforms have been introduced in Switzerland and Germany. They considerably changed the structure of national coordination and responsibilities in the higher education systems. The following milestones were set in the Swiss higher education system: The University Act of 1999, the Universities of Applied Sciences Act in 1995 along with the revision in the inter-cantonal Agreement on Financing of Cantonal Universities and the Cooperation Agreement between the Confederation and Cantons on Higher Education in 2000. In Germany, some of the milestones of the reforming process were: The Higher Education Act of 1999 and its abrogation in 2006, the Compensation Act of 2002, the reform of 2006 regarding cooperation between the Federal Government and the Länder along with corresponding new laws on higher education for the 16 Länder.[7]

In 1999, the second major reformation process, known as the Bologna Reforms, started and affected the whole European higher education sector. Given the political aim, which was to create the most competitive and dynamic knowledge-based economy in the world, one major task the European Union attempted to accomplish is an increase in overall productivity in the European countries (Council of the European Union, 2000; European Commission, 2012). In line with this political agenda, public authorities in the national governments agreed on establishing a common European higher education area by 2010 to strengthen both higher education and research across Europe. The main elements of the Bologna Reforms include the implementation of a pan-European, three-cycle system of degrees at the bachelor, master and doctoral levels based on credit points; the promotion of student and academic mobility; and the introduction of pan-European standards of quality assurance (Bologna Declaration, 1999).[8]

In Switzerland, the guiding Bologna principles were introduced by different legally binding directives issued by the Swiss University Conference for universities in 2003 and by the Swiss Conference of Cantonal Ministers of Education for universities of applied sciences and universities of teacher education in 2002. In Germany, the Bologna Reforms were likewise transposed by a legally binding directive issued by the Standing Conference of the Ministers of Education and Cultural Affairs in 2003, and later augmented in 2010. In both countries, the single-tier Diploma, Licentiate and Magistra Artium programmes were transformed into two-tier bachelor and master programmes.[9]

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[7] More information on the new governance and management instruments introduced can be found for Switzerland in Leporie (2007), Lienhard et al. (2005) and Perellon (2001) and for Germany in Küpper (2003) and Hartwig (2011).

[8] Detailed information on the Bologna Reforms are presented in the follow-up documents issued by the European Commission at conferences in Prague (2001), Berlin (2003), Bergen (2005), London (2007), Leuven/Louvain-la-Neuve (2009) and lastly in Budapest and Vienna (2010).

[9] The corresponding progress toward the adoption of the Bolgona Reforms has been continuously reported, among other outlets in the national reports on stocktaking (Bologna Secretariat, 2012).

However, the implementation rate of transforming the old study programmes into the new Bologna conforming study programmes did differ in the two countries. While the percentage of students enroled in the new study programmes had already been 85% for Switzerland in 2008/2009, it was lower for Germany, with only 30.9% in 2007/2008 (Swiss Confederation, 2008; German Federal Government, 2008). Thereafter, the implementation rate in Germany, however, exponentially rose. By 2010/2011, 78.1% of all study programmes offered at German universities accounted for the new bachelor and master structure (German Rector's Conference, 2010).[10]

In addition, procedures for quality assurance based on European criteria and standards were introduced, in both countries. Although, the establishment of internal quality assurances systems is set on a voluntary basis in Switzerland, Swiss public universities are obliged to follow quality standards set by the Swiss Centre of Accreditation and Quality Assurance, the national Accreditation Agency. They merely receive subsidies from the Swiss Confederation if such quality standards are met. In Germany, most of the Länder laws on higher education recently obliged the HEIs to introduce internal quality assurance systems. Concerning external quality assurance, which is mostly based on accreditation processes, the underlying accreditation procedures differ in the two countries: Institutional accreditation in Switzerland (Swiss Center of Accreditation and Quality Assurance, 2012) versus programme accreditation in Germany (since 2008 also system accreditation, that is, accreditation of a quality assurance system) (German Accreditation Council, 2012).

Summing up, both the introduction of new management and funding procedures and the adoption of the Bologna principles have induced considerable managerial and organisational changes in both Swiss and German HEIs, fostering at the same time further competition in the higher education sector. Given the political objectives of improving efficiency and productivity inherent in both the NPM Reforms and the Bolgona Reforms, an analysis on whether efficiency and productivity has really improved in the Swiss and German higher education sector is of great political as well as economic interest. In particular, evaluating the development of higher education performance allows us to draw further conclusions on how effective the deregulation processes have been in enhancing efficiency and productivity in the higher education sector.

3. Previous research on the dynamics of higher education productivity

A variety of studies have investigated the performance of HEIs, using non-parametric estimation techniques, such as Data Envelopment Analyses (DEA) and Full Disposable Hull (FDH) or parametric estimation techniques, such as Stochastic Frontier Analyses

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[10] The implementation rate is even higher at the German universities of applied sciences with 96.8% of overall study programmes. In fact, statistics of countries with this university type show that the new two-tiered study structure has been introduced, in most cases even more rapidly, at universities of applied sciences than at traditional universities (Autorengruppe Bildungsberichterstattung, 2008; Statistics Austria, 2008).

(SFA)(e.g., Kempkes and Pohl, 2010; Thanassoulis et al., 2009; Agasisti and Johnes, 2009; Bonaccorsi et al., 2006; Stevens, 2005; Izadi et al., 2002; Robst, 2001). However, most of the studies have focused on cross-section analyses of HEIs and thus provide empirical evidence only for the level of efficiency rather than changes in efficiency and productivity over time. Those studies that explicitly estimate the dynamics of higher education efficiency and productivity are relatively rare compared to analyses on other industries, such as the agricultural, transport or the energy sector.

Flegg et al. (2004) have adopted a DEA approach for 45 British universities for 1980-1992. Their findings indicate a growth in higher education productivity that was caused by a shift in the production frontier, that is, technological progress, instead of efficiency improvements. Similarly, Johnes (2008) reports a moderately average productivity growth in 112 English universities between 1996 and 2004 as the result of a positive technological change. However, he also found a decrease in the average level of efficiency. Worthington and Lee (2008) analysed 35 Australian universities between 1998 and 2003. Their analyses showed that most of the productivity gains for research-only were associated with technical and some scale efficiency improvements. In the case of teaching-only, the main driver of productivity gains was technological progress offset by a slight fall in technical efficiency. Some empirical evidence for continental Europe is provided, for example, by Agasisti and Johnes (2009) who investigated how productivity developed in the Italian higher education system from 2000-2003, the time span that directly followed the introduction of the Bologna Reforms in Italy in 1999. Their results indicate a growth in productivity as a result of both improvements in HEIs' efficiency and technological progress, while the latter was the main driver of the productivity change. However, the authors identified a decline in productivity from 2002 to 2003 caused mainly, as they assume, by the implementation costs of the Bologna Reforms.

Currently, there are only a few productivity studies of higher education that focus on cross-country comparisons.[11] Agasisti and Johnes (2009) analysed the productivity development of 127 English and 57 Italian HEIs between 2002/03-2004/05 and found opposing effects for the two countries. While English HEIs can realise productivity gains mainly as a result of technological progress, Italian's initial catching up in technical efficiency was somewhat outweighed due to the effort incurred by organisational changes (e.g. higher qualitative standards), the implementation of new teaching techniques (e.g. distance learning) and advanced information and communications technology, all affecting productivity negatively. Analysing 57 Italian and 46 Spanish public HEIs over the periods for 2000/01 and 2004/05, Agasisti and Pérez-Esparrells (2010) found productivity growth for both countries. However, in-depth analyses revealed that the Italian progress resulted from structural reforms (e.g., new bachelor and master curricula), while the Spanish progress was mainly driven by improvements in efficiency due to new funding models. The findings of Agasisti and Pohl (2012) in their analysis on 69 German and 53 Italian public universities for the year 2001 and the year 2007 indicate that productivity

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[11] The difficulties involved in gathering comparable panel data on input and output variables from different countries that reflect the higher education process might be a reason for the limited number of comparative cross-country analyses.

in higher education improved considerably in both countries. In addition to moderate catching up effects in efficiency, it was mainly technological progress that contributed to this productivity growth. However, Italian's efficiency improved more rapidly than Germany's. Parteka and Wolszczak-Derlacz (2011) further found productivity progress from 2001 to 2005 in their analysis of 266 HEIs across 7 European countries, namely, Austria, Finland, Germany, Italy, Poland, the UK, and Switzerland. However, in-depth analyses did show essential international differences with German, Italian and Swiss HEIs performing better in terms of productivity improvements, than did the HEIs in the other countries.

By now, there is no cross-country analysis solely comparing the productivity development of HEIs in Switzerland and Germany. But different studies on the performance of HEIs have been conducted for each country. Schenker-Wicki and Olivares (2009) and Schenker-Wicki and Hürlimann (2006) investigated the technical efficiency of Swiss universities using Data Envelopment Analysis on pooled data between 1999-2007 and 2000-2003. The authors found a general positive development in technical efficiency. In contrast, Filippini and Lepori (2007) estimated the technical efficiency of Swiss universities for the period from 1994 to 2003. Considering a cost-function approach based on Stochastic Frontier Analysis, their result suggests increased university costs. There is only one recent study that explicitly investigated the dynamics of productivity in the Swiss higher education sector, the one by Bolli and Farsi (2011). The authors explored how labour productivity developed from 1995 to 2007 in Swiss universities by applying a Malmquist productivity index based on a stochastic frontier approach. The results indicate a negative trend in overall productivity, particularly after 2002, with an average productivity decline of about 1% per year. As the authors argue, this decline in labour productivity could be the result of technological regress but also possible due to increasing inefficiency. Considering disciplinary differences, the result of their disaggregate analysis further suggests that scientific fields, such as economics and law, show the lowest performance, whereas science stands out as an exception for productivity improvement.

In the case of Germany, one of the first analyses where technical efficiency was investigated was the study by Backes-Gellner (1989), who explored the research performance of economics, business and sociology departments of 15 (former West German) universities. By considering the multiple outputs structure of teaching and research, a current cross-sectional efficiency analysis of 73 German HEIs was conducted by Warning (2004). However, possible changes in higher education productivity cannot be clearly captured by these investigations due to a lack of panel data structure. Quite recently, Kempkes and Pohl (2010) investigated how productivity and its main drivers have developed over time by analysing 72 public German universities between 1998-2003 at the aggregated level, that is, the level of university. Their results show that improvements in efficiency, rather than technological developments, have been the main source of productivity growth.

Given this overview on the previous analyses of higher education performance, two important issues for our productivity analysis of Swiss and German HEIs appear. The first and most notable issue is that except for Parteka and Wolszczak-Derlacz (2011) none of the productivity studies that non-parametrically estimated Malmquist productivity indices, assessed the statistical significance of their results, and hence, these studies should be interpreted with care. Second, only Bolli and Farsi (2011) analysed higher education productivity and its decomposed sources at a disaggregated level, that is, the level of scientific fields. However, previous studies have shown that higher education production varies across disciplines with respect to both their resource endowment and major output targets.

In this paper, we extend the previous empirical evidence by investigating and comparing the dynamics of productivity change and its components in the Swiss and the German higher education sector. Further, we employ a bootstrapping procedure to verify the statistical significance of the results obtained via non-parametric Data Envelopment Analysis techniques. Moreover, our analysis is based on a disaggregated approach differentiating between non-science and science disciplines. By doing so, we account for heterogeneity in the production process of different fields of higher education.

4. Theoretical background

In this section, we first introduce the conceptual background of productivity, technical efficiency and productivity change. Based on that analysis and against the background of higher education reforms that both the Swiss and German HEIs have recently faced (see Section 2), we derive the main hypotheses to be tested in this study.

4.1. The concepts of productivity, technical efficiency and productivity change

Productivity is defined as the ratio of output, y, over inputs, x, given an underlying production technology, the production possibility set T, as determined by ‘the social, technical, mechanical, chemical, and biological environment in which the production process takes place’ (Bogetoft and Otto, 2011, p. 59). The outer boundary of this production possibility set represents the production frontier built by decision-making-units (DMUs) that use the best possible combination of inputs to produce their outputs. In other words, HEIs that operate on this frontier are identified as technically efficient. HEIs below this frontier use suboptimal input-output combinations. Following the concept of frontier measures, the distance of a DMU to the production frontier tells us about the relative performance of that DMU in terms of technical inefficiency found in the production process. Hence, measuring technical efficiency means always benchmarking a specific HEI relative to its counterparts, given the underlying production technology.

A broad measure of productivity that includes all produced products and services by considering all input resources is total factor productivity (TFP). By applying the concept of TFP, we account also for output changes not explained by the rate of change in inputs used in production (Hornstein and Krusell, 1996). More specifically, the concept of TFP follows the consideration that a productivity change can also come from the more efficient use of the input resources through, for example, improvements in the management of production processes, organisational changes or more generally, innovation (OECD, 2008*a*).

Referring to the productivity development over time, TFP change can be decomposed into three different sources (Färe et al., 2008): Technological change (a shift of the production frontier due to technological progress, innovation and organisational changes), technical efficiency change (a catch up to the sector's production frontier due to diffusion and learning) and scale efficiency change (a movement along the frontier due to an alteration of the operation scale). Figure 1 illustrates the relationship between productivity, technical efficiency and productivity change and its sources graphically.

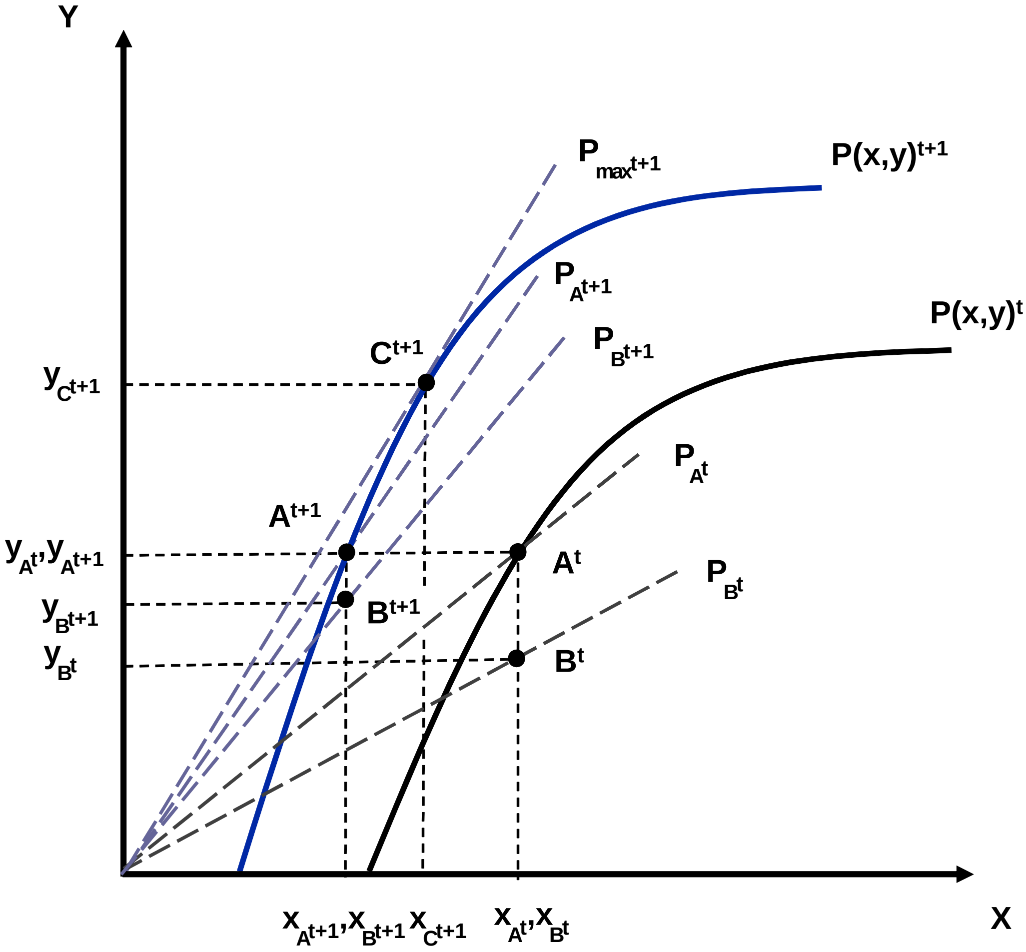

Figure 1: Productivity, technical efficiency and the decomposition of productivity change

In Figure 1, the vertical axis shows an aggregated vector of university output, Y, while the horizontal axis shows an aggregated input vector, X. First, focusing on period t the curve labelled $P(x,y)^t$ represents a variable returns to scale production frontier, given the underlying technology. This production frontier shows the maximum achievable output at each input vector and indicates the input-output combinations for the best performing universities. That means, a university at point A_t operating on the frontier produces the largest amount of outputs for given inputs and thus is identified as technically efficient.

Unlike A_t, the university at point B_t uses the same input, but it operates below the production frontier. Relative to the best practice production at point A_t, the input-output-combination at point B_t implies inefficient production. Thereby, the technical inefficiency is measured by the distance between B_t to the production frontier, $P(x, y)^t$, that is, $\overline{A_t B_t}$.

As productivity is defined by the ratio of outputs over inputs, productivity can be measured by the slope of a ray through the origin and the relevant production points A_t and B_t, as shown by the dashed lines in Figure 1. The slope of the ray through the origin and point A_t is steeper than the slope of the ray through the origin and point B_t, indicating a higher level of productivity for a university operating at point A_t than for a university operating at point B_t.

Considering the period $t + 1$, Figure 1 shows an upward shift of the production frontier, $P(x, y)^t$, to the new production frontier, $P(x, y)^{t+1}$, indicating technological change or, more precisely 'technological progress'. In the higher education sector, an upward shift of the frontier due to technological progress may occur, e.g. by introducing new information and communication technology as well as by changes in the organisational structures, such as those followed by the Bologna Reforms. In an efficient world, technological progress would lead to an equivalent change in productivity. However, interpreting a productivity change synonymously with technological change cannot hold in an inefficient world. This distinction becomes important because political efforts toward an increase of innovation in an inefficient sector may be wasted, while a lack of innovation in an efficient industry may result in stagnation (Worthington and Lee, 2008).

In particular, a change in productivity from one year to the next can be the result of a single source or a combination of different sources (Färe et al., 2008). Referring to Figure 1, we assume that a university at point A_t, for example, moves to the new production point A_{t+1} in the second period. A_{t+1} still operates on the frontier and is hence identified as technically efficient, representing best practice as in the initial period. Nevertheless, fewer inputs are now necessary to produce the same output level ($Y_{A^t} = Y_{A^{t+1}}$) as before. Indicated by the steeper slope of the ray through the origin, as shown by the dashed line $P_{A^{t+1}}$, the productivity of A_{t+1} increases. However, this improvement of productivity is solely due to a technological change that shifted the production frontier upwards.

Unlike the production at point A_{t+1}, a university at point B_{t+1} has increased its productivity by both a change in its underlying technology and a change in its technical efficiency. First, technological progress allows the production of B_{t+1} using fewer inputs than in period t, graphically shown by the frontier shift. Second, the distance of the new production point to the new frontier declines ($\overline{A_{t+1} B_{t+1}} \leq \overline{A_t B_t}$), that is B_{t+1} becomes also more technically efficient when compared to the initial period. The total productivity change is shown by the dashed lines, that is $P_{B^{t+1}}$ is steeper than P_{B^t}.

However, the maximum possible productivity in period $t + 1$ is given by point C_{t+1}, where the ray from the origin is a tangent to the new production frontier $P(x, y)^{t+1}$. At this point, there is a third source of productivity change, namely, a change in scale efficiency, which occurs by exploiting scale effects. As shown in Figure 1, at any point to the left of C_{t+1} the production frontier exhibits increasing returns to scale, while at any other point to the right of C_{t+1} it exhibits decreasing returns to scale. Accordingly, for all production points different that to C_{t+1}, there is scope to improve the productivity by adjusting higher education production toward the optimal scale of operation. For example, if B_t's new production point is C_{t+1} in the second period, a university could improve its productivity also by increasing its scale of production, as graphically shown by the movement from B_{t+1} to C_{t+1} along the frontier. Therefore, a university operating at this new production point is both technical and scale efficient. Hence, its productivity growth results from a combination of technological change, technical efficiency change and scale effects.

4.2. Hypotheses

The recent reform processes in the European higher education sector (see Section 2.1) have resulted in essential managerial and organisational changes, thus affecting the performance of HEIs. Cost-consciousness, transparency and strategic market diversification have become important pillars for successful positioning in an increasing 'marketised' environment (Dill, 2003). If the effects aimed for by reforming the sector are fulfilled, the increase in potential competition should lead to higher efficiency levels and, generally speaking, to higher productivity among the HEIs in Switzerland and in Germany. We begin by providing a brief theoretical analysis to underscore the hypotheses to be tested in this analysis.

Extended institutional autonomy and thus enhanced organisational decentralisation and more 'market-like' intended managerial practices[12] by NPM Reforms may lead to a rising responsiveness of Swiss and German HEIs in their decision-making. Autonomous and decentralised organisation, where responsibility and accountability is delegated to organizational units, for example, to cost or profit centres, increases the liability of profit and losses (Massy, 1996). When considering organisational sub-units, such as faculties or departments, as production optimising DMUs, one may then suppose that they will strive constantly to produce more efficiently. Aghion et al. (2010) in particular argue that both greater autonomy and greater accountability, induced by an increased reliance on competitive funding and enhanced competitive pressure, are when taken together, two of the main key drivers for performance improvements in HEIs.

Further, both new management and governance structures introduced by NPM Reforms along with the harmonisation of the European higher education area that occurred through the Bologna Reforms induced a process of differentiation (Hartwig, 2011). In particular, institutional diversity is assumed to increase the overall performance of the whole higher education system (German Council of Science and Humanities, 2010), as HEIs might differentiate according to their strengths and their institutional missions (Olivares and Wetzel, 2011). Opposed to the situation in the past, HEIs can now make

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[12] New budgetary allocation mechanisms, such as competitive and performance-oriented funding, were implemented, while at the same time, various accountability rules relating to reporting, auditing, and quality assurance were established. Introducing such NPM instruments into higher education management, the governmental authorities created an environment of 'quasi-markets' where market behaviour is thus induced among the public European HEIs (Teixeira et al., 2004).

strategic decisions on their study programmes in terms of design, curricula, target groups (e.g. international students, part-time students and executive education students) and signalling quality standards (e.g. accreditation labels, ranking participation). Thereby, they can position in the market by finding their own market niche (Daraio et al., 2011). In an increased globalised higher education market, the institutional flexibility to define and redefine, for example, study programmes is indeed a crucial competitive factor that does require substantial change in the ways that HEIs operate (Chandler, 2010).

Apart from the higher education reforms, the cutting-edge information and communication technology (ICT) that has been adopted and diffused in nearly all industries and sectors over the last decades might have further enabled HEIs to position themselves in the market as a leading player in terms of advanced technology use or in terms of cost savings, or both (Schneckenberg, 2009; Cohn and Cooper, 2004; McCann et al., 1998). The implementation of new ICT in HEIs has resulted not only in major professional and cultural changes for the faculty, but has also affected the organisation itself by resulting changes in teaching methods, work processes, avenues for recognition and research opportunities (Marshall, 2010; Fisser, 2001). For example, technological progress relates to course design (permanent access to course material independent from place and time); digitisation of library services and electronic publishing; research (analysis tools, laboratory equipment); teaching concepts and instructional technology (interactive learning, distance learning, Internet instruction, digital media and communication channels, e.g. podcasts for mass lectures); and administrative services (record and exchange information, digital data storage, information systems, e.g. Intranet, accounting systems). Such new technologies are assumed to improve higher education productivity (Chandler, 2010; Schneckenberg, 2009; McCann et al., 1998). Accordingly, HEIs can realise cost savings associated with the use of new technologies as, for example, Internet instruction reduces the number of faculty needed for teaching (Yablon and Katz, 2001; Crawford, 2001). At the same time, students have become increasingly able to inform themselves about HEIs' reputation online, such as through international and national rankings.

Giving the institutional flexibility that HEIs recently gained, the exploitation of potential scale effects in production might further incentivise HEIs to streamline their production process toward higher efficiency. HEIs are likely to realise economies of scale if they experience lower per unit costs by expanding their outputs (Cohn and Cooper, 2004). In other words, efficient HEIs must be large enough in terms of student numbers and research activities to ensure full utilisation of their assets and infrastructure entities like class and computer rooms or libraries and laboratories equipped with machinery and other techniques. Recent empirical evidence on scale effects in higher education, among them Filippini and Lepori (2007) for Switzerland and Olivares and Wetzel (2011) and Johnes and Schwarzenberger (2011) for Germany, indicates the existence of economies of scale.

However, the transition processes in terms of new managerial practices, reorganisation, and new ICT may have induced supplemental input resources. Therefore, improvements in efficiency resulting from managerial changes might be outweighed by the financial and personnel burden that higher education reforms may have also caused. Moreover, the reorganisation for Swiss and German HEIs represents an enormous challenging task, such as new study designs, new or at least adjusted curricula, altered study lengths, internationalisation, and also efforts on programme accreditation undertaken at German HEIs.[13] In the long run, the positive effects of organisational changes may increase the productivity in higher education. But the organisational reforms effort that initially occurred could have had a negative effect on the production process and therefore on the productivity development at least in the beginning of the reform process. Moreover, a faculties' resistance to adopting new technologies and deterrent investments in ICT could be the reason for a lack of or an only moderate technological change in the higher education sector (Chandler, 2010; Schneckenberg, 2009; McCann et al., 1998).

To explore the dynamics of productivity in the Swiss and German university sector, we analyse productivity through an in-depth analysis of technical efficiency change, technological change and scale efficiency change over time. If the reforms fulfilled their aims and enhanced competition, the following main hypotheses should hold:

H 1: Productivity increased in the Swiss and German public university sector from 2001 to 2007, a period during which the reform processes occurred.

Moreover, as changes in productivity result from a combination of different sources, we formulate the following three sub-hypotheses. Given increasing competition in the higher education sector, HEIs are increasingly forced to improve their efficiency in the production process. To catch up to the frontier, it is – in more general terms – about learning from the best by monitoring best practice. Although the reform processes may have raised input resources (e.g. operating expenses and personnel resources) temporarily, changes in managerial processes fostered persistent input reductions in the long run. Hence, we derive the following sub-hypothesis:

H 2.1: Technical efficiency increased in the Swiss and German public university sector and is one of the main drivers of productivity growth during the observation period.

Second, as has been argued, reorganisation and new ICT influenced the higher education production process. While in the long run, new production technologies will shift the production frontier of HEIs upwards, in the short run, new production technologies may have had rather a negative or only a moderately positive impact on higher education for two reasons: The organisational burden induced by implementing new technologies and the possible resistance of faculties to adopt new technologies. Hence, we expect a u-shaped development of technological change with a decreasing development at a decreasing rate in the beginning of the observation period. Therefore, we derive the following sub-hypothesis:

H 2.2: Technological change has been negative or only moderately positive in the Swiss and German public university sector during the observation period.

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[13] For example, Schenker-Wicki and Olivares (2010) show that there is indeed an increasing effort caused by the German system of programme accreditation which obliges German HEIs to accredit each of the new bachelor and master programmes.

Third, we turn to possible scale effects: Deregulation in higher education providing more autonomy and institutional flexibility, may have enabled HEIs to exploit economies of scale. Utilising cost advantages through output expansion may be one differentiation strategy to positioning well in the market. Especially small HEIs with high fixed costs that used to be restricted by former public higher education regulations may have potentials to improve their scale efficiency by adjusting to a more optimal scale of operation. Hence, we derive the following sub-hypothesis:

H 2.3: Scale efficiency in the Swiss and German public university sector increased during the observation period.

Referring back to Section 2, where we provided a brief overview on the higher education systems in Switzerland and Germany, we suggest that institutional and structural differences between both countries may have had an influence on how HEI productivity has developed over time. Moreover, productivity may has developed differently between various scientific disciplines because of heterogeneous production processes. Scientific disciplines substantially differ from one another with respect to their resource endowment and major output targets (Dundar and Lewis, 1995; Johnes, 2004). Given both the country-specifics between the Swiss and the German higher education systems and the discipline-specifics across the scientific fields, we formulate the following sub-hypotheses:

H 3.1: Productivity and its sources developed differently in the Swiss and German universities during the observation period.

H 3.2: Productivity and its sources developed differently across the non-science disciplines and the science disciplines in the Swiss and German universities during the observation period.

5. Methodology

To analyse the development of productivity for Swiss and German universities, we estimate the non-parametric Malmquist productivity index as defined by Caves et al. (1982). We adopt the Malmquist productivity index for four reasons. First, the Malmquist index is superior to alternative indexes of productivity growth, such as the Törnqvist index and the Fisher productivity index, as this index is calculated using the distance functions proposed by Shephard (1953, 1970). The main advantage of the distance function approach is that it allows the identification of 'best practice' production by modelling the distance of a DMU from the production frontier as a function of the vector of inputs, x, and the level of outputs, y. Thereby, this index rests exclusively on quantity information, requiring neither price information nor assumptions on behavioural objectives, such as cost minimisation or profit maximisation behaviour (Grifell-Tatjé and Lovell, 1997). Second, the Malmquist productivity index can be calculated using non-parametric estimation techniques, such as Data Envelopment Analysis, which does not impose any assumptions on the functional structure for the production technology.

Specifying such assumptions is particularly difficult for the higher education production process (Jongbloed, 2008; Deming, 2005; Ehrenberg, 2000; Bowen, 1980). Third, the Malmquist productivity index easily accommodates a multi-input, multi-output production technology – as is the case in the higher education sector. Finally, the index has the advantage of providing insights on the constituent sources of productivity change, that is, technological change, technical efficiency change and scale efficiency change.

Characterising the 'production technology', as determined by the technological environment and managerial structures underlying the production process (Bogetoft and Otto, 2011), a distance function can be specified as either input-oriented or output-oriented, depending on the assumption for whether inputs or outputs are exogenously determined. While an input-oriented distance function aims at identifying how much the input vector may be proportionally contracted when holding the output vector fixed, an output-oriented distance function means searching for the largest proportional expansion of the output vector, given a fixed input vector. For HEIs, both perspectives can be appropriate and in particular depend on the focus of investigation. However, Coelli and Perelman (1999) do show that the choice of the orientation will have only marginal influences on the efficiency scores obtained.[14]

For this study, an output orientation seems more appropriate, as the typical problem for an HEI might be to maximise outputs (e.g. third-party funds, students, publications) given its inputs (e.g. staff, non-personnel expenditures) rather than minimising the HEI's university core budget by holding the output-level fixed. Nevertheless, one may argue that the output maximising approach may lead to inappropriate incentives on the part of universities in the sense that they solely target an increase in the number of students and graduates, respectively. The consequence may be a potential decline in higher education quality. However, in Switzerland, there is a system of internal and external quality assurance implemented by every university and supervised by the Centre of Accreditation and Quality Assurance of the Swiss Universities.[15] In Germany, most of the HEIs have established internal quality assurance systems as mandated by almost all the Länder laws, while external quality assurance mainly occurs through programme and system accreditation of various accreditation agencies in that country.[16]

By modelling the production technology in the higher education sector as an output distance function, we investigate how much HEIs can increase their output vector while holding the input vector fixed. Following Fried et al. (2008), we define the output distance function on the input set, $P(x)$, as:

$$D_O(x, y) = min\left\{\theta : (y/\theta) \in P(x)\right\} \tag{1}$$

where $P\left(x\right)$ represents the set of all non-negative input vectors $x = (x_1, ..., x_K) \in R_+^K$ that can produce the non-negative output vector $y = (y_1, ..., y_M) \in R_+^M$. $D_O(x, y)$ de-

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[14] In the input- and output-oriented models, the same frontier is estimated and, hence, the same DMUs are identified as being efficient. Solely, the efficiency measure of the inefficient DMUs may differ.

[15] `http://www.oaq.ch/pub/en/01_00_00_home.php`

[16] `http://www.akkreditierungsrat.de/index.php?id=9&L=1` and `http://www.akkreditierungsrat.de/index.php?id=5&L=1`

notes the distance from the university's output set $P(x)$ to the production frontier. Färe and Primont (1995) showed that the distance function, $D_O(x, y)$, is linearly homogeneous to degree 1 in outputs and satisfies the economic regularity conditions of monotonicity and convexity, that is, the function is non-decreasing and convex in outputs, y, and non-increasing in inputs, x. θ is the scalar distance by which the output vector can be deflated and is interpreted as the level of inefficiency (see e.g. Coelli, 2000). According to the Farrell (1957) definition[17], if $y \in P(x)$, then $D_O(x, y) = \theta \leq 1$ which means that the distance function will take a value that is less than or equal to 1 if the output vector, y, is an element of the feasible production set, $P(x)$. If the output vector is located on the outer boundary of the output set, the production frontier, the universities are identified as being fully efficient, implying a value of technical efficiency equal to 1. Values between 0 and 1 correspond to universities that operate inefficient with output vectors resting below the production frontier.

Given a distance function of two data points, for example, in period t and in period $t + 1$, we can then use the Malmquist productivity index, defined as the ratio of two distance functions, to calculate the development of productivity over time (Caves et al., 1982). Following Färe et al. (1994) the output-oriented Malmquist productivity index between a period t and a period t + 1 is specified as:

$$M_O^{t,t+1} = \left[M_O^t \cdot M_O^{t+1}\right]^{\frac{1}{2}} = \left[\frac{D_O^t\left(x^{t+1}, y^{t+1}\right)}{D_O^t\left(x^t, y^t\right)} \cdot \frac{D_O^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_O^{t+1}\left(x^t, y^t\right)}\right]^{\frac{1}{2}}. \tag{2}$$

Using the geometric mean of M_O^t and M_O^{t+1} allows to arbitrarily choose period t or period $t+1$ as the reference period (Färe et al., 2008). A Malmquist value, $M_O^{t,t+1}$, greater than 1 indicates a productivity growth from period t to period $t+1$, whereas a value less than 1 indicates a decline in productivity.

One main advantage of the Malmquist productivity index is the identification of the sources which cause the productivity growth or decline. In particular, we are able to distinguish changes in the relative position of a university to the production frontier of best practice and also changes in the position of the production frontier itself. In order to decompose the productivity change into its sources, an equivalent way to rewrite the Malmquist productivity index is (Färe et al., 2008):

$$M_O^{t,t+1} = \underbrace{\frac{D_O^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_O^t\left(x^t, y^t\right)}}_{\text{efficiency change}} \cdot \underbrace{\left[\frac{D_O^t\left(x^{t+1}, y^{t+1}\right)}{D_O^{t+1}\left(x^{t+1}, y^{t+1}\right)} \frac{D_O^t\left(x^t, y^t\right)}{D_O^{t+1}\left(x^t, y^t\right)}\right]^{\frac{1}{2}}}_{\text{technological change}} \tag{3}$$

where the first component of Equation 3 measures the change in technical efficiency between the periods t and $t+1$. If the ratio is equal to 1, there is no change in technical efficiency over time. If the ratio exceeds 1, the technical efficiency has increased over the two periods, meaning that a university has moved closer to the production frontier of best practices that are defined for the sector. A value less than 1 implies a decline

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[17] Following the Farrell (1957) definition, technical efficiency represents the reciprocal of the value of the (Shepard) distance function.

in technical efficiency. The second component of Equation 3 measures the change in the production technology between the two periods t and $t+1$ and reflects a shifting of the production frontier. This component has the value 1 when there is no technological change, and it takes a value greater than 1 (less 1) if the change in production technology has a positive (negative) effect.

Considering variable returns to scale in higher education production further allows to identify whether an increase in technical efficiency is indeed due to improvements in efficiency (pure efficiency), or alternatively due to scale adjustments of operation (scale efficiency). Scale efficiency, defined as the amount by which a university's efficiency could be improved by moving to its optimal scale (e.g. Ray, 2004; Coelli et al., 2005), is calculated by dividing the efficiency score obtained under the assumption of constant returns to scale (CRS) by the efficiency score obtained under the assumption of variable returns to scale (VRS). As in general the Malmquist productivity index is estimated under the constraints of CRS, we also include the constraints of VRS in the production process, allowing us to formulate the first component of Equation 3 even more specifically, such as:

$$M_O^{t,t+1} = \underbrace{\frac{D_O^{t+1}\left(x^{t+1}, y^{t+1}\right)_{VRS}}{D_O^{t}\left(x^{t}, y^{t}\right)_{VRS}}}_{\text{technical effic. change (Eff}\Delta)} \quad \underbrace{\frac{S_O^{t+1}\left(x^{t+1}, y^{t+1}\right)}{S_O^{t}\left(x^{t}, y^{t}\right)}}_{\text{scale effic. change (Scale}\Delta)} \cdot \underbrace{\left[\frac{D_O^{t}\left(x^{t+1}, y^{t+1}\right)}{D_O^{t+1}\left(x^{t+1}, y^{t+1}\right)} \frac{D_O^{t}\left(x^{t}, y^{t}\right)}{D_O^{t+1}\left(x^{t}, y^{t}\right)}\right]^{\frac{1}{2}}}_{\text{technological change (Tech}\Delta)} \tag{4}$$

where

$$Scale\Delta = \frac{S_O^{t+1}\left(x^{t+1}, y^{t+1}\right)}{S_O^{t}\left(x^{t}, y^{t}\right)} = \left(\frac{D_O^{t+1}\left(x^{t+1}, y^{t+1}\right)_{CRS}}{D_O^{t+1}\left(x^{t+1}, y^{t+1}\right)_{VRS}} \Big/ \frac{D_O^{t}\left(x^{t}, y^{t}\right)_{CRS}}{D_O^{t}\left(x^{t}, y^{t}\right)_{VRS}}\right) \tag{5}$$

with the first component of Equation 4 representing changes of pure technical efficiency measured relative to VRS technology. The second component of Equation 4, repeated in Equation 5 in more detail, provides a measure of the contribution of scale economies to productivity change. In particular, it reflects the change of scale efficiency for the two periods, meaning possible output expansion up to the most productive scale of operation.

Following Färe et al. (1994), we derive the required distance measures for the output-oriented Malmquist productivity index by using linear programming based on Data Envelopment Analysis (DEA), which is a non-parametric estimation technique introduced by Charnes et al. (1978). Unlike parametric stochastic frontier measures that require assumptions for the underlying functional form and the distribution of the inefficiency term, DEA is a more relaxed efficiency estimator, as no assumptions are required with respect to the functional relationship of the inputs and outputs. Based on linear programming, DEA instead envelopes the observed data as tightly as possible and uses the input and output data to compute a piece-wise linear production frontier for best practice DMUs. The efficiency for each DMU is calculated based on the distance relative to the production frontier. To derive the output-oriented Malmquist productivity indices several linear programmes have to be solved for each pair of data.[18]

As DEA provides only point estimates it lacks common statistical properties. Therefore, the results have to be interpreted with care. However, Simar and Wilson (1999) developed statistical inference methods that can be used to overcome the problem of absent tests for statistical significance. To determine if any increase or decline in productivity is statistically significant rather than just an artefact of sampling variations, measurement errors or other noise in the data, Simar and Wilson (1999) propose a bootstrapping approach in which the data-generating process is replicated by generating an appropriately large number of pseudo samples. From these samples 95% confidence intervals can be constructed to test the statistical significance of the Malmquist productivity indices. Following this approach, we apply a bootstrap procedure with 2,000 replications.[19]

6. Data

The unique panel data used in this study were taken from several higher education statistics provided by the Federal Statistical Offices in Switzerland and Germany for the period of 2001 to 2007. Our database comprises detailed disaggregated information for scientific fields[20] at 10 cantonal Swiss universities and 77 public German universities. We eliminated universities of the private sector, universities of applied sciences *Fachhochschulen* and all specialised universities exclusively oriented to theology and administrative sciences or the fine arts and music. In addition, we excluded the two German universities of Armed Forces.

As the Swiss and German higher education sector is characterised by large institutional heterogeneity, we identified outliers in the sample by applying the outlier correction model proposed by Wilson (1993). For most of the years examined, we found that observations for the ETH Zurich were detected as outliers. This finding is not surprising as ETH Zurich along with EPF Lausanne are the two Swiss federal universities and directly regulated and completely financed by the Swiss Federal Government. By contrast, the cantonal universities are operated by the sovereign cantons and are co-funded by both the Confederation and the other university cantons. In Germany, the public universities are regulated and financed by the Länder (see Section 2). Consequently, we removed all observations for the two Swiss federal universities, ETH Zurich and EPF Lausanne, from the sample.

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[18] The corresponding linear programming for computing the Malmquist productivity indices is explained in more detail in Appendix B.9.1.

[19] The formula details of the bootstrap procedure used for our analysis are provided in Appendix B.9.2.

[20] For Switzerland, we use data at the following scientific fields: Humanities and social sciences; economics; law; natural sciences; engineering; and interdisciplinary sciences. For Germany, we use corresponding data, namely, linguistic and cultural sciences; sport; law, economic and social sciences; mathematics, natural sciences; agronomy, forestry and nutritional sciences; and engineering.

To account for any discipline-related heterogeneity, we differentiate between the non-sciences and the sciences.[21] This allows us to disentangle differential effects between the scientific fields that otherwise may compensate each other. In doing so, we assume that input and output variables will differ markedly between these fields. In particular, we split our sample into two subgroups comprising (i) the non-science disciplines, such as linguistics, cultural sciences, arts, sport and legal, economic and social sciences and (ii) the science disciplines, such as mathematics, natural sciences, engineering, agronomy, forestry and nutritional sciences. Due to a lack of clear statistical classification, we removed all observations of human and veterinary medicine.

In accordance with previous efficiency studies on higher education, we used three input and two output variables for our analysis.[22] The first input variable comprises the operating expenditures, covering e.g. rentals and leases, building and property maintenance, consumables and technical equipment. To capture the labour input, we further include academic personnel (professors, assistant professors, research assistants) and non-academic personnel (technical and administrative staff) as input variables, both of these measured in full-time equivalents.

As multiple-output organisations, the universities' two core activities are teaching and research. In addition, universities usually conduct third-mission activities, such as entrepreneurial ventures and political consultancy. As there is no data available on the third-mission activities of Swiss and German universities, we only include output measures on the universities' teaching and research activities in our analysis. To capture the teaching activities of universities, we use the number of undergraduate and graduate students enroled in bachelors and masters programmes as well as those enroled in the former Swiss licentiate and the former German diploma and magister artium programmes (these degrees are comparable to a master degree). We prefer to use the number of students rather than the number of graduates, as the number of students currently being educated is what affects the costs of higher education (Agasisti and Johnes, 2010). If we used the number of graduates, we would ignore the fact that students' human capital increases during their studies and not solely upon degree completion (Carrington et al., 2004).[23]

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[21] A lower disaggregation level will likely cause problems of multicollinearity between the input and output variables for different subjects (Johnes and Salas-Velasco, 2007).

[22] Note that with an increasing number of inputs and outputs, the factor combinations of the production process rise exponentially and, therewith, there is the probability that most of the DMUs become efficient. As a result the number of efficient DMUs shaping the production frontier increase and the benchmarking results obtained become meaningless. Therefore, Cooper et al. (2006) propose that the underlying sample should be at least three times larger than the total number of input and output variables, while Dyson et al. (2001) recommend that the number of observations should be at least twice the product of the number of inputs and outputs.

[23] When using graduates as an output measure we would have to control for student quality, because the success of degree completion heavily depends on each individual student's entrance knowledge and individual effort. A relatively good quality indicator for this is a tertiary entrance test score often used in analyses of HEIs in Anglo-Saxon countries (Carrington et al., 2004). Unfortunately, similar to other inputs and outputs, such quality indicators are highly rare or even totally unavailable for the Swiss and German higher education sector.

To capture the research activities, we use the total amount of external third-party funds.[24] We also consider the funds granted by research funding organisations, such as the Swiss National Science Foundation (*Schweizerische Nationalfonds*), Commission for Technology and Innovation (*Kommission für Technologie und Innovation*), German Research Foundation (*Deutsche Forschungsgemeinschaft*), the European Union, other non-profit organisations, private foundations and the business and industry sectors. Using data on third-party funds as an output measure is preferable to using data on publications or citations, for two reasons: First, third-party funding is assumed to be a suitable performance measure, as it represents a kind of 'market value' of a university's research activities (see e.g. Harman, 2000; Johnes, 1997). We follow (Johnes and Salas-Velasco, 2007) who argue that the acquisition of external third-party funds follows a successful researcher's track record and may, therefore, be considered as a 'quality adjusted measure' of the actual research conducted. In other words, it signals research reputation and quality for the scientific community. Second, especially in Germany, the amount of acquired third-party funding is one of the most important performance measures for research activities initiated by the Länder's and the universities' resource allocation mechanisms. Publications or citations are only rarely included in the funding models (Broemel et al., 2010). The most serious problem when using third-party funding as a performance measure we are able to address. As some disciplines are more inclined to attract external funds than are others (e.g. engineering and natural sciences vs. linguistics, history, and philosophy) any analyses has to be done at a disaggregated level.

The unbalanced panel data set we use for our analysis, then, contains a total of 76 non-science observations (42 science observations) for the 10 Swiss universities and 543 non-science observations (446 science observations) for the 77 German universities for 2001, 2003, 2005 and 2007. We use an unbalanced panel to account for developments in productivity growth caused by newcomers or leavers with respect to the level of scientific fields. We drop observations when all output variables or all input variables have zero values. Allowing for a special university profile in terms of focusing on the teaching or the research output[25], we replace a zero output by 0.1. We further replace a zero input by 0.01.[26] Moreover, all monetary variables are expressed in thousand units and adjusted for inflation using the Consumer Price Indices for Switzerland and Germany, respectively, based on the benchmark year of 2000 (State Secretariat for Economic Affairs, 2011; German Council of Academic Experts, 2010). We further converted the financial data for operating expenses and third-party funding into an artificial common currency called purchasing power standard (PPS) provided by Eurostat (2011). Thereby we account not

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[24] Due to the fact that doctoral (PhD) students are often employed as teaching and research assistants, we did not include them as proxies for the research output to avoid any possible biases from double counting as both input and output.

[25] Structural zeros in primary data represent a fundamental characterisation of the underlying decision-making of an institution. When university management decides not to produce certain outputs, Thompson et al. (1993) assume that it made a conscious decision choice to do so.

[26] The replacements of zero values with an arbitrary, small positive value are necessary, because DEA cannot be run with zero values.

Table 1: Summary of descriptive statistics of input and output variables[a]

		Academics (FTE)		Non-academics (FTE)		Operating expenses		Students		Third-party funds	
		non-science	science	non-science	science	non-science	science	non-science	science	non-science	science
Switzerland											
2001	Mean	329.17	327.87	66.70	136.00	4105.66	8163.05	3598.63	691.60	4221.84	7960.48
	Std.dev.	223.89	233.53	53.81	122.28	3913.83	6681.91	2635.14	499.98	3845.42	6141.17
	Min	12.55	29.60	0.01	0.01	164.87	493.59	158.00	50.00	67.90	158.80
	Max	745.84	645.14	202.75	357.90	13595.31	22215.37	9329.00	1481.00	15538.67	19001.42
2003	Mean	357.35	348.89	74.63	138.92	4868.08	9092.63	4105.37	737.40	5316.55	10088.24
	Std.dev.	236.84	260.70	59.19	131.91	4308.79	8247.25	2997.34	573.32	5294.92	8063.98
	Min	35.91	32.35	1.30	4.80	671.55	441.42	303.00	27.00	482.49	80.27
	Max	757.64	667.84	222.60	398.15	14987.12	26727.13	10856.00	1727.00	22692.44	22747.84
2005	Mean	397.23	331.90	82.17	135.50	4675.09	8590.90	4183.95	728.00	5846.58	8994.79
	Std.dev.	258.15	273.10	66.99	133.39	4357.20	8578.40	2921.76	596.80	5973.03	7911.01
	Min	55.06	21.61	5.54	2.26	773.21	119.12	598.00	43.00	419.46	119.49
	Max	894.88	685.48	244.83	413.30	16671.47	29764.90	10598.00	1925.00	26476.77	20099.50
2007	Mean	423.14	335.06	90.07	136.07	5478.83	8032.40	4388.11	772.73	7888.06	9582.15
	Std.dev.	266.45	273.01	72.16	134.50	5151.42	8396.91	2921.10	616.72	7767.09	8229.07
	Min	78.77	25.36	5.10	0.45	866.05	240.90	687.00	8.00	721.84	164.75
	Max	971.17	737.97	251.40	407.88	18666.38	29273.02	11110.00	1955.00	34561.46	21145.64
Germany											
2001	Mean	244.79	436.97	74.32	232.95	2032.75	6466.59	5771.87	3431.38	2320.15	11650.83
	Std.dev.	174.87	334.98	79.38	195.64	2491.24	6058.48	4872.43	2494.98	2227.96	12368.55
	Min	23.00	7.00	0.01	1.00	0.10	0.10	37.00	102.00	0.10	0.10
	Max	979.00	1598.00	476.00	990.00	15073.55	28820.31	27875.00	10538.00	11722.00	76756.62
2003	Mean	250.54	444.51	68.50	207.12	2118.20	6459.70	6076.04	3648.54	2754.48	12338.65
	Std.dev.	179.47	342.65	72.68	171.97	2399.38	5753.64	4837.67	2715.51	2589.27	12169.73
	Min	23.00	3.00	1.00	0.01	18.55	0.10	0.10	135.00	0.10	0.10
	Max	1030.00	1645.00	405.00	799.00	15623.80	26829.58	26634.00	10919.00	14342.20	72460.90
2005	Mean	235.86	418.59	61.13	186.32	2409.17	6851.78	5413.05	3498.37	2959.31	13003.46
	Std.dev.	173.08	331.25	64.27	152.25	2918.69	6647.45	4041.99	2630.30	2987.35	13523.28
	Min	16.00	3.00	0.01	0.01	21.99	0.10	95.00	3.00	0.10	0.10
	Max	981.00	1572.00	372.00	724.00	16288.05	36486.59	21506.00	10575.00	17597.66	86037.16
2007	Mean	249.61	451.49	67.99	231.10	3167.97	8977.66	5174.10	3505.70	3209.34	15966.68
	Std.dev.	185.63	350.57	81.19	192.87	3649.79	8750.19	3775.59	2554.87	3199.25	16291.88
	Min	11.00	11.00	1.00	0.01	0.10	0.10	90.00	28.00	0.10	0.10
	Max	1160.00	1770.00	442.00	1041.00	16852.17	48020.43	23485.00	10446.00	19895.77	96595.08

[a] The number of observations amounts to Switzerland with N_{nsc}=19 (19,19,19) in 2001 (2003,2005,2007) and N_{sc}=10 (10,11,11) in 2001 (2003,2005,2007) and to Germany with N_{nsc}=133 (136,137,137) in 2001 (2003,2005,2007) and N_{sc}=109 (113,112,112) in 2001 (2003,2005,2007).

Source: Own calculations based on data of the Swiss and German Federal Statistical Offices. All monetary variables are expressed in thousand units and are adjusted for inflation using the country's GDP deflator of 2000 and for purchasing power of the different currencies using the Eurostat purchasing power parity exchange rates.

only for currency conversion, but also for differences in the price levels and purchasing power between Switzerland and Germany.

Table 1 presents a summary of the descriptive statistics of the variables used for our analysis, differentiated by country and between the non-sciences and the sciences for the single years 2001, 2003, 2005 and 2007. These summary statistics on the input and output variables show substantial differences between and within Swiss and German universities, as indicated by the standard deviation and minimum and maximum values. The most apparent difference is that the mean value for the total number of students enroled in the non-sciences is substantially higher than that for students enroled in the sciences, which is true for both Switzerland and Germany. Further, average third-party funds were higher for the sciences than for the non-sciences, reflecting the fact that research in the sciences is more costly than research is in the non-sciences.

An analysis of how the input and output variables developed over time reveals that especially the amount of third-party funding has risen in both countries. While in Switzerland the growth rate of external funding increased by approximately 46% (17%) in the non-sciences (sciences), in Germany that growth rate increased by approximately 28% (27%) in the non-sciences (sciences).[27] As can be seen in Table 1, the average number of student enrolments increased by approximately 18% (11%) in the non-sciences (sciences) over the whole period for Swiss universities, while the average value of German student enrolments decreased after peaking in 2003 for both the non-sciences and the sciences. For the non-sciences this output measure even declined by approximately 11% from 2001 to 2007, while the measure moderately developed with a percentage increase of 2% for the sciences.

The increasing student enrolment in the non-sciences in Swiss universities is reflected by a corresponding increase in both FTE of academic personnel (22%) and FTE of non-academic personnel (26%) over this time. In contrast, in German universities the number of FTE of academic personnel remained nearly unchanged, while a slight cutback occurred for the non-academic personnel that ranged between 9% for the non-sciences and 1% for the sciences. For operating expenses, the corresponding amount essentially increased in both countries except for Swiss science disciplines.

7. Results

7.1. Main results

The results for total factor productivity (TFP) change and its components for Swiss and German universities, which we calculated via the non-parametric Malmquist productivity index are displayed in Table 2, differentiated between the two countries. The results in Table 2 report the average year-specific, the average annual and the average

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[27] When comparing both countries, surprisingly the percentage increase of third-party funds in the non-sciences was more than twice as high in Swiss universities as in German universities. In the sciences, the percentage increase was higher for German universities than it was for Swiss universities. However, we do have to consider that the two Swiss federal institutes of technology with the greatest financial third-party volume were removed from this dataset.

cumulative change rates of TFP and its components for three models. In Model I, we benchmarked all observations, without differing between the non-sciences and the sciences, against a common production frontier. In Model II and Model III, we separately ran analyses for the non-sciences and the sciences, respectively.

First, as can be seen from Model I in the upper part of Table 2, where all disciplines are included and benchmarked against a common frontier, average TFP increased in both the Swiss and the German universities over the observation period 2001-2007. On average, the Swiss and the German universities experienced an annual average TFP growth of about 4%. However, the sources of this positive productivity change did differ between the two countries. While the Swiss productivity growth resulted solely from improvements in technical efficiency and scale efficiency, the productivity growth in German universities is a combination of almost equal improvements in all three components, that is, technological progress, technical efficiency and scale efficiency.

Table 2 further reveals that all average TFP measures as well as all average measures for its components change their magnitude and partly their sign for both Switzerland and Germany when separately calculated for the non-science disciplines and the science disciplines (see Model II and Model III). As expected, this finding indicates substantial heterogeneity in the development of productivity and its components across the scientific fields.

The average cumulative change rates of TFP and its components – also displayed in Table 2 – provide additional information on the average development of TFP and its sources over the whole observation period. In Figure 2, these values are graphically visualised for all three models, with the first year (2001) set equal to 1. Thereby, a value equal to 1 implies no change, a value greater than 1 implies a positive change and a value less than 1 implies a negative change for the TFP measures.

Comparing the models graphically reveals that the cumulative development of TFP change, technological change and technical efficiency change in the overall model (Model I) are provoked mainly by the fact that the sciences outperform the non-sciences (see Model II and Model III). For both countries, the positive cumulative values for technical efficiency change are higher in the sciences than in the non-sciences. Further, the cumulative value for technological change is less negative in the sciences than in the non-sciences in Switzerland, and even considerable positive for the sciences in Germany. Only in the cumulative scale efficiency change, the non-sciences show a better development than the sciences, in both countries. In order to account for this heterogeneity, we focus our further analysis on the results of Model II and Model III, wherein we analysed the productivity development for the non-sciences and the sciences independently from each other.

Referring to the results obtained for the non-sciences (Model II), Figure 2 shows that Swiss universities' TFPs considerably increased from 2005 onwards after a rather moderate development in the initial years of the observation period. The cumulative value of TFP change indicates an average productivity increase of about 27% over the whole observed period. In particular, continuous improvements in scale efficiency as well as technical efficiency can be identified as the main drivers for this positive productivity development, which even outweighed the technological decrease that occurred over the

Table 2: Average change rates of TFP and its components for Swiss and German universities over the period 2001-2007[a,b]

	N	TFP change	Technological change (TechΔ)	Technical efficiency change (EffΔ)	Scale efficiency change (ScaleΔ)
Model I: All disciplines, differentiated by country					
Switzerland					
2001-2003	29	7.73	−2.25	9.28	4.75
2003-2005	29	3.28	−10.48	12.42	6.44
2005-2007	30	16.89	8.42	6.28	4.45
Annual average	88	4.48	−0.87	4.55	2.57
Cumulative	88	30.05	−5.12	30.57	16.45
Germany					
2001-2003	242	12.61	9.83	2.16	0.93
2003-2005	249	8.87	−4.69	10.54	3.72
2005-2007	249	4.72	3.76	−1.00	1.92
Annual average	740	4.25	1.39	1.88	1.09
Cumulative	740	28.38	8.62	11.80	6.69
Model II: Non-science disciplines, differentiated by country					
Switzerland					
2001-2003	19	3.63	−4.16	0.35	7.18
2003-2005	19	2.61	−9.54	13.21	5.26
2005-2007	19	19.86	−1.75	3.47	20.05
Annual average	57	4.13	−2.64	2.73	5.19
Cumulative	57	27.45	−14.82	17.55	35.43
Germany					
2001-2003	133	12.86	1.99	4.57	6.41
2003-2005	136	7.54	0.60	5.67	3.18
2005-2007	137	−0.11	1.82	−5.42	4.42
Annual average	406	3.26	0.73	0.74	2.31
Cumulative	406	21.23	4.47	4.51	14.66
Model III: Science disciplines, differentiated by country					
Switzerland					
2001-2003	10	8.06	−10.96	19.37	3.52
2003-2005	10	1.62	−4.85	1.79	6.70
2005-2007	11	11.30	4.45	3.33	3.04
Annual average	31	3.40	−2.02	3.86	2.18
Cumulative	31	22.22	−11.51	25.55	13.82
Germany					
2001-2003	109	11.47	7.45	6.14	0.89
2003-2005	113	9.09	−2.26	7.30	3.01
2005-2007	112	9.36	4.01	4.52	0.83
Annual average	334	4.87	1.48	2.95	0.78
Cumulative	334	32.98	9.23	19.03	4.79

[a] All measures are expressed in percentage terms. [b]In Model II, the average scale efficiency change for Swiss universities would raise over 50% in 2003, when including the value of 3.98 obtained for scale effects for the University of Lucerne. However, this value indicates an exceptional increase of about 400% in scale efficiency for this university and, therefore, we ommited this single value from the results.

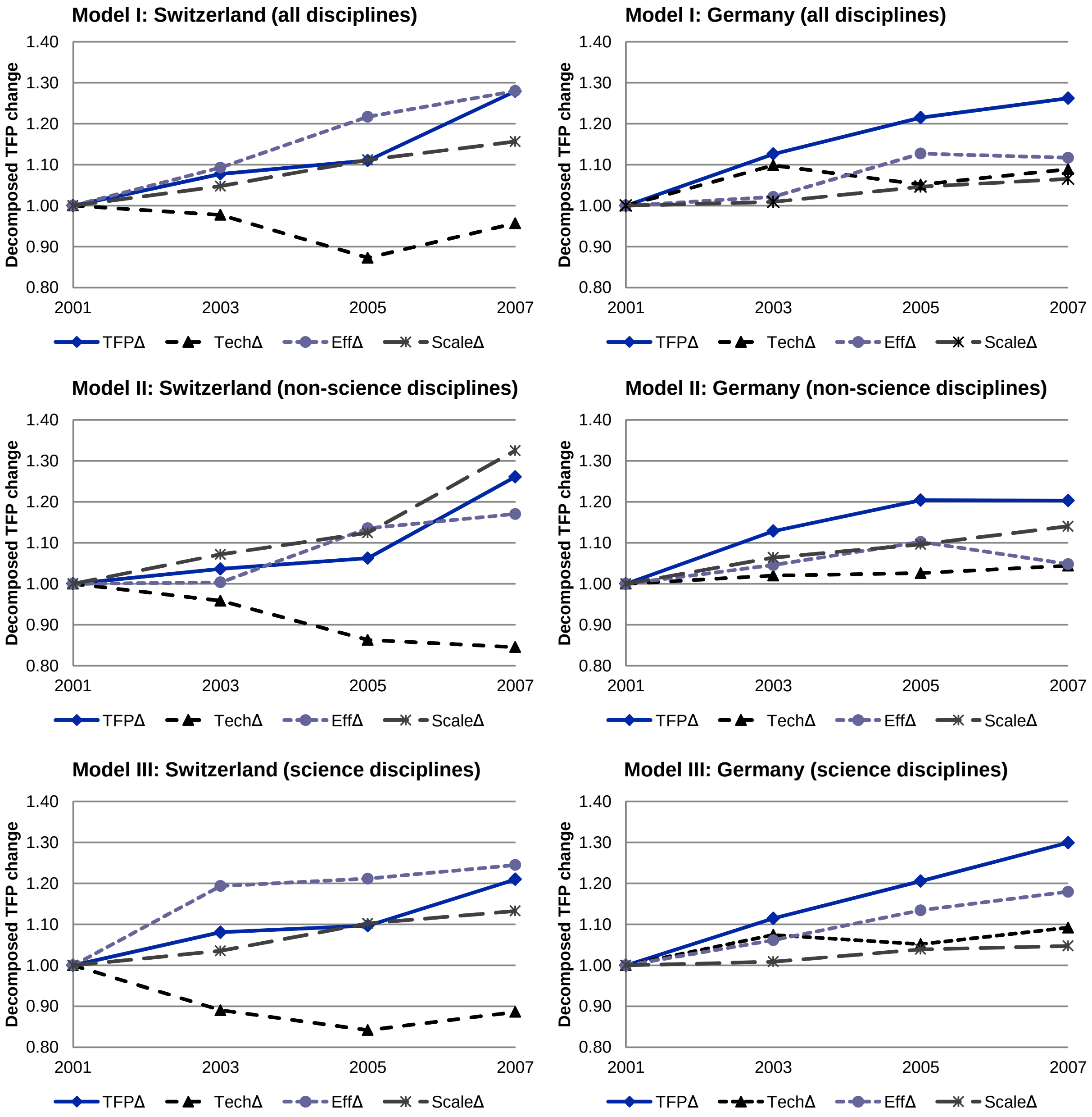

Figure 2: Cumulative indices of TFP and its components for Swiss and Germany universities

observation period. A different picture is revealed for German universities: The moderate productivity growth in the initial period freezed after 2005. This development is provoked essentially by a decline in technical efficiency. However, positive scale effects compensated this effect. On average, we found a cumulated TFP increase of about 21% over the whole observed period.

Turning to our results for the sciences (Model III), we also found on average a productivity increase in both countries. In Switzerland this development was driven by an excessive increase in technical efficiency from 2001 to 2003 along with a continuously positive development of scale efficiency and a slight recovery in the negative trend of technological change after 2005. By contrast, the productivity growth in the sciences for German universities resulted from continuous but moderate improvements in technical efficiency and – when compared to Swiss universities – a slight positive development in technology change. Despite the steady increase in the productivity of Swiss universities with an average cumulated TFP growth rate of about 22%, the German universities showed a higher productivity growth rate over the whole period, as reflected by the average cumulated TFP growth rate of 33%.

7.2. Tests of statistical inference

To test the robustness of our non-parametrically derived results we applied the bootstrapping approach outlined in Section 5. As shown in Table 3, the estimation of 95% confidence intervals predicts that most of the change rates were statistically significant on the 5% level. For example in Model II, out of 40 year-specific estimates of positive TFP change in the non-sciences in Swiss universities, 33 (83%) were statistically different from unity. For the German universities, we found that out of 217 estimates, 152 (70%) cases showed a statistically significant positive TFP change at the 5% level. A similar pattern is revealed for the positive change rates of the TFP components, namely, technological change, technical efficiency change and scale efficiency change. Counting cases in which the changes rates were significant and greater than 1, we can conclude that statistically significant productivity improvements were registered in 70%-83% of the cases in Model II and in 70%-86% of the cases in Model III. For negative change rates with values lower than 1, a similar pattern is shown with 69%-88% significant cases in Model II and 67%-91% significant cases in Model III. Altogether, the tests of the statistical inference indicates that the change in TFP and its components deviate only little from the raw statistics in Table 2.

To determine whether the estimates we obtained for the TFP change and its components statistically differed between Switzerland and Germany as well as between the non-science and science disciplines, we tested for the significant differences between these groups. As we had to reject the hypothesis tests of normally distributed estimates using a Kolmogorov-Smirnov test, we followed Banker et al. (2010) and applied the non-parametric Wilcoxon rank sum test, known as the Mann-Whitney test, to evaluate whether the results significantly differed across both the two countries and the scientific

Table 3: Statistical inference of year-specific change rates between 2001-2007[a]

	Positive change			Negative change			No change		
	Numbers		in	Numbers		in	Numbers		in
	5% sign.	All	%	5% sign.	All	%	5% sign.	All	%
Model II: Non-sciences, differentiated by country									
Switzerland									
TFPΔ	33	40	83%	14	17	82%	-	-	-
TechΔ	20	25	80%	27	32	84%	-	-	-
EffΔ	26	30	87%	18	23	78%	3	4	75%
ScaleΔ	32	40	80%	14	16	88%	1	1	100%
Germany									
TFPΔ	152	217	70%	142	189	75%	-	-	-
TechΔ	194	262	74%	100	144	69%	-	-	-
EffΔ	133	179	74%	142	199	71%	19	28	68%
ScaleΔ	159	225	71%	129	170	76%	6	11	55%
Model III: Sciences, differentiated by country									
Switzerland									
TFPΔ	14	20	70%	10	11	91%	-	-	-
TechΔ	11	15	73%	13	16	81%	-	-	-
EffΔ	12	14	86%	10	14	71%	2	3	67%
ScaleΔ	14	17	82%	8	11	73%	2	3	67%
Germany									
TFPΔ	164	208	79%	84	126	67%	-	-	-
TechΔ	134	181	74%	114	153	75%	-	-	-
EffΔ	135	180	75%	95	129	74%	18	25	72%
ScaleΔ	123	160	77%	118	163	72%	7	11	64%

[a] Statistical significance at the level of 5% is derived from 2,000 bootstrapped replications by computing 95% confidence intervalls.

fields. Non-parametric tests are more appropriate in this context as they do not make assumptions on how underlying estimates are distributed (Golany and Storberg, 1999).[28]

As can be seen in Table 4, the results of the Mann-Whitney tests confirmed that the differences we found for the change in productivity and its sources between Switzerland and Germany and between the non-science disciplines and the science disciplines were indeed partly statistically significant on different significance levels. In particular, focusing on the non-science disciplines, the Mann-Whitney test affirmed at the 10% and 5% significance level, respectively, the differences between Swiss and German universities for the TFP change, the technology change and the scale efficiency change. In contrast, for the science disciplines we only observed a statistically significant difference between Switzerland and Germany for the technology change on the 5% level.

7.3. Discussion

The estimates we obtained by computing the Malmquist productivity index showed some interesting trends regarding the development of productivity and its sources in both the

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[28] More information on the use of non-parametric test statistics can be found in e.g. Banker and Natarajan (2011).

Table 4: Statistical inference of group differences in year-specific change rates[a,b]

	$P > \|z\|$			
Comparison groups	TFP	TechΔ	EffΔ	ScaleΔ
Switzerland vs. Germany	0.207	0.000***	0.473	0.007***
Non-sciences vs. sciences	0.058*	0.069*	0.000***	0.500
Model II: Non-science disciplines				
Switzerland vs. Germany	0.100*	0.011**	0.536	0.014**
Model III: Science disciplines				
Switzerland vs. Germany	0.875	0.007**	0.389	0.260

[a] The Mann-Whitney test is used to test for statistically significant group differences, based on statistically significant estimates of the years-specific change rates of TFP and its components between 2001-2007. [b] The significance levels 10%, 5% and 1% are denoted by *, ** and ***.

Swiss and German universities. Due to different methodological approaches, sample periods and variable definitions, the possibility of comparing our results with previous research is quite limited.

In starting our discussion, we first draw attention to the varying results for the TFP measures for the two countries. Although we found a positive change in productivity for both the Swiss and the German universities, the sources of the productivity growth differ in both countries. Hence, hypothesis 3.1 cannot be rejected: Productivity and its sources developed differently in the Swiss and German universities during the observation period. In particular, our findings show that the developments in technology and in scale efficiency between Swiss and German universities significantly differ, indicating country-specific structural or reform-related differences, or both, between the two higher education systems. Our analysis further reveals that significant differences between the non-science disciplines and the science disciplines exist in terms of TFP change, technological change, technical efficiency change and scale efficiency change. Hence, hypothesis 3.2 cannot be rejected: Productivity and its sources developed differently across the non-science disciplines and the science disciplines in the Swiss and German universities during the observation period. As argued before, the scientific disciplines substantially differ from each other and therefore an analysis on the performance of higher education should account for this heterogeneous production. Using data at the university level can lead to biased results and, hence, should be interpreted with some care. In the following, we thus concentrate on a discussion of the results we found for the non-science disciplines (Model II) and the science disciplines (Model III).

Our findings indicate a positive trend in the development of technical efficiency for both Swiss and German universities; the catching up effects largely occurred between 2001 and 2005. Hence Hypothesis 2.1 cannot be rejected: Technical efficiency increased in the Swiss and German public university sector and is one of the main drivers of productivity growth during the observation period. Technical efficiency improved more in the sciences than in the non-sciences which might be due to structural differences present across these scientific fields. The implementation of new managerial and new governance structures introduced at non-science faculties may have provoked considerable – maybe even more complex – restructuring processes in the initial period of the reformation because these faculties are often notably larger than science faculties, at least in terms of student enrolments. In contrast to the general positive trend in technical efficiency, there was one exception. For the non-sciences, our results indicated a stagnation and even a slight decrease in technical efficiency between 2005 and 2007 in German universities. This finding could be explained by decreasing student enrolments that occurred after a peak in 2003 which, however, were accompanied by increasing third-party funding but at the same time also by increasing inputs, especially in terms of operating expenses (see the descriptive statistics in Table 1). The decline in student enrolments may be the result of different developments, such as the interruption of the student cohort in 2001 due to reduced school years from 13 to 12 years in two German Länder, Mecklenburg-Western Pomerania and Saxony-Anhalt; and both increasing alternative job options for school leavers due to considerable economic recovery during these years and declining job prospects, especially in non-science disciplines (Sekretariat der Ständigen Konferenz der Kultusminister der Länder, 2006; Egeln and Heine, 2007).

Hypothesis 2.2, stating that technological change has been negative or only moderately positive in the Swiss and German public university sector during the observation period, is likewise confirmed. Comparing the results for both the non-science and the science disciplines between Switzerland and Germany, reveals the following: A considerable decline in technological change for Swiss universities, shifting the production frontier downwards. This clear initial negative trend did not surprise. Both, the organisational changes that essentially affected teaching and research activities as well as new technologies that were adopted and diffused in the higher education sector implied not only a financial and administrative, but also a personnel burden. The internal organisation of the universities changed substantially, including the skill requirements for management and employees. In other words, such considerable organisational changes do take time and resources in order to reorganise management and the workplace (Hornstein and Krusell, 1996).

Given that the Swiss transformation process toward a Bologna conforming higher education system was mostly completed in 2007/2008, the main burden of reformation, especially in the non-sciences, might have already accomplished by the Swiss universities. By contrast, considering the low implementation rate of Bologna conform degrees of about 31% in Germany in 2007/2008 (German Federal Government, 2008), the moderatly positive trend in technology for German universities in both the non-sciences and the sciences might be misleading. As we assume a u-shaped development of technological change, we may presume that this positive trend will turn into a decreasing development in the upcoming years. Hence, future research is still needed to evaluate how that change in technology will indeed develop.

Further, varying faculty cultures in universities might indicate the differing resistance of university faculties to organisational changes and may explain the differences we found for the technological change. In particular, some faculties, such as those in the sciences, might be more inclined to restructuring internal processes and introducing new technologies than were faculties in the non-sciences (Schneckenberg, 2009; Fisser, 2001). This suggestion and the probably less extreme personnel and administrative effort due to lower student enrolments, when compared with the non-sciences, may provide an explanation for the higher decline in technological change in the initial period and the slight recovery from the technological regress afterwards that we found in the science disciplines for Swiss universities.

Moreover, a clear trend in the development of scale efficiency can be deduced from our results. For both the non-science disciplines and the science disciplines, Swiss and German universities have experienced a positive scale efficiency change. Hence, hypothesis 2.3 cannot be rejected: Scale efficiency in the Swiss and German public university sector increased during the observation period. This result is broadly in line with existing studies on the Swiss and German higher education sector (e.g. Filippini and Lepori, 2007; Olivares and Wetzel, 2011; Johnes and Schwarzenberger, 2011). The deregulation processes have led to positive changes in scale efficiency, meaning that universities have adapted their production processes, so they are more closely aligned to their optimal size of operation. The positive scale efficiency change especially in the Swiss non-sciences may be explained by the fact that departments increased their size, indicated by an increase of the outputs that was higher than the increase in the inputs (see the descriptive statistics in Table 1). This expansion might have been a consequence of pushing the outcome in higher education as intended by the reforms that public authorities introduced in recent years.

Then, referring to our results for the overall development of productivity, we did find some evidence to support hypothesis 1: Productivity increased in the Swiss and German public university sector from 2001 to 2007. Altogether, catching up in technical efficiency was identified as one of the key sources for the change in productivity for both Swiss and German universities, while increasing scale efficiency was the second source that considerably contributed to the increase in productivity. Technological regress narrowed the TFP change in Swiss universities.

To summarise our findings, the hypotheses we derived for this analysis are to be confirmed. Hence, we can conclude that the reformation process that occurred in the Swiss and the German university sector over the last decade has indeed increased university efficiency and productivity. Nevertheless, we also find some indication that the administrative and personnel burden which these higher education reforms have caused may have partly outweighed this positive development.

8. Conclusion

This study is the first cross-country analysis to investigate the dynamics of productivity in the Swiss and the German public university sector by separately benchmarking the non-science disciplines and the science disciplines of these two countries against a common production frontier. In particular, we analyse the development in productivity of Swiss and German universities from 2001 to 2007, a period in which the universities faced substantial structural changes. Several higher education reforms were initialised in the sector, aiming at the improvement of both efficiency and productivity. A cross-country analysis of these two higher education systems leads to valuable insights because

Switzerland and Germany display similarities as well as differences in higher education in terms of institutional characteristics and economic terms.

To investigate whether efficiency and productivity in the Swiss and German university sector have increased as intended by the New Public Management and the Bologna Reforms, we analysed total factor productivity and its key drivers, decomposing them into different sources, namely, technological change, technical efficiency change and scale efficiency change. Most notably, our analysis is one of the few where statistical inference methods were employed to overcome the problem of absent tests of statistical significance whereof non-parametric estimation techniques particularly lack. Using a rich panel dataset of disaggregate information on 10 Swiss universities and 77 German universities at the level of scientific fields, we further accounted for the heterogeneity in higher education production by analysing TFP change and its sources separately for both the non-science disciplines and the science disciplines. Thereby, we based our analysis on a distance function approach and applied the non-parametric Malmquist productivity index by using Data Envelopment Analysis.

Our results indicate that the intended effects of the national and international higher education reforms that occurred across Europe since the late 1980s have indeed partially been achieved in both the Swiss and the German public university sector. Analysing the period of 2001 through 2007, we found a general positive trend in the development of productivity for both Swiss and German universities. The comparative analysis, however, revealed that the Swiss universities experienced a higher TFP growth rate in the non-science disciplines, while the German universities experienced a higher TFP growth rate in the science disciplines. A more rapidly implementation of the national and international reforms in Switzerland may be one possible explanation for this finding. The better performance for German universities in the sciences may be misleading and hence interpreted with care. Given the overall low implementation rate toward Bologna conform degrees in the non-science and the science disciplines in Germany in the early years of the reforms, one may rather assume that the reform processes have only tentatively started in Germany and may speed up later in the following years not included in our observation period.

Overall, the results for TFP change indicate two key drivers. Catching up to the frontier of best practice production by improving technical efficiency was by far the most important driver of productivity growth. In addition, we found a considerable positive change in scale efficiency, that is, Swiss and German universities realised economies of scale, meaning they improved their efficient production by moving closer to an optimal scale of operation. The decomposition of TFP change further reveals that technological regress obtained for Swiss universities shifted the production frontier downward, thereby lowering the increases in productivity. The decline in technology does not surprise as the reform processes clearly implied a challenging task for HEIs in terms of structural reorganisation of management, governance and teaching and research activities. Finally, our results point to structural differences across the scientific disciplines, as we found divergent patterns for the TFP change and its sources in both the non-sciences and the sciences.

Some opportunity for further research should be noted. As the observation period for this research covers only the time span from 2001 to 2007, analyses using a more recent panel data set would help to evaluate the ongoing trend in the development of university productivity for Switzerland and Germany. Further, due to data unavailability, we were not able to incorporate the issue of quality into our analysis. Hence, including variables that address the quality aspect of higher education production would be of great benefit for further ongoing research. It would allow for assessing the development of higher education performance more precisely, given that managerial and organisational changes can essentially affect the quality of both teaching and research.

To summarise we can state that the aim of the European higher education reformation processes has been met but merely halfway at this point in time. As indicated by the technological regress found for Swiss universities, it seems that productivity growth in the Swiss university sector has been partially outweighed by the burden that the managerial and organisational changes have induced on the HEIs. For the German higher education system, our results indicate that essential changes in terms of efficiency and productivity improvements can be expected for the upcoming years when the reorganisation in German HEIs will be completed. Our analysis also demonstrates that for both countries, there is still considerable scope remaining for improving university performance in both countries.

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A. Appendix

A.1. Linear programming using the DEA estimator

Following Färe et al. (1994), the required distance measures for the output-oriented Malmquist productivity index are calculated using the DEA estimator, which is based on linear programming. For the i-th DMU, four distance functions are calculated in order to measure the productivity change between the periods t and $t+1$. Assuming constant returns to scale (CRS), this requires the solving of four linear programming problems as defined in the following Equations.

The first two linear programmes (see Equations 6 and 7) are used to compute Malmquist productivity estimates, where production points are compared from the same period, t and $t+1$, respectively. The second two linear programmes (see Equations 8 and 9) represent a situation, where production points are compared to technologies from different time periods:

$$\begin{aligned} \left[D_O^t(x^t, y^t)\right]^{-1} &= max_{\theta,\lambda}\theta, \\ s.t. \quad -\theta y_i^t + Y^t\lambda &\geq 0, \\ x_i^t - X^t\lambda &\geq 0, \\ \lambda &\geq 0, \end{aligned} \tag{6}$$

$$\begin{aligned} \left[D_O^{t+1}(x^{t+1}, y^{t+1})\right]^{-1} &= max_{\theta,\lambda}\theta, \\ s.t. \quad -\theta y_i^{t+1} + Y^{t+1}\lambda &\geq 0, \\ x_i^{t+1} - X^{t+1}\lambda &\geq 0, \\ \lambda &\geq 0, \end{aligned} \tag{7}$$

$$\begin{aligned} \left[D_O^t(x^{t+1}, y^{t+1})\right]^{-1} &= max_{\theta,\lambda}\theta, \\ s.t. \quad -\theta y_i^{t+1} + Y^t\lambda &\geq 0, \\ x_i^{t+1} - X^t\lambda &\geq 0, \\ \lambda &\geq 0, \end{aligned} \tag{8}$$

$$\begin{aligned} \left[D_O^{t+1}(x^t, y^t)\right]^{-1} &= max_{\theta,\lambda}\theta, \\ s.t. \quad -\theta y_i^t + Y^{t+1}\lambda &\geq 0, \\ x_i^t - X^{t+1}\lambda &\geq 0, \\ \lambda &\geq 0, \end{aligned} \tag{9}$$

where θ is a scalar, representing the efficiency score for the i-th DMU, and λ is a $Nx1$ vector of constants. Following the concept of technical efficiency proposed by

Farrell (1957)[29], θ satisfies the condition of $\theta \leq 1$, with a value of 1, indicating efficient production, while a value between 0 and 1 implies inefficient production.

To allow that the production technology exhibits variables returns to scale (VRS), we include a convexity constraint, that is $N1'\lambda = 1$, to each of the linear programmes in the Equations 6 to 9. Changes in the relative position to the production frontier can then be specified as changes of pure technical efficiency or changes of scale efficiency.

A.2. Statistical inference of Malmquist productivity indices

The process developed to generate confidence intervals for Malmquist productivity indices is adapted from Simar and Wilson (1999) and includes the following steps: First, it is given the original sample of $\ell = \{(x_{it}, y_{it}) \,|i = 1, ..., N; t = 1, 2\}$ of observations on N DMUs in two time periods, period t and $t+1$. The bootstrap procedure of the Malmquist productivity indices for a DMU, i, yields the bootstrap values $\left\{\hat{M}_i^* \left(t_1, t_2\right) (b)\right\}_{b=1}^{B}$, where B is the total number of replications performed with a pseudo samples drawn from the 'original' estimate, $\hat{M}_i \left(t_1, t_2\right)$. The bootstrap values can be used to find the values of a_α^* b_α^* such that the statement

$$\begin{aligned} &Prob\left(-b_\alpha^* \leq \hat{M}_i \left(t_1, t_2\right) - \hat{M}_i \left(t_1, t_2\right) \leq -a_\alpha^* | \ell\right) \\ &= 1 - \alpha \end{aligned} \tag{10}$$

is true with high probability.

Second, rearranging the terms yields an estimated $(1 - \alpha)$-percent confidence interval

$$\hat{M}_i \left(t_1, t_2\right) + a_\alpha^* \leq M_i \left(t_1, t_2\right) \leq \hat{M}_i \left(t_1, t_2\right) + b_\alpha^*, \tag{11}$$

with the change in productivity to be statistically significant if the confidence interval does not include 1. For the purposes of this study $\alpha = 0.05$ which generates 95% confidence intervals for the Malmquist productivity indices.

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[29] The Farrell measures are obtained by taking the reciprocal of the efficiency values by the Shepard distance function.