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The Dynamics of Productivity in Swiss Universities

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Abstract This paper analyzes the productivity of Swiss university departments between 1995 and 2007. Using a parametric input distance function we estimate and decompose the Malmquist productivity indexes in line with Fuentes et al. (2001) and Atkinson et al. (2003). By contrast to those studies, this paper proposes a panel data specification to account for unobserved heterogeneity across production units. The adopted model is a mixed-effects model with department-specific fixed effects and time trends with random coefficients. An autoregressive stochastic term is used to model inefficiency shocks with gradual dissipation by adaptation and learning. The results indicate a negative trend in overall productivity particularly after 2002, with an average rate of about one percent per year. Our decomposition analysis suggests that the observed decline can be mainly associated to a gradual technical regress rather than changes in technical efficiency. Following an early period of slow growth, the technologcal decline coincides with the recent developments in Switzerland's higher education system in line with the Bologna Accords. The results point to various patterns of productivity change across different fields. While eco-

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nomics/business, medicine and law show a considerable decline, engineering and humanities have a fairly neutral trend and the science departments stand out as an exception with a small but positive growth.

Keywords Parametric Distance Function · Malmquist Index · Decomposition · Swiss Universities · Bologna Accords

JEL: C23,D24,I23,J24

1 Introduction

Swiss universities with more than seventy percent public funding[1], are among the world's most expensive universities for tax payers. The rapid growth in public expenditures and federal funds reflect the government's priority in promoting world-class universities. An analysis of productivity growth can be used to assess to what extent additional funds have resulted in a better performance. The dynamics of productivity is particularly interesting in the last two decades when the Swiss universities have undergone a number of reforms similar to those initiated in many other European countries.

In a country with a strongly heterogeneous higher education system, government authorities have aimed at improving accountability and transparency by uniform and compatible standards. A notable reform starting form 1995 was the aggregation of various applied tertiary schools to seven regional "universities of applied sciences" (UAS) (Confederation, 1995). The emerging UAS model was expected to lighten the financial burden of higher education with less expensive alternatives but also to raise quality by promoting competition with mainstream universities. The most important and longest reform has been brought about by the Bologna Accords in 1999. As an early signatory, Switzerland has followed Bologna guidelines that are closely reflected in the instructions issued by the "Rectors' Conference of the Swiss Universities" in 2003 (CRUS, 2003).

[1] Source: Swiss Federal Statistical Office (SFSO, 2010b).

Following this conference, Swiss universities increased their coordinated efforts to transform their traditional single-degree system (Licentiate) to a system offering Bachelor and Master programs. Year 2003 can be marked as a culminating point by two other initiatives namely the introduction of quality assurance guidelines (SUC, 2003) and the adoption of intellectual property policy by the country's two engineering schools (ETH Zurich and Lausanne) in order to control and eventually capitalize on their research output (ETH, 2004).

While focusing on the harmonization of university degrees and programs (NAFSA, 2007), the ongoing reforms are often considered as measures that could improve the performance of European universities in order to match the performance of their US counterparts (see, e.g., Borghans and Cörvers, 2009). It is argued that by enhancing mobility of students and competition among universities, compatibility will result in improved performance.[2] In practice, however, the excessively slow pace of implementation and the observed difficulties in the usage of unified systems have raised questions about the desirability of any top-down reform (see, e.g., Kruecken, 2007; Neave and Amaral, 2008; Crosier et al., 2007).

Switzerland presents itself as an interesting case in which, after a decade of transition between the old systems and the unified model, the Bologna's harmonization process has reached its final stage. This period coincides with a more or less stable growth of about three percent per year in the country's public expenditures on universities(Swiss Federal Statistical Office, SFSO, 2010b). Unlike certain European countries that have reportedly shown little success in the implementation of the Bologna system (Veiga and Amaral, 2009; Witte, 2008), Switzerland can claim an overall success in achieving convergence in its higher education system. On one hand, this relative success is expected to have, at least for harmonization advocates, a positive impact on productivity. On the other hand, with a cumbersome transition process, occasionally requiring several parallel regulations, the burden of reforms might compromise universities' productivity.

[2] Mobility and competition are among the key policy points recommended by many experts such as Aghion et al. (2008).

An analysis of productivity in Swiss universities could be used as an empirical basis for guiding higher education policies in Switzerland but also in other countries committed to Bologna reforms. However, with the exception of two studies (Schenker-Wicki and Olivares, 2009; Filippini and Lepori, 2007), the topic has received little attention in the empirical literature. To our knowledge this paper is the first attempt in analyzing the productivity growth in Swiss universities during the last decade with a sample period covering the implementation of harmonization reforms. The output measures include the number of students and the amount of research grants. We use a panel data set from twelve universities over a thirteen year period from 1995 to 2007. The data are available by six scientific fields differentiated into fifteen subgroups, allowing for a department-level analysis with about 1200 observations from about a hundred university departments. We use a translog input distance function with five inputs including labor inputs in four categories and a single capital input measured by non-labor expenditures. We use three outputs, namely enrolled students and financial grants in two categories. We focus on the Malmquist index which measures productivity growth. The adopted methodology is in line with Fuentes et al. (2001) and Atkinson et al. (2003). The econometric specification incorporates individual intercepts estimated via fixed effects to account for different sources of heterogeneity, random time trends and an autoregressive stochastic term representing the variation of technical efficiency.

This paper extends the previous literature in two methodological aspects. First, we adopt a mixed effects specification that allows a separation of temporal effects from the time-invariant heterogeneity, while allowing an individual differentiation in the estimates of productivity growth. Secondly, we propose a new approach based on an autoregressive term, for modeling the potential persistence of inefficiencies and the gradual improvements through learning.

The results indicate that productivity has declined over the sample period. The overall negative trend in productivity as measured by a Malmquist index suggests that the Swiss universities are on average about five percent less productive in 2007 compared to 1995. The results show that most of the decline has occurred after 2002 with an average annual rate of one percentage point. The productivity decrease is particularly pronounced in certain fields such as economics/business, medicine and law. Science departments stand out as an exception with a small but positive growth.

Overall, the analysis provides suggestive evidence of a productivity decline over the sample period, favoring the hypothesis that the reforms have been a burden for universities. Whether the longer term benefits can counter the immediately observed effects remain to be explored. The results also suggest that technical change can account for a major part of productivity decline. However, the estimated autocorrelation parameter suggests that the inefficiency shocks are persistent. It could take several years before a complete dissipation of inefficiencies.

The remainder of the paper is organized as follows. The next section relates this paper to the existing literature concerning the measurement of university productivity over time. Sections 3 and 4 provide descriptions of the econometric specification and the data, respectively. Section 5 discusses our main results. Section 6 attempts to relate productivity growth to measures of openness and the progress of the Bologna reform. Section 7 concludes the paper.

2 Review of the Literature

Empirical research in university productivity and efficiency is documented in a relatively small but rapidly growing body of literature. Some of these studies are reviewed in two surveys by Worthington (2001) and Johnes (2004). As far as productivity growth is concerned, this literature is characterized by two distinct methodologies: Non-parametric estimation of Malmquist index (Malmquist, 1953) derived from a Data Envelopment Analysis (DEA) in line with Färe et al. (1994) and parametric estimation of translog functions using Stochastic Frontier Analysis (SFA) as in Nishimizu and Page (1982).[3]

[3] For more recent applications see Saal et al. (2007) and Das and Kumbhakar (2010).

Fuentes et al. (2001) provide a discussion of theoretical differences between the two methods. However, few studies have compared the empirical outcomes of the two approaches in the case of university productivity. An exception is Kempkes and Pohl (2010) who report more or less similar results for German universities' data from the 1998-2003 period.

A thorough comparison of these methods is beyond the scope of this study. It is nevertheless important to note that both methods have appealing advantages: As pointed out by Fuentes et al. (2001), the indivisible production factors are readily amenable to discrete ratios such as the Malmquist index. On the other hand, parametric methods are easily adaptable to panel data providing a possibility to account for time-invariant heterogeneity.

The advantages of parametric methods can be combined with the intuitiveness of the Malmquist productivity index. In particular, the parametric method proposed by Fuentes et al. (2001) and Atkinson et al. (2003) allows us to exploit the panel aspects of the data while retaining the discrete nature of the productivity measure in consistence with economic data. Adopting a parametric approach to estimate the Malmquist productivity index, this paper is the first of the kind in the context of higher education.

In the case of Switzerland, the related empirical literature is limited to two studies: Schenker-Wicki and Olivares (2009) estimate the development of universities' technical efficiency between 1999 and 2007, using a Malmquist index based on DEA, whereas Filippini and Lepori (2007) estimate a variable cost function using a true random effects SFA (Greene, 2005), on the data between 1994 and 2003. Schenker-Wicki and Olivares (2009) report a generally positive development in technical efficiency, whereas Filippini and Lepori (2007)'s findings suggest a statistically significant technological regress reflected in a positive trend in costs. The contrasting difference between these two studies might be partly explained by methodological differences especially regarding the treatment of unobserved heterogeneity.

Among the empirical studies of university productivity in other countries we focus on those that have used relatively long panel data. Both DEA and SFA approach have been used. Flegg et al. (2004) and Flegg and Allen (2007) have adopted the DEA approach for British universities. Their findings suggest productivity growth due to a shift in the production frontier over periods of 1980-1992 and 1994-2003, respectively. Similarly, Johnes (2008) reports a moderate productivity growth in English universities between 1996 and 2004, partly offset by a decrease in the average level of efficiency. On the other hand, Stevens (2005) applies the SFA approach to English and Welsh universities between 1995 and 1997. He finds evidence for a technological regress but an increase in technical efficiency. Robst (2001) finds a positive trend coefficient in his cost function estimates for US universities between 1991 and 1995. Kuo and Ho (2007) analyze the efficiency of Taiwanese universities in the period 1992-1999. They find evidence for technological progress as well as improvements in the technical efficiency.

In the case of Australian universities Abbott and Doucouliagos (2009) apply Battese and Coelli (1995)'s SFA model to data from 1995 to 2002. They find that while the production frontier has shifted outwards, the efficiency level of universities has decreased. Worthington and Lee (2008) have used DEA and reported productivity growth between 1998 and 2003. They identified technological progress as a main source of productivity. On the other hand, using a parametric stochastic frontier in line with Cornwell et al. (1990), Horne and Hu (2008) analyze data between 1995 and 2002 and find no discernible time trend.

Before turning to this paper's contribution it is worth noting that productivity measures are necessarily based on immediate outputs rather than long-term impacts. To the extent that a university output is an investment in human capital to be assessed in the long run, these productivity measures are all but incomplete pictures of academic performance. This shortcoming can be partly countered by using quality proxies such as publication quality, citations, graduates' employment prospect etc. However, most of these measures are subjective but also could vary strongly among different fields. Moreover, most of the differences regarding the mix of various fields of education and research across universities are omitted from empirical models. Therefore, productivity estimates might be biased due to structural differences that remain unobserved due to data limitations or measurement difficulties. Virtually all previous studies have pooled the longitudinal data across universities, hence do not exploit the panel data advantages to account for unobserved heterogeneity. Among the exceptions we should mention Filippini and Lepori (2007) and Horne and Hu (2008) that include university-specific effects in their estimations.

The adopted approach in this paper is similar to Horne and Hu (2008) and Farsi (2008) in that we use individual intercepts to account for the unobserved factors pertaining to an individual production unit (here, a university department). Recognizing the difficulty of measuring quality, we assume that unobserved differences across universities can be captured by time-invariant factors specific to each university department. This assumption implies that the unaccounted temporal variations can be associated with productivity changes. It is important to note that a department-level analysis reduces potential biases due to different mixes of fields in a university, but also alleviates the apparent developments due to peculiar changes in certain scientific fields. For instance, if a field of study such as genetics has undergone characteristic changes that made it substantially more costly, a university with a large genetics department could appear less productive in a university-level analysis, whereas, a model with department-specific random trends assigns the changes correctly, to the specific field rather than the university.

3 Methodology

We use an input distance function to model the productivity changes measured by a Malmquist index. The adopted methodology is similar to the approach proposed by Atkinson et al. (2003) and Fuentes et al. (2001). The input distance function at any period, t, is defined as the maximum possible reduction of input vector, x, while retaining a given level of output vector, y, and time-invariant characteristics, z:

$$D_I(x_{jt}, y_{jt}, z_j, t) = max\{\varrho : (x_{jt}/\varrho) \in L(y_{jt}, z_j, t)\} \tag{1}$$

where subscript j denotes the production unit (here, a university department). $L(y_{jt}, z_j, t)$ is the feasible input set and ϱ is a scalar ($\varrho \geq 1$) measuring possible reductions in inputs, whose minimum value ($\varrho = 1$) corresponds to fully efficient production units. A measure of relative inefficiency can be defined as D_I, representing the relative excess in input factors due to technical inefficiency. The input distance function needs to satisfy certain regularity conditions. Namely, it must be non-decreasing in inputs, linearly homogeneous in inputs and decreasing in outputs.

Assuming separability between observed input/output variables (x_{jt}, y_{jt}) and the excluded characteristics and time (z_j, t), the distance function in logarithm can be written in a translog functional form as in Coelli and Perelman (2000):

$$lnD_I(x_{jt}, y_{jt}, z_j, t) = TL(x_{jt}, y_{jt}) + \theta(z_j, t) \tag{2}$$

where $TL(x_{jt}, y_{jt})$ is a translog function of observables and $\theta(z_j, t)$ is an unknown function that includes the model's incidental parameters.

We approximate the time-invariant portion of function $\theta(z_j, t)$ using department-specific intercepts estimated via fixed effects. In particular, we specify the stochastic function $\theta(z_j, t)$ as a function of department-specific characteristics z_j, plus a quadratic function of time:

$$\theta(z_j, t) = f(z_j) + \sum_{p=1}^{2} \phi_j^p * [t]^p \tag{3}$$

where $f(.)$ is an arbitrary function and the coefficients ϕ_j^1 and ϕ_j^2 correspond to the linear and quadratic trends representing the temporal variation of the distance function for department j. We assume that these department-specific trends vary around field-specific mean values with a bivariate normal distribution, that is: $(\phi_j^1, \phi_j^2) \sim N\left(\lambda_f^p, \Sigma_\phi\right)$. Subscript f denotes the scientific field and the means of this distribution $(\lambda_f^1, \lambda_f^2)$ represent the average time trends for each scientific field. Σ_ϕ is a homoscedastic variance-covariance matrix.[4]

The department j's technical inefficiency measured by the distance function (lnD_I) can be decomposed into a time-invariant part u_j, and a time-varying part $\epsilon_{j,t}$:

$$lnD_I(x_{jt}, y_{jt}, z_j, t) = u_j + \epsilon_{j,t} \tag{4}$$

where u_j is a department-specific effect and $\epsilon_{j,t}$ is an autoregressive process defined below. Note that while the distance function (D_I) is a positive metric, its log (lnD_I) can be negative. In fact the full efficiency is reached when $lnD_I = u_j + \epsilon_{j,t}$ tends toward $-\infty$. Therefore, there is no restriction on the stochastic term ϵ_{jt}. As we see later, the term u_j is an incidental parameter captured by department-specific intercepts.[5] Using equations 2, 3 and 4, the econometric specification of the distance function is obtained as follows:

$$lnD_I(x_{jt}, y_{jt}, z_j, t) = TL(x_{jt}, y_{jt}) + f(z_j) + \sum_{p=1}^{2} \phi_j^p * [t]^p = u_j + \epsilon_{jt} \tag{5}$$

Rearranging the terms we have:

$$TL(x_{jt}, y_{jt}) + \sum_{p=1}^{2} \phi_j^p * [t]^p + \alpha_j - \epsilon_{jt} = 0 \tag{6}$$

[4] We assumed no correlation, because our preliminary regressions indicated that the correlation coefficients were mostly insignificant. Moreover, the quadratic trends were quite small hence, practically negligible.

[5] As we see later, the term u_j cancels out in calculating efficiency changes.

with $\alpha_j = f(z_j) - u_j$ denoting the individual intercepts. Expanding the translog function for three outputs and four inputs, we have:

$$\begin{aligned} TL(x_{jt}, y_{jt}) &= \sum_{r=1}^{4} \beta_r lnx_{rjt} + \frac{1}{2}\sum_{r=1}^{4}\sum_{s=1}^{4} \beta_{rs} lnx_{rjt} * lnx_{sjt} \\ &+ \sum_{m=1}^{3} \gamma_m lny_{mjt} + \frac{1}{2}\sum_{m=1}^{3}\sum_{n=1}^{3} \gamma_{mn} lny_{mjt} * lny_{njt} \\ &+ \sum_{r=1}^{4}\sum_{m=1}^{3} \zeta_{rm} lnx_{rjt} * lny_{mjt} \end{aligned} \tag{7}$$

The translog parameters must satisfy the usual symmetry restrictions.[6] By imposing linear homogeneity in inputs on equation 7, the inputs can be normalized by an arbitrary input (denoted x_1).[7] By substituting the translog function from equation 7 into equation 6 and transferring the numeraire input (x_1) to the left hand side we can obtain an empirically estimable distance function:

$$\begin{aligned} -lnx_{1jt} &= \sum_{r=2}^{4} \beta_r lnx^*_{rjt} + \frac{1}{2}\sum_{r=2}^{4}\sum_{s=2}^{4} \beta_{rs} lnx^*_{rjt} * lnx^*_{sjt} \\ &+ \sum_{m=1}^{3} \gamma_m lny_{mjt} + \frac{1}{2}\sum_{m=1}^{3}\sum_{n=1}^{3} \gamma_{mn} lny_{mjt} * lny_{njt} \\ &+ \sum_{r=2}^{4}\sum_{m=1}^{3} \zeta_{rm} lnx^*_{rjt} * lny_{mjt} \\ &+ \sum_{p=1}^{2} \phi_j^p * [t]^p + \alpha_j - \epsilon_{jt} \end{aligned} \tag{8}$$

[6] $\beta_{rs} = \beta_{sr}$, $\gamma_{mn} = \gamma_{nm}$ and $\zeta_{rm} = \zeta_{mr}$ $\forall r, s, m, n$

[7] Thanks to linear homogeneity (LH) it does not matter which input is selected as the numeraire. The LH condition requires that any proportional increase in all inputs causes the same increase in the distance function. In a translog function this condition can be readily expressed by linear constraints on the coefficients. Namely, in our case: $\sum_{r=1}^{4} \beta_r = 1$, $\sum_{s=1}^{4} \beta_{rs} = 0, \forall r$ and $\sum_{r=1}^{4} \zeta_{rm} = 0, \forall m$.

Note that the estimation of the distance function is equivalent to a regression model (equation 8) in which the numeraire input variable, x_1, with a negative sign is regressed on all other observables including the remaining input variables normalized by the numeraire input, that is, $x_r^* = x_r/x_1$ (see, e.g., Coelli et al., 2005). In principle, the model in equation 8 may include any observed output characteristics in addition to the included inputs and outputs.[8]

Equation 8 is a mixed effects linear model with individual fixed effects α_j, and random coefficients ϕ_j^1 and ϕ_j^2, which can be solved using appropriate distribution assumption for the error term ϵ_{jt}.[9] In our specification, the stochastic term, ϵ_{jt}, is defined as an autoregressive process of order one, i.e. $\epsilon_{jt} = \rho\epsilon_{jt-1} + v_{jt}$, where v_{jt} is an *iid* normal error with variance σ_v^2. ρ is the autocorrelation coefficient that satisfies $0 < \rho < 1$. With the autoregressive process, we assume that each period brings about an improvement in the persistent inefficiency from previous years reflected in ρ, but also has its own new shock v_{jt}. The value of ρ can indicate the rate of learning and the persistency of inefficiency. Roughly speaking, according to the autoregressive model, the remaining effect of an inefficiency shock after n years, will decrease to $(1/\rho)^n$ of the initially induced inefficiency.

The hierarchical structure of the time trends (ϕ_j^1,ϕ_j^2), allows us to identify the rate of technological progress in each one of the six scientific fields as fixed parameters λ_f^1 and λ_f^2, while accounting for variations across departments with fixed effects. This is an important feature of the model because many potential drivers of productivity such as globalization could vary across scientific fields (see, e.g., Borghans and Cörvers, 2009). Assuming that competition fosters productivity growth, one could expect a higher productivity growth in disciplines such as science and engineering that are more exposed to globalization compared to certain fields such as law that have strong country specificity.

[8] In an alternative specification discussed in section 6, we have considered additional variables such as the diversity of students and degrees.

[9] We estimate equation 8 using the xtmixed command of Stata 12.

Productivity could also vary across scientific disciplines because of different developments of complexity and asymmetry of information. In order to ensure efficiency, organizations and incentive mechanisms need to adapt. For instance higher complexity might require a higher wage differential due to efficiency wages. To the extent that the adjustment of incentive mechanisms is difficult in public organizations, one can expect a lower productivity growth in disciplines that have gone through substantial progress, hence greater complexity. A plausible example is the relatively rapid transformation of business and economics into highly quantitative disciplines during the last decades, causing difficulties and disagreements in evaluating academic activities. Assuming that institutions do not allow a rapid adjustment to such developments (for instance by adjusting wages), we might expect a lower productivity growth in these fields compared to other disciplines.

For time trends, in addition to the quadratic form, we have considered several alternatives, including a specification with year dummies and another with piecewise linear trends in two to four intervals. Our preliminary analysis indicated that the results are not sensitive to the specification of the time trends. Similar to Cornwell et al. (1990), Lee and Schmidt (1993), Kneip et al. (2003) and Sickles (2005), we favor a quadratic trend because it allows one to keep the number of trend coefficients within a reasonable limit.

3.1 Malmquist Index and its Decomposition

Based on the distance function estimations, we predict the corresponding Malmquist indices (Caves et al., 1982a,b). In the case of input distance functions, for any given production unit j, at a given period t, the Malmquist productivity index measures the decrease in the distance function between two periods t and $t+1$, while fixing the technology frontier either at period t or at $t+1$. In line with Fuentes et al. (2001), we define the Malmquist index as the predicted value of the input distance function in period t, divided by the predicted value of the function in period, $t+1$, while retaining the frontier at t. Therefore, using equation 5 we can write the Malmquist index as:

$$M_I(x_{jt}, y_{jt}, x_{j,t+1}, y_{j,t+1}, z_j, t) = \frac{D_I(x_{jt}, y_{jt}, z_j, t)}{D_I(x_{j,t+1}, y_{j,t+1}, z_j, t)} = \exp\left[TL(x_{jt}, y_{jt}) - TL(x_{j,t+1}, y_{j,t+1})\right] \tag{9}$$

where the translog function $TL(.)$ can be estimated from equation 7. Note that the estimated trend coefficients do not enter the expression of Malmquist index, thus allowing for technical progress to be included in productivity growth.

Färe et al. (1997) suggest to write the Malmquist index as the product of two component. The first term, technical efficiency change (ΔTE), captures the change in the distance to the current frontier, hence allowing the frontier shift over time. The second element, called technical change (ΔT), uses the inputs/outputs of period $t+1$, in both the numerator and the denominator, but allows the production technology to shift. The Malmquist index can therefore be decomposed into two components respectively representing changes in technical efficiency and technical progress:

$$\begin{aligned} M_I(x_{jt}, y_{jt}, x_{j,t+1}, y_{j,t+1}, z_j, t) &= \Delta TE(x_{jt}, y_{jt}, x_{j,t+1}, y_{j,t+1}, z_j, t, t+1) * \Delta T(x_{j,t+1}, y_{j,t+1}, z_j, t, t+1) \\ &= \left[\frac{D_I(x_{jt}, y_{jt}, z_j, t)}{D_I(x_{j,t+1}, y_{j,t+1}, z_j, t+1)}\right] * \left[\frac{D_I(x_{j,t+1}, y_{j,t+1}, z_j, t+1)}{D_I(x_{j,t+1}, y_{j,t+1}, z_j, t)}\right] \end{aligned} \tag{10}$$

Using equations 5 and 6 the two components can be written as:

$$\Delta TE(x_{jt}, y_{jt}, x_{j,t+1}, y_{j,t+1}, z_j, t, t+1) = \exp\left[TL(x_{jt}, y_{jt}) - TL(x_{j,t+1}, y_{j,t+1}) - \phi_j^1 - \phi_j^2(1+2t)\right] \tag{11}$$

$$\Delta T(x_{j,t+1}, y_{j,t+1}, z_j, t, t+1) = \exp\left[\phi_j^1 + \phi_j^2(1+2t)\right] \tag{12}$$

In the context of the higher education sector, technical change can be specified as technological improvements in equipment as well as managerial and organizational innovations. Typical examples include new technologies in research labs, computation centers and administration systems, but also curriculum reforms and initiatives for better coordination between various activities. Changes in technical efficiency can be related to adaptation and learning as well as institutional changes and incentives. With the development of universities, institutional and technological changes bring new challenges that might require new qualifications, but also adaptations in organization and contracts. For instance, optimal usage of a computerized registration system needs an adaptation from the part of administrative staff. Another relevant example is the increasing stress on research output such as publication that might increase the asymmetry of information between managers and researchers. This might need an adaptation in labor contracts to adjust the incentive mechanisms or to adapt the monitoring and evaluation systems. New challenges can be considered as inefficiency shocks that appear at each period and gradually dissipate by learning and adaptation.

4 Data and Specification

Modeling a university's production process requires certain assumptions regarding the input/output sets. The universities' ultimate outputs should ideally represent the long-term value of research and education and the added value on the society's human capital. Lacking an adequate measure of final outputs, empirical studies generally use simple measures of intermediate outputs such as number of graduates, enrollments, publications, financial grants etc. (see, e.g., Abbott and Doucouliagos, 2009; Agasisti and Johnes, 2010). Main input factors are generally labor inputs including teaching and research staff. Due to data restrictions, only a few papers include capital and other inputs (exceptions include Filippini and Lepori, 2007; Eckles, 2010).

The model includes four labor inputs extracted from the personnel data provided by the SFSO. These inputs include full-time equivalent employees in four categories: "Professors", "Lecturers", "Assistants" and "Administrative and technical staff".[10] The fifth input is the department's non-labor expenditure, i.e. all expenditures except for wages and social security payments. Hence this input covers both material costs as well as capital services. We assume that the university's non-labor costs can be used as a proxy for capital inputs by a residual approach. This assumption might bring about two difficulties. First, measuring capital inputs by their costs ignores the variation of capital price across university departments. Secondly, in our data, the non-labor costs do not include the costs of many university buildings owned by the Swiss cantons. However, as the related differences across university departments are likely to be constant over time, we expect that these differences can be reasonably captured by individual fixed effects. [11]

The three outputs included in the model are: total enrollments, research grants from the Swiss National Science Foundation (SNSF) and other external funds. In line with Johnes and Johnes (2008) and Thanassoulis et al. (2009), the number of enrolled students at the university captures the teaching output. The student body can be grouped into four categories corresponding to the degree programs offered in the sample period, that is: PhD, Licentiate, Bachelor and Master. In

[10] "Professors" include full and associate professors, "Lecturers" include assistant professors, lecturers and senior scientific staff. The category "Assistants" contains employed doctoral students and junior scientific staff such as post-doc assistants.

[11] Furthermore, our proxy for the stock of real estate, the floor space, available for about half of the sample period shows relatively little variation over time, suggesting that assuming fixed real estate stock is not unrealistic.

our sample, the two latter programs appear starting from 2002, whereas Licentiate is the single undergraduate degree program prior to the Bologna reform. We exclude PhD students because they are generally employed by the university as part-time assistants, thus included as an input. In order to have a clear definition we aggregate all students into one group, including Licentiate, Bachelor and Master students.

Similar to previous studies (Abbott and Doucouliagos, 2009; Agasisti and Johnes, 2010), we measure the research output by the amount of acquired external funds.[12] We have not included the number of publications that could be considered as an important research output. However, the extremely variable range of publication quality as well as differences across fields in respect to the relevance of journal publications could cause considerable measurement errors. External funds on the other hand, provide a relatively uniform measure of research output. Assuming that the process of selection of grants works with a reasonable effectiveness, we can consider that external funds represent the market value (or the society's valuation) of a university's research output.

We distinguish funds from the SNSF, a main body for financing fundamental research projects, from other external funds that are mainly used for applied projects. More than half of the latter category stems from private sources (SFSO, 2010b). The rest contains funds from the Swiss innovation promotion agency CTI, research mandates from the government, European and international research programs as well as income from services and continuing education. We deflate all monetary values by the Swiss Consumer Price Index (CPI) to year 2005 and report values in thousand Swiss Francs (CHF).

A meaningful comparison of different universities should account for the quality aspects of the education and research activities. Quality aspects entail however, complex factors that are

[12] Research funds can be considered as an intermediate output for a university. For further discussion of intermediate and final outputs see Agasisti and Pérez-Esparrells (2009) and Garcia-Aracil and Palomares-Montero (2010).

difficult to measure. These factors are either unobservable such as the faculty's commitment and researchers' effort, or prone to selection effects such as the initial ability of the admitted students. In this paper, department-level fixed effects can capture the unobserved time-invariant quality aspects.

As seen in the previous section, the model includes field-specific trends with random coefficients across departments. Our estimations indicated a considerably different trend in the two newly founded universities in the sample, namely the universities of Lugano and Lucerne. Founded in 1997, these universities indicate an initial rapid growth in terms of enrollments and other activities, which could not be handled with a random effect. Therefore, in the final specification we included a shift in linear and quadratic trend coefficients for these universities.

The data used in this study are based on various indicators of the Swiss higher education sector (see SFSO, 2010b) for all Swiss university departments between 1995 to 2007. The data are organized into departments based on universities and scientific fields according to the SFSO classification. The SFSO classification divides the higher education sector into seven main scientific fields: humanities, science, engineering, economics and business, law, medical sciences and interdisciplinary fields. With the exception of two cases namely, law and economics/business, each field is divided into several departments (see table 1).

In most Swiss universities, the existing organization of the departments follows a similar classification. However, in some cases, multiple university departments are included in a single SFSO department. An exception is the case of interdisciplinary studies that is defined as a main field, but usually included in another school or department, depending on the university. Given the non-uniform definition of this field across universities and the difficulty to assign meaningful inputs and outputs, we exclude all interdisciplinary departments from our analysis. Therefore, we focus on fifteen departments organized in six fields (see table 1). After excluding observations with invalid and missing values, the final dataset consists of an unbalanced panel of 1238 observations

Table 1: *Distribution of observations across universities and departments*

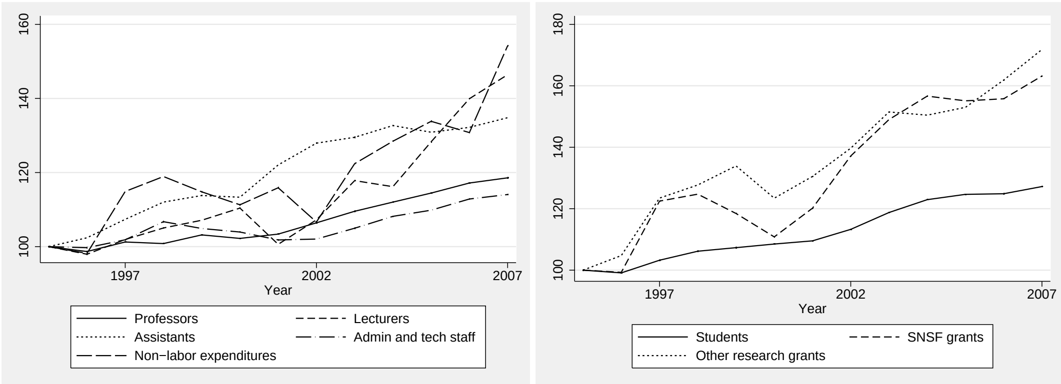
Name	Observations	Departments
Universities		
Federal universities		
ETH Lausanne	60	5
ETH Zurich	127	11
Cantonal Universities		
University of Berne	152	12
University of Basel	143	11
University of Fribourg	116	9
University of Geneva	156	12
University of Lausanne	126	10
University of Lucerne	35	4
University of Neuchâtel	117	9
University of St. Gallen	26	2
University of Lugano	37	4
University of Zurich	143	11
Total	**1238**	**100**
Scientific Fields[1]		
Humanities		
Theology	102	8
Linguistics and Literature	99	8
History and Cultural Studies	110	9
Social Sciences[2]	124	11
Economics and Business	127	10
Law	124	10
Science		
Mathematical and Physical Sciences[3]	121	10
Natural Sciences[4]	117	9
Medical Sciences		
Medicine	77	6
Dentistry	52	4
Veterinary Medicine	26	2
Pharmacology	57	5
Engineering		
Architecture and Geodesy	50	4
Mechanical and Electrical Engineering	39	3
Agricultural Engineering and Forestry	13	1
Total	**1238**	**100**

[1] Based on SFSO (2010a)'s classification.
[2] Social sciences include psychology, education, sociology, social work, cultural anthropology, political sciences and communication.
[3] Also include computer science and astronomy.
[4] Natural sciences include chemistry, biology, geoscience and geography.

from 100 university departments distributed over 12 universities across a sample period of 13 years. The distribution of the observations across universities and departments is given in table 1. In terms of number of departments, humanities have the largest share with about 35 percent, followed by science departments and medical schools with about 18 percent, whereas economics, law and engineering represent the smallest shares each with about 10 percent of the sample.

Figure 1 shows the development of total inputs and outputs over the sample period (1995-2007) normalized by their 1995 values. As shown in figure 1(a), the highest growth among inputs occurred in the "lecturers" category, increasing by nearly 50% since 2000. "Assistants" expanded by about 35% while "Professors" and "Administrative and technical staff" grew less than 20%.

Figure 1(b) shows a considerable difference in the growth of output measures. While the number of students expanded by less than 30%, the corresponding growth in research grants



(a) Inputs (b) Outputs

Fig. 1: *Development of Swiss universities (1995-2007)(numbers are total values indexed to 1995)*

reached more than 60%. Comparing the two graphs, one can observe a consistent pattern of growth in that the professor and student bodies show a similar growth, whereas the research staff and grants have moved in a similar pattern, picking up speed after year 2000. The numbers point to a rise in productivity in terms of research activities, with about 60% increase in output with only 40% input growth. However, it is not clear to what extent these gains could be associated with economies of scale. The distance function approach allows us to abstract the gains in scale economies from genuine productivity growth.

A descriptive summary of the variables included in the model along with the notation used for input/output variables are provided in table 2. In a small number of departments one of the input/output variables (especially the external funds) can be zero in one or several periods, resulting in a zero value for about 5 percent of the sample. In order to accommodate the logarithmic form in the translog function, we replaced these zero values by a negligible positive number, well below the corresponding smallest positive values observed in the sample.[13] In addition to the main variables we also constructed three variables that we use in alternative specifications of the distance function. In particular, we used the share of foreign (non-Swiss) students to proxy

[13] We tried several alternative replacing values. The estimation results show little sensitivity to the choice of this value. The final results reported in this paper are based on replacing all zero values of inputs/outputs by 0.1. The exact number of observations with zero values depend on the variable, varying from 0 for non-labor expenditures to 65 for SNSF external funds.

the department's openness, and two measures of diversity of the ongoing degree programs (share of Licentiate granted degrees and sum of squared shares for all three degrees) as proxies for the progress of the Bologna reform. The analysis of variation of these proxies and their relation with the productivity results will be discussed in section 6.

Table 2: *Summary statistics*

Variable	Definition	Mean	Std.Dev.	Min	25th %ile	50th %ile	75th %ile	Max
y1	Number of enrolled students	981	944	0	256	717	1342	6167
y2	External funds from the SNSF[1]	2988	4682	0	276	881	3086	21386
y3	Other external funds[1]	5519	9677	0	456	1523	5653	59301
x1	Number of Professors[2]	25	22	0.7	10	20	34	137
x2	Number of Lecturers[2]	20	32	0	4	10	22	285
x3	Number of Assistants[2]	129	172	0	31	69	139	961
x4	Number of Admin and technical staff[2]	63	91	0	8	24	80	642
x5	Non-labor Expenditures [1]	9219	18936	0	1088	2869	8509	159904
Student openness	Share of foreign students	0.21	0.14	0	0.11	0.18	0.30	0.91
Bologna 1	Share of Licentiate degrees[3]	0.93	0.21	0.01	1	1	1	1
Bologna 2	Sum of squared degree shares[3]	0.93	0.17	0.33	1	1	1	1

[1] in thousand 2005 Swiss Francs.
[2] full-time equivalent (FTE).
[3] based on 3 groups: Licentiate, Bachelor, Master.

5 Results

5.1 Estimation Results

Table 3 shows the estimation results of four models. All four models have individual fixed effects and random coefficients for trend variables. The difference between model 1 and 2 is that Model 1 contains *iid* residuals (transient inefficiency), whereas in Model 2 the residuals are modeled as an autoregressive error term AR1 (persistent inefficiency). Models 3 and 4 represent variations of model 1 that include additional control variables, namely openness with respect to foreign students and a measure capturing the implementation rate of the Bologna reform.

Table 3: *Parameter estimates of the input distance function*

Inputs: professors (x1), lecturers (x2), assistants (x3), administrative staff (x4)

Inputs (continued): non-labor expenditures (x5)

Outputs: students (y1), SNSF research grants (y2), other research grants (y3)

N=1238	Model 1	Model 2	Model 3	Model 4
y1	-0.237***	-0.271***	-0.272***	-0.272***
	(0.033)	(0.037)	(0.037)	(0.037)
y2	-0.047***	-0.041***	-0.041***	-0.041***
	(0.009)	(0.009)	(0.009)	(0.009)
y3	-0.029***	-0.040***	-0.040***	-0.040***
	(0.008)	(0.008)	(0.008)	(0.008)
y1y1	-0.034***	-0.038***	-0.038***	-0.038***
	(0.007)	(0.008)	(0.008)	(0.008)
y2y2	-0.010***	-0.009***	-0.009***	-0.009***
	(0.002)	(0.002)	(0.002)	(0.002)
y3y3	-0.007***	-0.009***	-0.009***	-0.009***
	(0.002)	(0.002)	(0.002)	(0.002)
y1y2	0.005***	0.006***	0.006***	0.006***
	(0.002)	(0.002)	(0.002)	(0.002)
y1y3	0.005*	0.003	0.003	0.003
	(0.002)	(0.002)	(0.002)	(0.002)
y2y3	0.004***	0.005***	0.005***	0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
x2	0.099***	0.098***	0.098***	0.098***
	(0.012)	(0.012)	(0.012)	(0.012)
x3	0.119***	0.135***	0.135***	0.135***
	(0.024)	(0.024)	(0.024)	(0.024)
x4	0.039*	0.055***	0.055***	0.055***
	(0.020)	(0.021)	(0.021)	(0.021)
x5	0.093***	0.084***	0.083***	0.084***
	(0.013)	(0.013)	(0.013)	(0.013)
x2x2	0.026***	0.031***	0.031***	0.031***
	(0.008)	(0.008)	(0.008)	(0.008)
x3x3	0.243***	0.257***	0.257***	0.257***
	(0.031)	(0.029)	(0.029)	(0.029)
x4x4	0.019**	0.020**	0.020**	0.020**
	(0.009)	(0.010)	(0.010)	(0.010)
x5x5	-0.022***	-0.020***	-0.020***	-0.020***
	(0.007)	(0.006)	(0.006)	(0.006)
x2x3	-0.070***	-0.069***	-0.069***	-0.069***
	(0.012)	(0.012)	(0.012)	(0.012)
x2x4	0.018**	0.010	0.010	0.010
	(0.008)	(0.008)	(0.008)	(0.008)
x2x5	0.016**	0.019***	0.019***	0.019***
	(0.006)	(0.006)	(0.006)	(0.006)
x3x4	0.023	0.021	0.021	0.021
	(0.015)	(0.015)	(0.015)	(0.015)
x3x5	0.020**	0.023**	0.023**	0.023**
	(0.010)	(0.009)	(0.009)	(0.009)
x4x5	0.004	-0.002	-0.002	-0.002
	(0.004)	(0.004)	(0.004)	(0.004)
x2y1	-0.010***	-0.012***	-0.012***	-0.012***

	(0.004)	(0.004)	(0.004)	(0.004)
x2y2	0.003	-0.002	-0.002	-0.002
	(0.003)	(0.003)	(0.003)	(0.003)
x2y3	-0.005	0.001	0.001	0.001
	(0.005)	(0.005)	(0.005)	(0.005)
x3y1	0.026***	0.031***	0.031***	0.031***
	(0.008)	(0.007)	(0.007)	(0.007)
x3y2	-0.008	-0.011*	-0.011*	-0.011*
	(0.006)	(0.006)	(0.006)	(0.006)
x3y3	-0.008	-0.016**	-0.016**	-0.016**
	(0.007)	(0.007)	(0.007)	(0.007)
x4y1	-0.009*	-0.013**	-0.013**	-0.013**
	(0.005)	(0.005)	(0.005)	(0.005)
x4y2	0.001	0.005	0.005	0.005
	(0.004)	(0.004)	(0.004)	(0.004)
x4y3	0.003	0.005*	0.005*	0.005*
	(0.003)	(0.003)	(0.003)	(0.003)
x5y1	-0.014***	-0.013***	-0.013***	-0.013***
	(0.004)	(0.003)	(0.003)	(0.003)
x5y2	0.008**	0.007**	0.007**	0.007**
	(0.003)	(0.003)	(0.003)	(0.003)
x5y3	0.012***	0.010***	0.010***	0.010***
	(0.003)	(0.003)	(0.003)	(0.003)
New_lin	0.098***	0.112***	0.113***	0.113***
	(0.033)	(0.043)	(0.043)	(0.043)
New_squ	-0.007***	-0.007***	-0.007***	-0.007***
	(0.002)	(0.003)	(0.003)	(0.003)
Humanities_lin	0.019**	0.012	0.012	0.012
	(0.008)	(0.010)	(0.010)	(0.010)
Economics_lin	0.008	0.008	0.007	0.008
	(0.014)	(0.019)	(0.019)	(0.019)
Law_lin	-0.002	-0.015	-0.015	-0.015
	(0.014)	(0.018)	(0.019)	(0.019)
Science_lin	0.006	0.025*	0.025*	0.025*
	(0.010)	(0.013)	(0.013)	(0.013)
Medicine_lin	-0.002	0.015	0.015	0.015
	(0.011)	(0.014)	(0.014)	(0.014)
Engineering_lin	-0.023	-0.038*	-0.038*	-0.038*
	(0.015)	(0.020)	(0.020)	(0.020)
Humanities_squ	-0.002***	-0.001*	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Economics_squ	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Law_squ	-0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Science_squ	-0.001	-0.002*	-0.002*	-0.002*
	(0.001)	(0.001)	(0.001)	(0.001)
Medicine_squ	-0.001	-0.002	-0.002	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)

Engineering_squ	0.002*	0.003*	0.003*	0.003*
	(0.001)	(0.002)	(0.002)	(0.002)
Student openness			-0.005	-0.005
			(0.131)	(0.131)
Bologna 1			0.005	
			(0.028)	
Bologna 2				0.002
				(0.035)
Constant	-0.792***	-0.826***	-0.831***	-0.828***
	(0.095)	(0.150)	(0.155)	(0.157)
Random Effects				
sd(trend_lin)	0.030***	0.009	0.009	0.009
	(0.004)	(0.014)	(0.014)	(0.014)
sd(trend_squ)	0.002***	0.001	0.001	0.001
	(0.0003)	(0.0005)	(0.0005)	(0.0005)
Autocorrelation				
ρ		0.784***	0.784***	0.784***
		(0.092)	(0.092)	(0.092)

Standard errors in parentheses.

*, ** and *** denote significance at 10%, 5% and 1%, respectively.

All models include department fixed effects. Model 2, 3, and 4 have an AR1 error term.

Models 3 and 4 include additional control variables.

All models have random coefficients on time trends.

Inputs, x, and outputs, y, are in logs and normalized by their corresponding median values.

Coefficients of terms with the input variable, x1, can be obtained by the linear homogeneity constraints (see footnote 6).

The regression results are generally plausible in the sense that the first-order output coefficients have a negative sign and the input coefficients are positive. The input coefficients can be interpreted as the corresponding input share in the distance function at the sample median. Considering model 2, for instance, the results indicate a total share of 24 percent for lecturers and assistants, a small share of 5.5 percent for administrative staff and about 8 percent for non-labor costs. Using the linear homogeneity condition the share of professors will amount to about 62 percent ($.62 = 1 - .1 - .14 - .06 - .08$) of resources.

The first-order output coefficients (table 3) are output elasticities at the sample median. Again, considering model 2 as an example, the output coefficients suggest an elasticity of nearly 0.3 for teaching output (coefficient of y_1) as opposed to an elasticity of only 0.08 for research outputs (sum of the coefficients of y_2 and y_3). This implies about three times higher cost elasticity for students compared to research activities. In particular, these numbers suggest that 10% increase in students would require 3 percent more resources whereas the same proportional increase in research will require only less than one percent overall increase in production factors. These results indicate the dominant weight of students as well as professors in the distance function.

The standard deviation of the trend components is significant across models with normally distributed error term, suggesting a considerable heterogeneity across departments. Model 2 shows a statistically significant autocorrelation coefficient, ρ, with a relatively high value of 0.8. This suggests that the half-life of an inefficiency shock (fall to half of initial inefficiency) is about 4 to 5 years and the entire course of learning process following a shock takes more than 10-15 years. The coefficient's confidence interval remains below one, implying that our estimates are not affected by potential non-stationarity (unit root). In the two following paragraphs we will discuss the development of the Malmquist indices and their decomposition based on models 1 and 2. Further discussion of the productivity results and their relationship with Bologna reform and openness based on models 3 and 4, will be presented in Section 6.

5.2 Malmquist Index and its components

Figure 2 displays the Malmquist productivity index and its components obtained from the model with autoregressive error term (model 2). The graph represents the median values[14] over all departments normalized to year 1995. The numerical values are also listed in table 4. Regarding the overall development of productivity depicted in figure 2, our results suggest a slightly increasing productivity until around 2002 followed by a fall in productivity. Overall, the model shows about

[14] We preferred median values over means because they were less affected by outlier estimates in a few departments.

5 to 6 percent decrease in productivity between 1995 and 2007, with the main effect appearing after 2002.

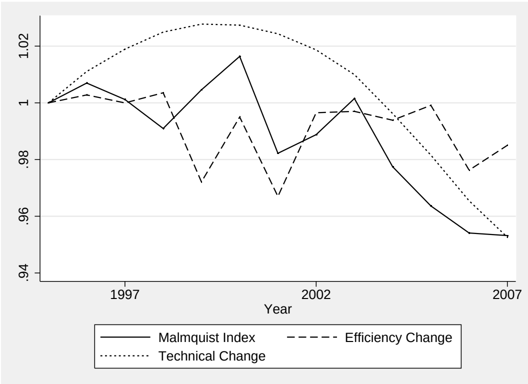


Fig. 2: *Malmquist productivity index and its components indexed to 1995 (based on median values)*

The results indicate a fairly significant technical progress of about 1% per year from 1995 to 2000, followed by a regress after 2000, with about the same rate. As for changes in technical efficiency (figure 2), the results suggest that inefficiency is not responsible for the decline in productivity within the sample period.

The details of numerical results by scientific field are listed in table 4. The corresponding Malmquist indices for each scientific field appear in the appendix in figure 4

Figure 4 in the appendix reveals substantial heterogeneity in the productivity development across scientific fields. None of the fields displays a clear positive trend. The engineering departments display a negative trend in the beginning followed by a relative recovery at the end. Humanities and science fields display a reverse pattern, i.e. some productivity growth in early years and a decline towards the end of the period. While productivity growth in engineering, humanities and science has been neutral, economics and business, medicine and law experienced negative productivity growth, most pronounced for medicine.

In the case of medical departments, part of the decline might be associated with the increasing resources used in university hospitals. However, due to the difficulties in separating educational and clinical resources (see, e.g., Kempkes and Pohl, 2010), this explanation should be considered with caution. Regarding other departments, the estimated productivity trends are not entirely consistent with the hypothesis about positive effects of globalization. Moreover, we do not see a systematic difference between fields that can be considered as location-specific with others that have fairly universal features. However, the hypothesis of information asymmetry and complexity could be considered as a possible explanation for productivity decline in disciplines such as economics and business, law, and to some extent humanities. If the increasing usage of formal models and quantitative analysis can be considered as a reflection of increasing complexity in these fields, part of the productivity decline might be explained by the system's reluctance in adjusting financial incentives. Another effect could be related to the increasing attention of certain faculty to non-academic but lucrative activities like private consulting. Such tendencies that are more pronounced in law and business, can provide some explanation as to the relatively strong decline in law schools and economics/business departments.[15]

As the numbers listed in table 4 suggest, in a majority of departments the efficiency component of productivity remain negligible at the end of the sample period. Two possible exceptions are medicine and economics/business. In these departments, technical efficiency can account for about a third of the productivity changes.

The results of technical change by scientific field (table 4) suggest an overall regress (inward shift) of the frontier, more or less similarly observed for most scientific fields. The only exception are humanities and science departments that have shown some progress. Regarding the trend components capturing the difference in developments of newly founded universities, table 3 displays a significant positive sign of the linear trend and a significant negative sign of the quadratic

[15] We are grateful to Milad Zarin for pointing out this phenomenon to us.

trend. These results imply that these universities have experienced a rapid progress at the outset but the pace has slowed over time.

We also analyzed the productivity development across different universities. However, because of the great variety among universities regarding size and department mix, we could not detect any conclusive evidence for significant productivity differences across universities. In general, the observed patterns may be equally well explained by differences in specialization. This is particularly the case for relatively small universities. For instance, the estimated trends appear to suggest a substantial productivity growth for the departments in universities of Lucerne and Lugano (the two newly founded universities) and a relatively steep decline in departments of the ETH Lausanne. But, all three universities consist of only a few departments belonging to diverse fields with presumably different productivity growths.[16] The university of Zurich shows the steepest decline in productivity among comparably large universities, whereas universities of Lausanne and Geneva, the two universities located at the country's borders, show a more or less constant productivity over the sample period. The ETH Zurich and the University of Berne are the only universities with positive productivity growth. Although these universities are all comparable in size, the size of different departments varies considerably among them. Overall, we contend that the differences in productivity growth could be associated to fields of specialization rather than differences among universities.

6 Openness and the Bologna Reform

In this section we discuss possible explanations for the productivity estimates reported in section 5. In particular we examine the impact of openness to foreign students and the Bologna reform. We measure openness by the share of enrolled foreign students. As shown in Figure 3 after a

[16] Moreover, the decomposition analysis indicates some discrepancy for the very same universities, namely, a substantial technical progress but a slight decline in technical efficiency for universities of Lugano and Lucerne. This can be explained by the small number of observations in these groups and the potential effect of outlier values.

Table 4: *Malmquist productivity index and its components based on fixed effects model with autoregressive efficiency term (Model 2)*

Unit	Index	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Total	M	1.007	1.001	0.991	1.005	1.016	0.982	0.989	1.002	0.977	0.964	0.954	0.953
Total	T	1.011	1.019	1.025	1.028	1.027	1.024	1.019	1.010	0.996	0.982	0.965	0.953
Total	TE	1.003	1.000	1.004	0.972	0.995	0.967	0.997	0.997	0.994	0.999	0.976	0.985
Humanities	M	1.017	1.015	1.020	1.027	1.058	0.999	1.055	1.052	1.075	1.035	0.985	0.977
Economics	M	1.004	1.000	0.911	0.892	0.912	0.841	0.983	0.979	0.935	0.918	0.868	0.858
Law	M	0.982	0.894	0.954	0.943	0.993	0.911	0.906	0.911	0.885	0.899	0.876	0.876
Science	M	1.065	1.021	1.084	1.059	1.044	1.034	1.057	1.042	1.059	1.061	1.048	1.037
Medicine	M	0.991	1.061	1.032	0.927	0.952	0.963	1.026	1.008	0.850	0.857	0.858	0.871
Engineering	M	0.960	0.919	0.927	0.896	0.902	0.945	0.976	0.928	0.920	0.928	0.902	0.983
Humanities	T	1.011	1.019	1.025	1.028	1.028	1.026	1.020	1.011	1.001	0.987	0.971	0.953
Economics	T	1.006	1.008	1.009	1.007	1.002	0.994	0.983	0.970	0.955	0.937	0.917	0.894
Law	T	0.986	0.973	0.961	0.950	0.940	0.930	0.921	0.913	0.906	0.900	0.894	0.889
Science	T	1.023	1.043	1.060	1.072	1.081	1.086	1.086	1.082	1.075	1.063	1.048	1.028
Medicine	T	1.012	1.021	1.027	1.029	1.027	1.021	1.013	1.000	0.979	0.960	0.937	0.912
Engineering	T	0.965	0.939	0.918	0.903	0.894	0.890	0.891	0.898	0.910	0.928	0.952	0.983
Humanities	TE	1.006	1.000	0.999	0.982	1.008	0.967	1.010	1.005	1.075	1.037	0.999	1.007
Economics	TE	0.998	1.000	0.904	0.888	0.919	0.848	0.994	1.010	0.977	0.983	0.947	0.962
Law	TE	0.998	0.919	0.987	1.000	1.046	0.968	0.971	0.997	0.977	1.003	1.002	0.985
Science	TE	1.041	0.979	1.023	0.988	0.969	0.950	0.956	0.964	0.982	0.999	1.005	1.007
Medicine	TE	0.976	1.032	1.004	0.909	0.924	0.935	1.010	1.000	0.873	0.902	0.918	0.955
Engineering	TE	0.993	0.982	1.014	0.994	1.009	1.045	1.073	1.000	1.009	1.012	0.963	0.953

The table displays indices for technical change (T), efficiency change (TE) and Malmquist (M) indices.
The numbers listed in the table are the median values of individual estimates.
The 1995 values are set equal to 1.

stagnation period before 2002, the share of foreign students has consideraby grown from about 20 percent to 25 percent within five years. This pattern is consistent with a main objective of the Bologna reform, namely students mobility. Figure 3 also displays two measures of the degree of implementation of the Bologna reform. The first measure, *Bologna 1*, is the share of old-regime degrees (Licentiate), defined as the number of granted Licentiates divided by total granted non-doctoral degrees (Licentiates, Bachelors and Masters). The second measure, *Bologna 2*, is a Herfindahl index defined as the sum of square shares of the three groups of degrees. In a given department, the first is a measure of the reform's penetration, whereas the second is a proxy for the diversity of degrees.

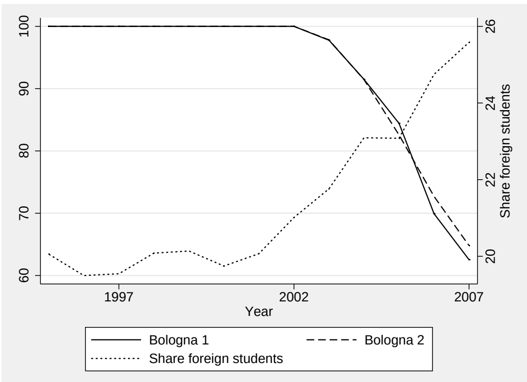


Fig. 3: *Overall trends of openness and the penetration of the Bologna reform*

As the reform takes effect, the two Bologna measures decrease at a similar rate on average, but showing different patterns of development among various departments. Figure 3 shows that after the first graduations according to the new system in 2003, the share of Licentiate degrees has a steep decrease. Approaching the 2010 deadline for the complete implementation of the reform, one expects to observe a small share of old-regime degrees. However, as shown in figure 3, with an average share of above 60 percent, the old-regime degrees are still a majority in 2007. This is partly because of the slow implementation but also due to the offered option to new students (until late into the reform) to choose between the old and new regimes. This flexibility combined with gradual changes in the courses offered in Licentiate programs required the simultaneous organization and functioning of at least several transitional systems.

Considering the additional labor resources to implement these systems, one can expect a negative effect on productivity namely, a positive effect for Bologna variables in the distance function.[17] As for the share of foreign students, our proxy for openness, we expected a positive association with productivity hence a positive coefficient in the distance function. However, the fixed-effect regressions (models 3 and 4 in table 3) indicate statistically insignificant effects for Bologna variables as well as the openness factor. It should be noted however, that the potential impact of these variables might have been suppressed by the rich structure of the time trends in our model. In fact, additional analyses with alternative specifications, indicate that the sign and significance of the two Bologna variables could be sensitive to the specification of random trends. In particular, models without random trends showed significant and positive effects for the Bologna variables. More importantly, the pattern of development of Bologna variables in figure 3 shows a striking similarity with the productivity decline depicted in figure 2, suggesting the implementation burden of Bologna reforms as a responsible for the estimated decline in productivity.

[17] A positive sign implies that a decrease in the Bologna variable has a negative impact on productivity.

Finally, it is important to note that a comparison of the graphs in figures 1 to 4 indicate a recurring pattern of remarkable change of trends at about year 2002. That year indicates a decreasing rate of productivity combined with an increasing rate of growth in research grants and intermediary scientific staff (lecturers) as well as share of students coming from abroad. Could this be due to an increasing competition for foreign students, to a paradigm shift from conventional teaching universities toward research universities with major external funds, or both? In fact, the last decade's policy developments in Swiss universities can be characterized by encouraging competition for international students and putting emphasis on research. Our analysis of productivity suggests that these changes are more likely associated with a decline in productivity than technical progress. This is a plausible result that can be explained by the fact that public universities with rigid governance and cumbersome administrative rules are slow in adapting themselves with their new roles. Moreover, the strong heterogeneity among different fields suggest that the new expectations might require different responses in various fields. In particular, this paper's results suggest that specific fields such as economics/business and law might need different strategies to cope with the changes. The administration of a university as a single public entity rather than relatively independent schools does not allow much room for flexibility and independent actions among various fields.

7 Conclusions

We proposed a panel data model to estimate Malmquist productivity index in the presence of strong unobserved heterogeneity. Similar to previous studies by Fuentes et al. (2001) and Atkinson et al. (2003), we use a parametric distance function that combines the benefits of a parametric methodology in panel data with the intuitive advantages of the Malmquist index as a discrete measure of productivity. The proposed model uses observation-specific intercepts and random coefficients to account for unobserved heterogeneity among production units in time-invariant factors as well as in productivity growth. The productivity measures vary not only by observed quantities but by idiosyncratic factors specific to individual production units. The presence of individual intercepts decreases the potentially important biases due to unobserved factors. Such factors are especially important in applications such as universities where the quality aspects are complex and difficult to measure. We also developed a decomposition approach that uses the dynamic structure of inefficiency shocks and their dissipation to separate efficiency changes from technical progress. The process of adaptation and learning are captured by an autoregressive stochastic term.

We applied the model to a panel data set from one-hundred Swiss university departments to analyze the dynamics of productivity from 1995 to 2007. The analysis is based on department-level data with specific outputs namely students and external funds. We assumed that the temporal variations in other outputs like faculty's publication record and quality of research output are reflected in the departments' success or failure in attracting external funds. The results point to a negative trend in productivity, particularly after year 2000, with an average productivity decline of about one percent per year. A major part of this decline coincides with the recent developments in Switzerland's higher education system following the adoption of the Bologna Accords. Moreover, the estimated decline corresponds to a pattern of growth in external funds, intermediary research staff, but also in the share of international students, all starting more or less in the same period.

Our decomposition analysis suggests that the observed productivity decline could be contributed to technical regress rather than to a rising inefficiency. We analyzed the heterogeneity in the estimated trends across scientific fields and universities. The results while pointing to substantial differences across scientific fields, do not favor considerable differences across universities. This pattern suggests that the sources of productivity lag are probably related to specific developments in each field rather than managerial differences among universities. In particular, humanities, science and engineering departments indicate a neutral productivity growth, while departments of economics/business, law and medicine show the lowest performance.

Given the complexity of the production process at universities, this study faces a number of limitations. First, the measures of inputs and outputs are imperfect. Concretely, we use measures of intermediate outputs to approximate final outputs. Furthermore, our input measures as well as our measure of educational output lack information about quality. Finally, our measure of capital input contains measurement error due to inconsistent accounting practices across universities and lack about information about capital prices. Secondly, we assume that technical change is neutral and that productivity changes and production factors are separable. For this reason, we refrain from analyzing economies of scale in this paper. Thirdly,

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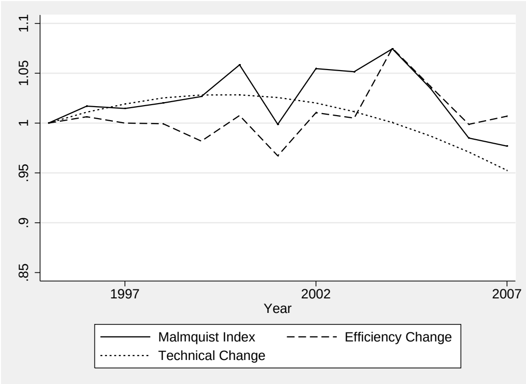
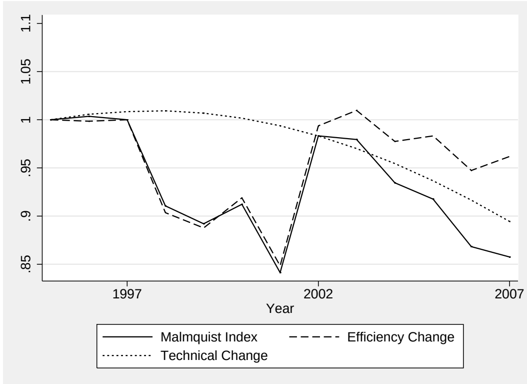
Appendix



(a) Humanities



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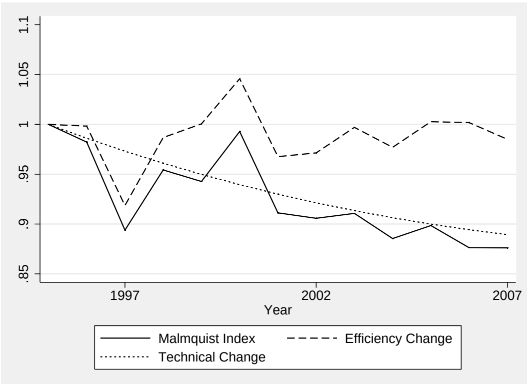
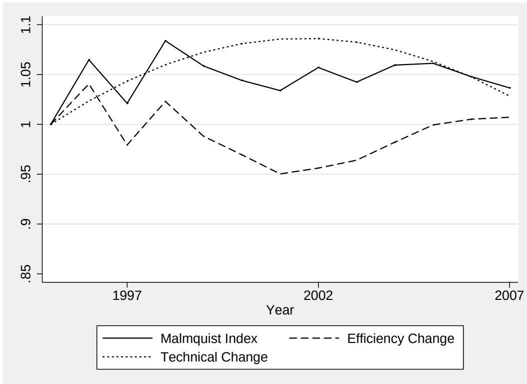


(c) Law



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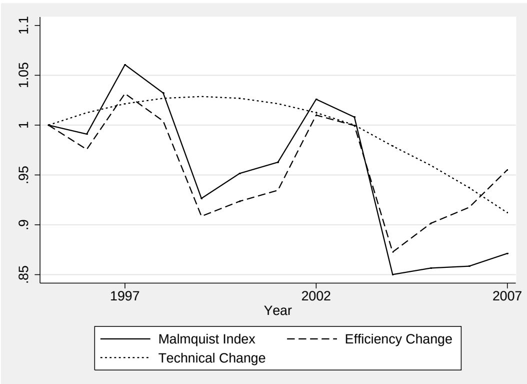
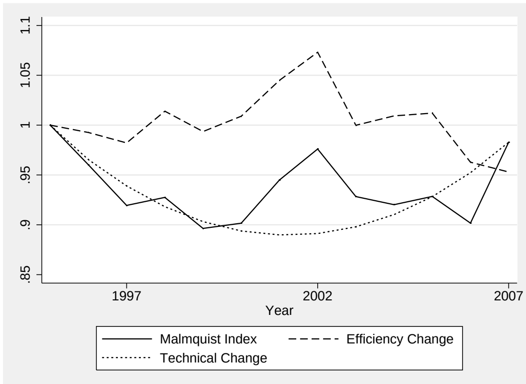


(e) Medicine



(f) Engineering

Fig. 4: *Malmquist productivity indices and its components for each field separately indexed to 1995 (based on median values)*