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EFFICIENCY OF FINNISH UPPER SECONDARY SCHOOLS: AN APPLICATION OF STOCHASTIC FRONTIER ANALYSIS WITH PANEL DATA

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Abstract: In this study the efficiency of Finnish upper secondary schools is evaluated with stochastic frontier analysis. Different stochastic frontier models for panel data are used to estimate education production functions. The results in matriculation examination are explained with comprehensive school grade point average, parents' socioeconomic background, resources, length of studies and decentralization of test taking on matriculation examination. Controls for schools with specialized curriculum are also included. The heterogeneity across schools is allowed by estimating both true random and true fixed effects models. The results show that the effect of teaching resources on examination results is even negative when the heterogeneity across schools is taken into account. Length of studies and decentralization of test taking affected negatively on student achievement. The inefficiency and the rankings of schools based on inefficiency score varied quite considerably depending on the type of stochastic frontier model. The lowest estimates for inefficiency were obtained with true random and true fixed effects models that separate time constant random or fixed effects from inefficiency.

Key words: Efficiency, stochastic frontier analysis, secondary schools

Tiivistelmä: Tutkimuksessa tarkasteltiin lukioiden tehokkuutta estimoimalla erilaisia tuotantofunktioita stokastisella rintama-analyysilla käyttäen paneeli-aineistoa. Ylioppilaskirjoitusten pakollisten aineiden puoltoäänten määrää selitettiin peruskoulun päättötodistuksen keskiarvolla, vanhempien sosio-ekonomisella taustalla, resursseilla, opiskelun kestolla ja ylioppilastutkinnon hajauttamisella. Erikoislukiot otettiin huomioon malleissa omilla muuttujillaan. Koulujen välinen ajassa pysyvä heterogeenisuus kontrolloitiin estimoimalla varsinaisia satunnaisten ja kiinteiden vaikutusten malleja. Tulosten mukaan resurssien vaikutus on jopa negatiivinen kun malleissa otetaan huomioon koulujen välinen heterogeenisuus. Opiskelun kestolla ja ylioppilastutkinnon hajauttamisella oli negatiivinen vaikutus suoritustasoon. Tehottomuus ja koulujen tehottomuuden mukainen järjestys vaihteli melko paljon stokastisesta rintamamallista riippuen. Keskimääräinen tehottomuus oli alhaisinta varsinaisten satunnaisten ja kiinteiden vaikutusten malleissa, jotka ottivat huomioon koulujen välisen ajassa pysyvän heterogeenisuuden.

Asiasanat: Tehokkuus, stokastinen rintama-analyysi, lukiot

Contents

1. Introduction

In industrialized countries the importance of high quality education as a source of well-being and economic growth is widely recognized. In most of these countries, education is publicly provided. Rising educational expenditures is another common feature for them. Because of aging population and increased global competition governments are facing additional pressures in financing. Education along with other sectors is thus competing from the resources to an increasing extent. In such a situation, enhancing the productivity and efficiency of the schooling system and schools is one way to maintain or even improve the provision of good quality education. The importance of the topic has also been widely recognized within OECD and EU (see e.g. Gonand *et al.*, 2007, Sutherland *et al.*, 2007 and Wössmann and Schütz, 2006).

In economics, efficiency is defined as unit's ratio of outputs to inputs to maximum feasible set of outputs to inputs. Measurement of efficiency in education is by no means straightforward. There are several features that make it controversial or at least complicated. Since education is often publicly funded information on input and output prices is usually missing. In some cases, there is no clear consensus (at least amongst the practitioners) on what the 'real' outputs are and how they should be measured. The same applies also to schooling inputs. Even if the understanding is reached, the process involves several inputs and outputs. In addition, some of the inputs are not controllable by schooling institutions even though their influence on outputs is evident. Despite the difficulties, there is plenty of research on educational production functions.[1]

Several methodological approaches have been used to overcome problems in educational efficiency measurement. They all have their advantages and shortcomings. The early studies of educational production function mostly used least-squares regression techniques. From the 1980's the use of non-stochastic Data Envelopment Analysis (DEA) has become quite common. The wide use of DEA in this context is mostly due to its flexibility. DEA easily allows the use of several inputs and outputs and no information on prices is needed. In addition, as it is a linear optimization technique no assumption about the exact functional form is required.

As a linear programming method, DEA does not allow statistical interference. In addition, being a deterministic approach, it does not distinguish statistical noise from inefficiency. As a consequence, inefficiency may be overestimated. For policy purposes, both of these factors may cause problems and uncertainty. In stochastic frontier analysis (SFA), these shortcomings are avoided and for this reason it is an interesting alternative to DEA. In addition to information on

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[1] See for reviews e.g. Hanushek (2003), Krueger (2003) and Worthington (2001).

efficiency differences, the information on estimated parameters i.e. the effect of quantitative inputs (such as class size, teachers' salaries, education and experience and environmental variables) on output is obtained.

Studies using SFA are in minority compared to applications of DEA[2] in the context of measuring the efficiency of schooling institutions. Most of these studies are using cross section data. Some studies compare the results of SFA and DEA (Sengupta and Sfeir, 1986 and Mizala *et al.*, 2002). Others concentrate on inefficiency differences and testing the relationship between test scores and spending in instruction (Deller and Rudnicki, 1993) or teachers' merit pay (Cooper and Cohn, 1997). Heshmati and Kumbhakar (1997) used a more sophisticated model introduced by Battese and Coelli (1995) which assumes that inefficiency has a truncated-normal distribution and is dependent on some e.g. environmental factors.

Only few studies make use of panel data. Barrow (1991) studied the efficiency of local education authorities using both cross-section and panel data with stochastic and deterministic methods. Johnes and Johnes (2005) analysed the cost efficiency of British universities using SFA allowing heterogeneity between universities with random parameters i.e. using true random effects model introduced by Greene (2005a, b). In this study, the efficiency of Finnish upper secondary schools is studied using different stochastic frontier models. A five year panel data is used for estimating educational production functions. School level differences in matriculation examination grades are explained with students' prior achievement, family background characteristics, and school resources, school size and some environmental factors. Both teaching expenditures per student and student-teacher ratio (with a smaller sample) are tested as measures of teaching resources.

Educational production function studies, such as this, using register data often suffer from two weaknesses. Variables measuring the school resources such as student-teacher ratio may produce biased results because of non-random sorting of students between schools and within schools between teaching groups. Another source of bias is produced by the omitted variables (see e.g. Averett and McLennan, 2004). Best way to overcome the non-random sorting of students between schools is to use randomized experiments (see e.g. Krueger, 1999). Other methods include quasi-experimental designs and instrumental variables approach (see e.g. Hoxby, 2000; Angrist and Lavy, 1997; Akerhielm, 1995; Goldhaber and Brewer, 1997). In the context of efficiency measurement, some of these techniques are, however, inappropriate and some are difficult to carry out.

The new variants of stochastic frontier models are able to take into account the bias caused by omitted variables and non-random assignment of students to

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[2] See for reviews e.g. Worthington (2001) and Johnes (2004).

schools. As the traditional random and fixed effects stochastic frontier models interpret all unobserved random or fixed effect as inefficiency (Pitt and Lee, 1981 and Cornwell *et al*., 1990), new true random and true fixed effects models (Greene, 2005a, b) allow the decomposition of inefficiency term into time-constant random or fixed effect and time varying inefficiency. Therefore, the unobserved time-constant school-specific factors are controlled by the fixed effects and separated from inefficiency.

In Finnish upper secondary schools students are not randomly assigned to different schools since students are admitted based on their comprehensive school Grade Point Average (GPA). The number of upper secondary schools varies from no school in small municipalities to tens of schools in larger cities. Competition to best schools is hard especially in larger cities. Students and parents choose the school based on school's curriculum (some of the schools have a specialized curriculum) and course offerings. Since larger schools are able to offer more extensive selection of courses they may attract better performing students. In this study, comprehensive school GPA is used for controlling the non-random assignment of students into schools. In addition, true fixed effects models are estimated with a five year panel. Fixed effects also capture the selection bias to the extent it is time-constant and not captured by the GPA. Bias caused by omitted variables can also be controlled by the true random effects models and they are also tested in this study.

In 1996 two different reforms took place in Finnish upper secondary schools. First, the grade system with fixed classes was abolished. Since then students were able to formulate their individual study plans and determine their own pace of learning. They were able to complete the school in 2 to 4 years. Before that students followed year classes and usually completed their studies in three years. As a consequence of the reform, the share of students using more the three years for their studies rapidly increased to over 10 per cent. In this study, it is possible to test whether the length of studies affects performance in matriculation examination.

Along with the individual study plans, the matriculation examination was also somewhat renewed so that students were able to take the tests in three consecutive examination periods. Before that, all the tests had to be taken during one examination period. As a result, students have during recent years increasingly 'decentralized' their test taking so that on average, students participate in two test taking periods. In this paper, the effect of 'decentralization'' of test taking on matriculation examination is also tested.

The paper continues as follows. In section 2 the Finnish upper secondary school system is described. The models and estimation methods are discussed in section 3. In section 4, data and variables used in the study are described. Section 5 presents the estimation results and section 6 concludes.

2.   Finnish upper secondary schooling

Finnish upper secondary schools provide a post-comprehensive education for students aged 16 to 19. The upper secondary school certificate together with the matriculation examination certificate provides eligibility for the university or tertiary level vocational education. Studies in upper secondary schools can be completed in 2–4 years. Most of the students complete the upper secondary schooling in three years. For approximately 20 percent of students it takes three to four years to complete the studies.

There are no year classes and upper secondary schools are in other words non-graded. Studies have been divided into courses. The school year is usually divided into five or six periods. A schedule is devised for each period, focusing on certain subjects. The students' progress and the composition of teaching groups thus depend on the students' choice of courses.

Upper secondary schooling concludes with a matriculation examination which is a compulsory nationwide test. The purpose of the examination is to discover whether students have assimilated the knowledge and skills required by the curriculum for the upper secondary school. The examination is arranged in upper secondary schools around the country. The Matriculation Examination Board is responsible for administering the examination, for preparing the tests and for the final assessment of the answer papers[3]. The results of each individual test are normalized to be comparable each year.

Matriculation examinations are arranged in autumn and in spring during a two-week examination period. Students can take individual tests in three consecutive examination periods. The examination consists of at least four tests; one of them, the Test in the candidate's Mother Tongue, is compulsory for all candidates. The candidate then chooses three other compulsory tests from among the following four tests: the Test in the Second Domestic Language, a Foreign Language Test, the Mathematics Test, and the General Studies Test. The candidate may include, in addition, as part of his or her examination, one or more optional tests (Foreign Language Test, Mathematics Test or General Studies Test).

As mentioned earlier, the admission to upper secondary schools is selective based on the Grade Point Average (GPA) in the comprehensive school. The application takes place through a national joint application procedure. Some 60 percent of the age cohort continues their studies at the upper secondary schools each year. The competition to best upper secondary schools is hard especially in big cities. Therefore, the average GPA of the students varies considerably across schools.

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[3] The preliminary assessment takes place by the teachers in each school.

Upper secondary schools are mostly maintained by the municipalities. In addition, there are some private schools, schools maintained by the joint organization of municipalities and some state owned schools. There are no school fees in municipal upper secondary schools. Municipalities cover school expenditure from their general revenue services which consist of local income tax, property tax and non-earmarked grants. Private schools get a state grant per student basis, and they also get funding from municipalities. Private schools may have minor fees.

3.   Models and estimation methods

Stochastic production frontier models were first introduced by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977). In these models, variation unexplained by the input variables is not completely interpreted as technical inefficiency but statistical noise and technical inefficiency are separated. In addition, as parametric statistical models, they also provide information on the effect of inputs on output.

In the following, it is assumed that schools *I* are maximizing their production of output and using *N* inputs to produce a single output. In addition, a cross-sectional data is assumed. A stochastic production frontier model can be written as

$$y_i = f(x_i; \beta) \exp\{v_i\} TE_i .$$

(1)

where $\left[f(x_i; \beta) \exp\{v_i\} \right]$ is the stochastic production frontier, y_i is a scalar output produced by school *I*, *i=1,…,I*, x_i is a vector of *N* inputs by school *I*, $f(x_i; \beta)$ is the production frontier and β is a vector of technology parameters to be estimated. The stochastic frontier consists of two parts: deterministic part $f(x_i; \beta)$, that is common to all schools and the school specific random part $\exp\{v_i\}$ which captures the effect of random shocks on each school. TE_i is the output oriented technical efficiency of school *i*. The equation (1) can be written as

$$TE_i = \frac{y_i}{f(x_i; \beta) \exp\{v_i\}} .$$

(2)

It defines technical efficiency as the ratio of observed output to maximum feasible output. Now y_i achieves its maximum feasible value of $\left[f(x_i; \beta) \exp\{v_i\} \right]$ if, and only if $TE_i=1$. Otherwise $TE_i<1$ provides a measure of shortfall of observed output to maximum feasible output in an environment characterized as $\exp\{v_i\}$, which is allowed to vary across schools.

Next, if we assume that $f(x_i; \beta)$ takes the usual log-linear Cobb-Douglas form the basic cross-section model in (1) is written as

$$\ln y_i = \beta_0 + \sum_n \beta_n \ln x_{ni} + v_i - u_i ,$$

(3)

where y_i depicts the output of school *i*, β's are parameters to be estimated, x_{ni} are the explanatory variables, v_i is the idiosyncratic error term distributed independently of u_i and as iid N(0, σ_v^2). And u_i is the nonnegative inefficiency

term for school i distributed as iid $N^+(0, \sigma_u^2)$. The error terms in (3) form the composed error term $e_i = v_i - u_i$ that is asymmetric since $u_i \geq 0$.

The error term e_i is positively skewed if $u_i \geq 0$. If $u_i=0$, then $e_i=v_i$, the error term is symmetric and there is no inefficiency in the data. In such case equation (3) can be estimated with ordinary least squares without inefficiency. Before proceeding the skewness of inefficiency term must be tested. Coelli (1995) has introduced one alternative but there are also other tests (see e.g. Kumbhakar & Lovell, 2000).

In case of inefficiency in the error term, a distributional assumption for it has to be made. The assumption of half-normal distribution is the most common one. Other possibilities are exponential, truncated-normal and gamma distributions. The selection of distribution is aided with some statistical tests (see Kumbhakar & Lovell, 2000). Sample means of inefficiencies may be sensitive to the distribution assumption whereas the rankings and top and bottom efficiency scores deciles are more likely to stay unaffected by it (Kumbhakar and Lovell, 2000 p. 90).

In this study, a one-sided likelihood ratio test introduced by Coelli (1995) is used to test the presence of half-normal distribution for inefficiency term. The test is based on λ coefficient which provides the relative contributions of u_i and v_i to e_i. One tests the hypothesis that $\lambda=\sigma_u/\sigma_v=0$. As $\lambda\to0$ the symmetric error component dominates the one-sided error component in the determination of e_i. In case $\lambda=0$, there is no technical inefficiency and the model returns to OLS.

The presence of truncated normal distribution, ($u_i\sim$iid, $N^+(\mu,\sigma_u^2)$) is tested using the assumption of H_0: $\mu=0$. If $\mu=0$ the density function returns to normal density function.

Next, the use of panel data is assumed. In basic pooled panel data model, the only difference is that the time dimension is added to the equation (3).

$$\ln y_{it} = \beta_0 + \sum_n \beta_n \ln x_{nit} + v_{it} - u_{it} \,, \tag{4}$$

where y_{it} is the output in period t, β's are parameters to be estimated, x_{nit} are the explanatory variables at period t, v_{it} is the idiosyncratic error term for each period t and u_{it} are the inefficiency terms for each school in each period.

In random effects models (Pitt & Lee, 1981) both between schools and within school variation is taken into account. The model assumes that the inefficiency term for each school is invariant through time and it is not dependent on other regressors. The estimated model becomes the following

$$\ln y_{it} = \beta_0 + \sum_n \beta_n \ln x_{nit} + v_{it} - u_i, \tag{5}$$

The weakness of model (5) is the assumption of inefficiency being constant through time. Especially in longer panels it is more likely that inefficiency varies through time. In true random and true fixed effects models more heterogeneity is allowed by dividing the school specific inefficiency term into unmeasured heterogeneity that is constant through time and into inefficiency that varies through time. The true random effects model is as follows

$$\ln y_{it} = \beta_i + \sum_n \beta_n \ln x_{nit} + v_{it} - u_{it}, \tag{6}$$

where β_i is a school specific random term defined as $\beta_i = \beta + w_i$ and in which w_i is distributed as iid $N(0, \sigma_w^2)$, v_{it} is the school specific random term and u_{it} is the inefficiency that varies through time.

If the familiar fixed effects model is used in efficiency measurement the school specific fixed effect that is constant through time is interpreted as inefficiency. The model is not in fact stochastic but "deterministic". The u_i of the most efficient unit equals zero. Thus the model is not measuring absolute inefficiency but inefficiency of school i relative to the other schools in the sample. The advantage of this model is that it is distribution free. But because it interprets the whole fixed effect as inefficiency it most likely overestimates the inefficiency. The fixed effects model by Cornwell *et al.* (1990) can be written as

$$\ln y_{it} = \beta_i + \sum_n \beta_n \ln x_{nit} + v_{it}$$

$$= \max(\beta_i) + \sum_n \beta_n \ln x_{nit} + v_{it} + \left[\beta_i - \max(\beta_i)\right] \tag{7}$$

$$= \beta_0 + \sum_n \beta_n \ln x_{nit} + v_{it} - u_i,$$

where $u_i = \max(\beta_i) - \beta_i > 0$.

In true fixed effects model the fixed effects and inefficiency effects are separate. The model allows for time varying inefficiency and takes into account the omitted variable bias. The model is written as

$$\ln y_{it} = \beta_i + \sum_n \beta_n \ln x_{nit} + v_{it} - u_{it}. \tag{8}$$

Heteroskedasticity is potentially a problem in stochastic frontier models (see e.g. Kumbhakar and Lovell, 2000). In cross-section models, it can appear in either of the error terms, and affect interferences concerning the production technology parameters and the error components. Thus, it can also have effects on the inefficiency estimates. If heteroskedasticity appears in the inefficiency term, the problem is more severe since both the estimates of production technology and inefficiency are biased. If v_i is heteroskedastic, only the inefficiency estimates are affected. If both error terms are heteroskedastic, the effect is not clear since the unmodeled heteroskedasticity causes biases in opposite directions. In such case, the overall bias can be small.

In random and fixed effects panel data models, only v_{it} can be heteroskedastic and even if it is ignored it does not cause serious problems for the results. In case of time varying inefficiency, heteroskedasticity may only appear in v_{it} in random effects model. In such a model, a time effect for the u_{it} is assumed and there are several alternatives to model it (see e.g. Cornwell *et al.*, 1990; Lee and Schmidt, 1993; Kumbhakar, 1990 and Battese and Coelli, 1992).

There are also other alternatives to model the heterogeneity in inefficiency term. Examples, such as the ones given by Battese and Coelli (1995) and Coelli *et al.* (1999) express u_{it} as a parametric function of some explanatory variables z_{it} that characterize e.g. the environment or the organization of the producer. In this study, no such variables are available. Thus, throughout the paper it is assumed that all explanatory variables depend directly on the dependent variable rather than inefficiency.

4. Data and descriptive statistics

This paper studies the efficiency of Finnish upper secondary schools using a school level panel data from years 2000–2004. Data includes most of the Finnish upper secondary schools. Some language schools that are not attending Finnish Matriculation Examination were excluded from the data. Also schools providing upper secondary education for adults were dropped out since their curriculum differs from that of youths. Some schools were also dropped because of data problems. The data is unbalanced consisting of 436 schools and the number of schools varies from 424 to 427 depending on the year.

The data was constructed from several different official registers. Matriculation examination grades and information on test taking as well as graduates' mother tongue and sex were obtained from the Matriculation Examination register. National joint application register provided the information on the Grade Point Average of comprehensive school report (GPA). Information on students' socio-economic status, length of studies, and size, location and type of owner of the school was obtained from Statistics Finland. Information on expenditure is obtained from the VALOS-register maintained by the Finnish National Board of Education.

School output is measured by *compulsory grades in matriculation examination*. As mentioned earlier, there are four compulsory exams in matriculation examination. The scores in each exam range from improbatur (failed) to laudatur (excellent) and they are converted to a scale from 0 to 7. The maximum score in compulsory subjects is therefore 24. In addition to compulsory subjects, students can take optional exams and they usually take one or two of them.[4] As an alternative output measure *all grades on matriculation examination* is also tested. This measure includes grades in both compulsory and optional subjects.

The average grade in compulsory subjects was 16.7 but there was a quite large variation across schools. In the top schools students performed on average 23.4 grades whereas at the bottom students had 10.7 grades on average. In all subjects the variation is even larger ranging from 11.3 to 34.7.

Students' prior attainment is controlled with the comprehensive school Grade Point Average (GPA). These grades are given by teachers. They are the best information available at the moment since students are not tested nationally at the end of comprehensive school. Information on GPA was linked at the student level before averaging it to the school level.

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[4] The average number of tests taken was during the research period 5.1.

Students' socio-economic status is measured with three different variables: E*ducation level of parents*, *share of white-collar workers*, and *share of single parents*. Also this information was linked to matriculation examination results at the student level before averaging it to the school level. Education level of the parents is an index by Statistics Finland that is based on years of schooling. Other controls for the students of each school include the s*hares of female* and *Swedish speaking students*. The latter one is included because the matriculation examination is quite language oriented. Swedish speaking students are usually fluent in Finnish (test that is compulsory for them). Therefore, they may be able to concentrate more in other foreign languages or other subjects and score higher in matriculation examination.

Heterogeneity of the student body may affect instruction and instructional methods. Some teachers often claim that it's difficult to adjust teaching methods if the skills of the students are very heterogeneous. This variable tests if it has some effect on student performance. Heterogeneity of the student body is measured with the standard deviation of grades in compulsory subjects in matriculation examination.

School resources are measured with two variables: *teaching expenditures per student and other current expenditures per student*. The effect of *average student teacher ratio* is also tested. Teaching expenditure consists of teachers' and principals' salaries, teaching materials and other costs that can be directly attributed to teaching. They contribute some 75 per cent of the total expenditures. Other expenditures consist of costs on meals, health care and counselling, administration, and rents (pure or calculatory) for the school properties. The expenditure information is averaged over the three years that students usually enrol upper secondary school. The costs are deflated to the year 2003 prices using the price index for public spending in education. The expenditures have risen partly because there was a reform in the pension insurance system that was implemented gradually since 1998. In order to take the effect of reform into account, the expenditures are deflated with chained deflator. The base year in the first deflator was 1995 and in the latter one 2000. Regional differences in expenditure information (mainly salaries and rents on property) are not taken into account.

There are quite considerable differences in teaching expenditures per pupil across schools. In 2000 the average teaching expenditure was some 3 300 euros. It varied, however, between 1 800 and 13 000 euros. In 2004 the average teaching expenditures per student were some 3 700 euros. The differences had somewhat diminished since the expenditures varied between 2 200 and 9 200 euros.

The VALOS-register provides the expenditure information at the level of service provider. In case the service provider (usually municipality) maintains more than one upper secondary school the information cannot be attributed to individual

schools. In most of the cases the service provider maintains only one upper secondary school. Larger cities and some bilingual areas are an exception. In the data there is school level expenditure information for 254–259 (depending on the year) schools and for 168–172 schools there is a municipality level average.[5]

The average student-teacher ratio is only obtained for the municipal upper secondary schools. The models including this variable are therefore estimated with a smaller data containing 343–369 schools depending on the year. This information is obtained at the school level. Thus it is a more accurate measure than the teaching expenditures per student. The number of teachers and principals are in full time equivalents. Due to absence of data the variable is averaged over two years instead of three years.

The upper secondary school can be completed in two to four years depending on the study plan of the student. For some 80 per cent of students the studies take three years. Longer *length of studies* may require more resources but it's not clear how it affects student achievement since students may either study more or they can use their time to other activities such as working. In 2004 the average length of studies was 3.1 years and it varied between 3 to 3.8 years. The length of studies is a school level average and it is obtained from the information about the number of students completing their studies. These figures are reported in half year accuracy.

The tests in matriculation examination can be taken in three consecutive examination periods. On average, students participate in 1.8 examination periods but this ratio has steadily increased. The advantage of taking tests in more than one examination period is that student can better concentrate for each test. It hasn't been, however, tested whether this is really the case and if the decentralization of test taking affects the results. The average decentralization of tests is calculated from individual level information on the number of times the graduate participated in examination periods.

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[5] To obtain school level expenditure information Government Institute for Economic Research (VATT) also made an own survey for those municipalities that had more than one upper secondary school. There were 53–54 such municipalities in the data. In the survey, municipalities were asked to report their school level expenditures and teaching hours as they are reported in VALOS-register. This information was obtained from 23 municipalities maintaining 70 upper secondary schools. Three biggest cities namely Helsinki, Espoo and Vantaa didn't submit the information. Based on information reported by the municipalities a percentage share of the total teaching and other expenditures were calculated for each school. Using this percentage share the expenditures in VALOS-register were divided for each school. For those schools that didn't report school level information the expenditures were divided using the share of number of students from the total number of students in the municipality. Models were also estimated using this expenditure information but it didn't affect the parameter or inefficiency estimates. The results didn't change either, when the models were estimated using the expenditure information of VALOS-register and leaving out the schools in Helsinki, Espoo and Vantaa. For this reason, in this paper, only the expenditure information of VALOS-register is used with a municipal level average for schools in municipalities with more than one upper secondary school.
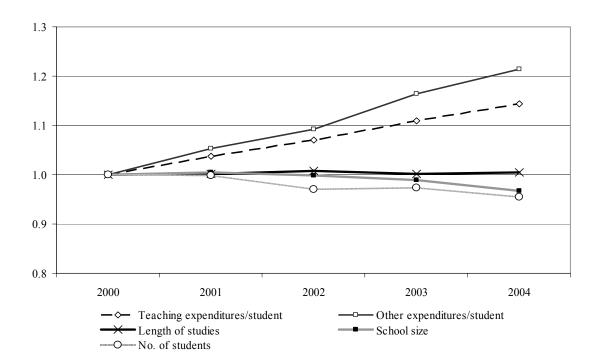
Some 13 percent of the upper secondary schools have a specialized curriculum. In these schools students can specialize in music, arts, sports, languages, natural sciences or mathematics. It is evident that specialization may have some effect on student performance. Students specializing in e.g. languages may have some advantage over other students because languages have quite large emphasis in matriculation examination. Separate dummies are used for schools having specialized curriculum in *sports*, *languages*, *mathematics and science*, and *music and arts*. It must be, however, noted that most of the schools having specialized curriculum also have the general track. Unfortunately it was not possible to separate the proportion of students following the general track from those following the specialized track.

The *average size of upper secondary schools* is quite small, some 260 students. And the smallest schools have only some 30 to 40 students and largest some 850 students. Most of the schools are maintained by the municipalities. Only some two per cent of the schools are *private* and one per cent *state maintained* schools. The latter ones serve as training schools for new teachers. As for the *location of the school*, about half of the schools are located in *urban* areas and one third in *rural* areas. The summary statistics are reported in Appendix 1.
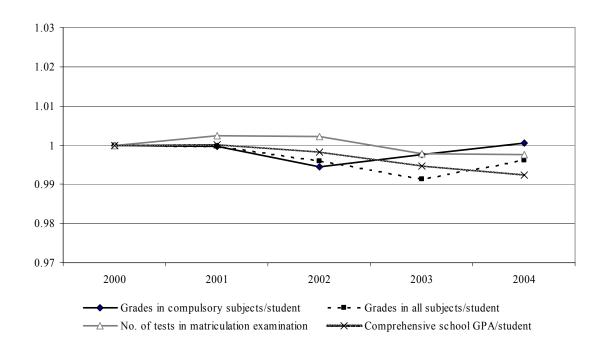
There are clear trends in some of the input variables (Figure 1). Expenditures in upper secondary schools have risen quite fast during the period. Teaching expenditures per student increased 14 per cent and other expenditures per student 21 per cent in five years. At the same time the average school size has gone down some five percent. This is mainly because the number of students has decreased especially in the rural areas.

Figure 1   *Trends in some input variables in 2000–2004*

There is no trend in matriculation examination grades per student (see Figure 2). This is because the scores are standardized to yield the same distribution every year. But even if the scores are standardized at the national level, the performance of single schools can vary much from year to year. The number of tests taken in matriculation examination has also remained stable. The same applies to comprehensive school GPA.

Figure 2   *Trends in matriculation examination grades and comprehensive school GPA in 2000–2004*

5. Results

Five different stochastic frontier models were estimated using an unbalanced panel data.[6] They were pooled stochastic frontier model, random effects (RE) model, fixed effects (FE) model and true random effects (TRE) and true fixed effects (TFE) model (Greene, 2005a, b).[7] In addition, there were two alternative models. In Model A teaching resources were measured with *teaching expenditures per student*. In Model B this variable was replaced with *student-teacher ratio*. The latter model was estimated with a smaller sample.

All the models were estimated assuming half-normal distribution for the inefficiency term. For the pooled panel data model and RE model the truncated normal assumption was also tested but the μ-term turned out to be statistically insignificant. Exponential distributional assumption didn't in most cases converge. There was heteroscedasticity related to school size in idiosyncratic error term v_{it} in the pooled panel data model and random effects model. The results are therefore heteroscedasticity corrected for those models. The correction had only minor effects on the results.

As for the choice between random or fixed effects models, Hausman specification test was performed. The results of the test supported fixed effects models. Since the panel is fairly short (five years) and some of the explanatory variables of interest stay constant through time, also the results of random effects models are presented and discussed.

Since the scores in each individual test in matriculation examination are normalized each year, the output measure is not genuinely increasing. The scores of each school are rather fluctuating around their yearly overall mean. To remove this kind of bias all the explanatory variables were centralized around their yearly overall mean. The models were also estimated using centralized variables. The centralization didn't affect the results. Therefore, they are not reported here but are available upon request.

The stochastic frontier model is appropriate for the description of the production technology since the lambda coefficient is statistically significant in all the models. There is, in other words, inefficiency that is captured with the term u_{it}. The variables explain quite high proportion of the variation in matriculation

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[6] The production function was first estimated with cross section data for each year separately. A Chow-test (H_0: $\beta_{i,2000}=\beta_{i,2001}=\beta_{i,2002}=\beta_{i,2003}=\beta_{i,2004}$, where $i=1,...,n$ depicts explanatory variables) was performed to test if the parameter estimates were statistically significantly different across years. According to results the H_0-hypothesis could not be rejected supporting the pooling of the data. In the following only the results of panel data models are presented. The results of cross section estimations are available upon request.

[7] Models were estimated with Nlogit 4.0/Limdep 10.0.

examination since the R-squared in normal OLS is 0.70[8]. In most of the models, the size of the parameter estimates is quite similar. Similar pattern concerning the size of the coefficients has also been reported by e.g. Greene (2005b). There are, however, some exceptions. The size of the effect of *parents' education*, *heterogeneity of the students* and *average length of the studies* can double in some models.

Most of the explanatory variables in these models have the expected sign. *Comprehensive school GPA* affects positively on matriculation examination scores. The effect is quite large since a one tenth growth in school's GPA gives 0.3 increase in grades. As for the students' socio-economic status, *parents' education level* and the *share of white collar workers* increase achievement whereas the *share of single parents* decreases it. Their effect is clearly smaller than the effect of GPA. Schools with higher share of female and Swedish speaking students perform better in matriculation examination. The *heterogeneity of the student body* affects negatively on examination results.

Both *teaching expenditures* and *other expenditures per student* have statistically significant coefficients in TRE model. Teaching expenditures is also statistically significant in TFE model. It seems that as soon as the unmeasured heterogeneity across schools is captured in the model, teaching expenditure turns out to be statistically significant.[9] Interestingly, the coefficient is negative in all models indicating that schools with higher teaching resources perform worse. There is no clear explanation for this. The size of the effect is, however, quite small.

Average length of the studies affects the matriculation examination results negatively in all models. The coefficient is statistically significant in TRE and FE models. It seems that on average the longer studies don't contribute to increased performance in matriculation examination. This is an interesting result since the length of the studies clearly increased after the year classes were removed from upper secondary schools and students were able to complete their studies in 2 to 4 years. It is also contrary to normal argumentation according to which increased time would enhance the results.

As mentioned earlier, in matriculation examination students can take tests in three consecutive test periods. According to results, the more students decentralize the test taking into several test periods, the worse they perform. This is a robust result. One reason behind this result might be that students more easily take tests "just to try their luck" and don't prepare themselves for the test as

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[8] The results can be obtained upon request.

[9] In TRE and TFE models it was also tested if the sign of the resource variables was affected by some variables that may affect the size of teaching and other expenditures namely school size and school location. It turned out that if these variables were omitted from the models the expenditure variables were statistically insignificant.

carefully as would be the case when there is no possibility to retake the test. The incentive to upgrade the test result later is perhaps small.

There are no systematic differences in achievement between students in schools with specialized curriculum compared to those in non-specialized upper secondary schools. Students in schools specializing in *mathematics and sciences* score two percentage points lower than students in non-specialized schools in some of the models. As for other groups, students in upper secondary schools specializing in *sports* score somewhat higher in TRE model. The same applies to students in schools specializing in *languages*. The results in schools specializing in *music and arts* do not differ from the results in general schools.

The performance of *private schools* is lower than the performance of schools maintained by the municipalities in pooled panel and TRE models. *State schools* don't differ from municipal schools. The performance of schools in *rural areas* is not statistically significantly different from performance in urban areas. Schools in *densely populated area* score somewhat higher relative to schools in urban area in pooled panel data and TRE models.

School size affects the performance of their students negatively and the coefficient is statistically significant in pooled panel data, RE and TFE models. The size of the coefficient is, however, quite small. The nonlinearities in school size were also tested by adding a second order term but it turned out to be statistically insignificant.

Table 1   *The results of panel data stochastic frontier models in 2000–2004. Dependent variable: average compulsory score in matriculation examination. Model A*

	Pooled panel data model	Random effects model	True random effects model	Fixed effects model	True fixed effects model
GPA	1.622	1.596	1.637	1.611	1.578
	(39.37)**	(38.86)**	(57.18)**	(17.99)**	(39.74)**
Parents' education	0.141	0.071	0.063	0.039	0.135
	(9.20)**	(5.12)**	(6.78)**	(2.18)*	(12.19)**
% white collars	0.001	0.001	0.001	0.001	0.001
	(2.57)	(2.94)**	(6.20)**	(3.01)**	(3.46)**
% single parents	-0.001	-0.0002	-0.0002	-0.000	-0.001
	(-4.26)**	(-1.09)	(-1.10)	(0.01)	(-6.13)**
Teaching expenditure/student.	-0.016	-0.019	-0.028	-0.000	-0.021
	(-1.55)	(-1. 66)	(-4.38)**	(0.01)	(-3.68)**
Other expenditure/student	-0.005	0.010	0.014	0.029	0.004
	(-0.88)	(1.34)	(3.73)**	(2.48)*	(1.09)
SD of matriculation exam score	-0.100	-0.080	-0.069	-0.055	-0.109
	(-9.66)**	(-9.19)**	(-10.68)**	(5.36)**	(-13.33)**
% Female	0.001	0.001	0.001	0.001	0.001
	(8.11)**	(4.94)**	(6.93)**	(3.75)**	(10.07)**
% Swedish speaking	0.001	0.001	0.001	0.0004	0.001
	(9.20)**	(7.26)**	(16.82)**	(0.64)	(15.83)**
Ave. length of studies	-0.060	-0.041	-0.108	-0.087	-0.111
	(-1.58)	(-1.25)	(-4.03)**	(1.60)	(-3.72)**
Ave. participation in exam periods	-0.102	-0.092	-0.100	-0.104	-0.108
	(-11.34)**	(-10.35)**	(-17.89)**	(8.17)**	(-17.96)**
School size	-0.011	-0.013	-0.007	-0.019	-0.016
	(-2.85)**	(-3.02)**	-(2.51)*	(1.13)	(-6.64)**
Languages	0.019	0.009	0.017	-0.017	0.016
	(1.24)	(1.11)	(2.011)*	(-0.53)	(1.744)
Mathematics and science	-0.018	-0.020	-0.020		
	(-2.88)**	(-1.78)	(-3.507)**		
Music and arts	-0.004	-0.001	0.008	0.006	-0.004
	(-0.55)	(-0.10)	(1.60)	(0.25)	(-0.97)
Sports	0.005	0.012	0.014		
	(0.07)	(1.43)	(2.35)*		
Private	-0.003	0.012	-0.012		
	(-0.65)	(1.45)	(-3.12)**		
State owned	0.017	0.015	0.018		
	(1.30)	(1.06)	(2.00)*		

Table 1 continues

Densely populated area	0.013	-0.003	0.009		
	(3.55)**	(-0.43)	(3.39)**		
Rural area	0.008	-0.013	0.003		
	(1.46)	(-2.17)*	(1.02)		
Year	0.003	0.004	0.004	0.003	0.004
	(3.29)**	(4.77)**	(6.38)**	(2.12)*	(77.89)**
Constant	-7.567	-7.960	-8.413	-6.261	
	(-3.86)**	(-5.36)**	(-6.99)**	(-2.50)*	
Lambda		0.207	1.008		1.349
		(16.98)**	(8.14)**		(19.41)**
Sigma(v)	0.052	0.377	0.034		0.059
Sigma(u)	0.046	0.078	0.035		0.080
Het: Constant	-1.627				
	(-4.46)**				
Het: School size	-0.832	-0.870			
	(-10.82)**	(-21.36)**			
Log-L	3117.66	3542.45	-3417.02		3301.12
No. of obs.	2133	2133	2133	2133	2133
No. of schools	436	436	436	436	436

t-values in parentheses, robust t-values in fixed effects model
* Significant at 5%
** Significant at 1 %
All explanatory variables in logarithmic form except ratios.

The results are very similar when teaching expenditures per student are replaced with *student-teacher ratio* and the model is estimated for a smaller sample consisting only of municipal upper secondary schools (Model B, see Table 2). The change has only minor influence on the coefficients of other variables. Interestingly, the coefficient of student-teacher ratio still has the unexpected sign in all the models and it is statistically significant in pooled panel data, RE and TFE models. In other words, the larger the group size the better is the results in matriculation examination. As discussed earlier, it is possible that the model lack for proper control for the whole selection bias.

Table 2   *The results of panel data frontier models in 2000–2004.*
Dependent variable: average compulsory score in matriculation
examination. Model B

	Pooled panel data model	Random effects model	True random effects model	Fixed effects model	True fixed effects model
GPA	1.673	1.570	1.614	1.570	1.611
	(36.87)**	(35.02)**	(53.24)**	(15.91)**	(36.15)**
Parents' education	0.126	0.069	0.057	0.040	0.105
	(7.27)**	(4.34)**	(5.58)**	(2.09)*	(8.70)**
% White collars	0.001	0.001	0.001	0.001	0.001
	(2.53)*	(2.34)*	(5.50)**	(2.65)**	(3.57)**
% Single parents	-0.001	-0.0001	0.000	0.000	-0.001
	(-3.00)**	(-0.62)	(0.02)	(0.76)	(-3.37)**
Student-teacher ratio	0.017	0.030	0.010	0.018	0.019
	(2.50)*	(4.10)**	(2.03)*	(1.16)	(4.30)**
Other expenditures/student	-0.003	0.014	0.010	0.033	0.000
	(-0.47)	(1.64)	(2.50)*	(2.51)*	(0.10)
SD of matriculation exam score	-0.091	-0.073	-0.060	-0.044	-0.105
	(-7.82)**	(-7.22)**	(-7.83)**	(-3.95)**	(-11.68)**
% Female	0.001	0.001	0.001	0.001	0.001
	(7.06)**	(4.65)**	(6.71)**	(3.82)**	(8.61)**
% Swedish speaking	0.001	0.001	0.001	-0.001	0.001
	(8.57)**	(7.04)**	(14.37)**	(-1.09)	(14.18)**
Ave. length of studies	-0.059	-0.041	-0.139	-0.132	-0.094
	(-1.32)	(-1.15)	(-4.75)**	(-2.28)*	(-2.83)**
Ave. participation in exam periods	-0.104	-0.091	-0.102	-0.106	-0.111
	(-10.60)**	(-9.43)**	(-16.97)**	(-7.86)**	(-16.78)**
School size	-0.006	-0.013	-0.004	-0.041	-0.010
	(-1.52)	(-2.44)*	(-1.29)	(-2.17)*	(-4.24)**
Languages	0.015	-0.033	-0.030	-0.063	0.012
	(0.51)	(-2.22)*	(-1.74)	(-4.05)**	(0.77)
Mathematics and science	-0.023	-0.012	-0.007		
	(-3.34)**	(-0.91)	(-1.17)		
Music and arts	-0.005	-0.0004	0.010		
	(-0.62)	(-0.04)	(1.89)		
Sports	0.003	0.018	0.015		
	(0.44)	(1.88)	(2.38)*		
Densely populated area	0.011	-0.004	0.006		
	(2.75)**	(-0.61)	(2.02)*		
Rural area	0.006	-0.014	-0.002		
	(1.15)	(-2.01)*	(-0.46)		

Table 2 continues

Year	0.003 (3.03)**	0.003 (4.25)**	0.004 (5.34)**	0.003 (2.39)*	0.004 (77.98)**
Constant	-7.792 (-3.65)**	-7.086 (-4.85)**	-7.810 (-5.86)**	-5.856 (-2.59)**	
Lambda		0.201 (15.35)**	1.181 (8.40)**		1.381 (18.12)**
Sigma(v)	0.055	0.393	0.032		0.059
Sigma(u)	0.033	0.079	0.038		0.081
Het: Constant	-1.752 (-4.23)**				
Het: School size	-0.776 (-8.54)**	-0. 890 (-19.37)**			
Log-L	2627.41	2997.19	-2898.39		2794.03
No. of obs.	1798	1798	1798	1798	1798
No. of schools	376	376	376	376	376

t-values in parentheses, robust t-values in fixed effects model
* Significant at 5%
** Significant at 1 %
All explanatory variables in logarithmic form except ratios.

All the models were also estimated using all grades in matriculation examination as the dependent variable. These results are reported in Appendix 3 and Appendix 4. The results were mostly similar with some exceptions to those presented above. The lambda coefficient in TRE model was statistically insignificant indicating that there is no inefficiency in the model and traditional RE model would be appropriate to describe the production. This result applied to Model A. In Model B in which *teaching expenditures per student* was replaced with *student-teacher ratio*, lambda coefficient was statistically significant indicating that there was some inefficiency.

The size of the effect of comprehensive school GPA is even larger in these models. As for the resource variables, *teaching expenditures per student* is statistically insignificant in all models. *Other expenditures per student* have positive and statistically significant coefficients in TRE, FE and TFE models. *Student-teacher ratio* had a positive and statistically significant coefficient only in RE model.

5.1 Inefficiency differences

There are clear differences in inefficiency of schools between the different stochastic frontier models (see Table 3).

Figure 3 and Appendix 5).[10] Traditional FE model, by labelling all school specific fixed effect as inefficiency, produces clearly the highest average inefficiency, some 15 per cent in Model A. As a consequence of taking into account school specific fixed effects and separating it from inefficiency, inefficiency decreases to 6 per cent. Therefore, interpreting whole school specific fixed effect as inefficiency most likely overestimates its magnitude. The same pattern applies to RE and TRE models although the average inefficiency is lower in both cases compared to fixed effects models. The clear difference in average inefficiency between random and fixed effects models highlights the importance of the choice of an appropriate model.

As for the variation in inefficiency scores across schools, it is also highest in FE model whereas TRE model produces the lowest variation each year. The results of pooled panel data and TFE model are also very close to that of TRE model.

Table 3 *Average inefficiency, standard deviation, minimum and maximum in panel data models for years 2000–2004. Compulsory score in matriculation examination as the dependent variable*
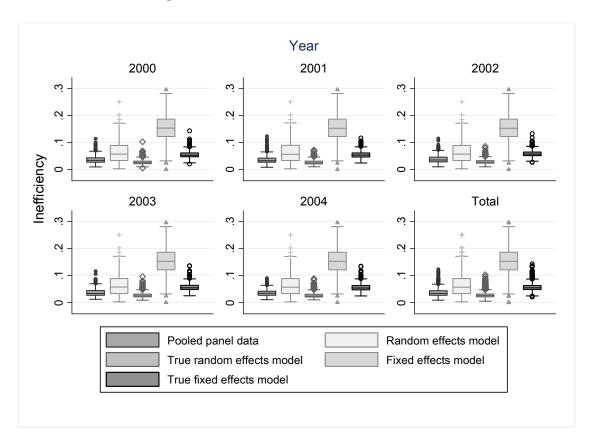
	Pooled panel	Random effects	True random effects	Fixed effects	True fixed effects
Model A					
Mean	0.037	0.064	0.027	0.154	0.056
Standard deviation	0.015	0.041	0.010	0.046	0.014
Min.	0.008	0.002	0.005	0.000	0.020
Max.	0.123	0.250	0.103	0.295	0.143
Model B					
Mean	0.026	0.065	0.030	0.179	0.057
Standard deviation	0.008	0.042	0.013	0.063	0.014
Min.	0.009	0.002	0.006	0.000	0.020
Max.	0.068	0.209	0.121	0.341	0.146

Change of output variable from compulsory grades to all grades in matriculation examination had some effect on inefficiency (see Appendix 6). Especially in random and fixed effects models the average inefficiency was higher. In true

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[10] The inefficiency score (1-TE_i) varies between 0 and 1 and the larger the figure the more inefficient the school.

random effects model, the lambda coefficient showed that there was no inefficiency. The replacement of teaching expenditures per student with student-teacher ratio and the use of smaller sample (Model B) had only minor effect on average inefficiency (see Table 37, Appendix 7 and Appendix 8).

Figure 3   *Average technical inefficiency in panel data models for years 2000–2004. Compulsory score in matriculation examination as the dependent variable. Model A*
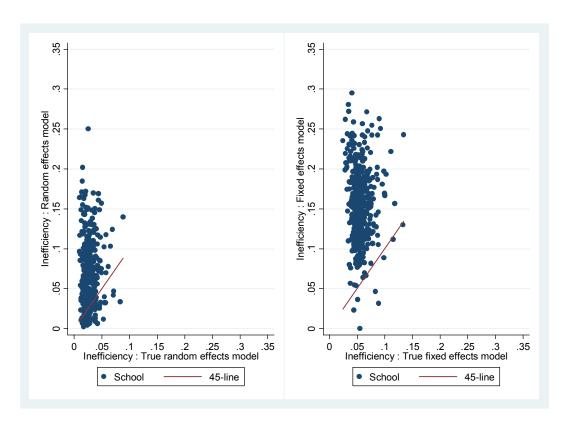
There are clear differences between the rankings based on inefficiency scores between the different stochastic frontier models (see Table 4). The rankings between RE and FE models are quite similar. That is also the case with TRE and TFE models. There is practically no relation between the rankings of RE and TRE models and FE and true TFE models. RE and TFE models also produce quite different rankings. The replacement of compulsory grades with all grades and teaching expenditures per student with student-teacher ratio didn't cause any real differences to Spearman correlation coefficients. Thus, the results are not reported here.

Table 4   *Spearman rank correlation coefficients between different stochastic frontier models. Compulsory score in matriculation examination as the dependent variable. Model A*

	Pooled panel data model	Random effects model	True random effects model	Fixed effects model	True fixed effects model
Pooled panel data model	1				
Random effects model	0.7465	1			
True random effects model	0.6804	0.1838	1		
Fixed effects model	0.6892	0.9031	0.1775	1	
True fixed effects model	0.5520	0.0069	0.9452	0.0163	1

The difference in inefficiency scores between the RE and TRE models and FE and TFE models is also depicted in Figure 4. It demonstrates the same pattern as the Spearman correlation coefficients. There is no systematic relationship between the RE and TRE models and FE and TFE models. RE and FE models produce high estimates for inefficiency by interpreting all random and fixed effects as inefficiency. According to TRE and TFE models, it is only partly inefficiency.
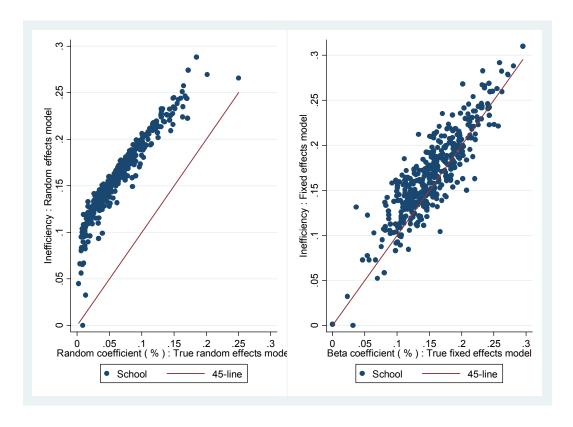
Figure 4   *Scatter plot of inefficiency scores between RE and TRE models (panel left) and between FE and TFE models (panel right) using compulsory score in matriculation examination as the dependent variable. Year 2004. Model A*

To further illustrate the differences between the models, the inefficiency scores of RE model is compared with random coefficients (as percentage deviation from the maximum value) of TRE model. The same comparison is also done between the inefficiency scores in FE model and beta coefficients (also as percentage deviation from the maximum value) in TFE model (see Figure 5). In TRE model, random coefficient depicts the school specific random effect. In TFE model the school specific fixed effects is depicted by the beta coefficient.

The figure shows that the constant through time random effect of schools is very similar in RE and TRE models. As expected, only the magnitude is smaller in TRE model. The same pattern applies between FE and TFE models. The difference in magnitude is, however, smaller than between RE and TRE models. Unfortunately, the problem of what should be counted as inefficiency remains unsolved. The advantage of TRE and TFE models is, however, that they allow the separate identification and investigation of time constant effects and time varying inefficiency.

Figure 5   *Scatter plot between inefficiency score of RE model and random coefficient of TRE model(panel left) and between inefficiency score of FE model and beta coefficient of TFE model (panel right) using compulsory score in matriculation examination as the dependent variable. Year 2004. Model A*

6. Conclusions

In this study, new variants of stochastic frontier models for panel data were used to evaluate the efficiency of Finnish upper secondary schools. These models allow the separation of random and fixed effects from inefficiency. Hence, they take the school-specific time constant heterogeneity into account and allow controlling the omitted variables bias quite common in education production function studies. True fixed effects model also control to some extent the non-random selection of students into schools.

Both the results of random and fixed effects were presented. The choice between these two alternatives is complicated and there are several factors that influence it. The results of Hausman specification test supported the fixed effects models. And so did the less restrictive assumption of fixed effects model that unmeasured heterogeneity can be correlated with the included variables. True fixed effects model, however, takes only into account the within school variation. Since the panel used in the study was fairly short, there was no variation through time in some of the variables, and the variation across schools was also considered important, the results of random effects models were also presented.

The estimation results were very similar to previous studies. Variables related to students' earlier school success (comprehensive school GPA) and family background were the strongest predictors of performance in matriculation examination. In most of the models, the effect of school resources (teaching expenditures per student) was not statistically significant. Taking into account the school specific heterogeneity with the true random and true fixed effects models turns the coefficient significant. The effect is, however, small and negative. The effect of student-teacher ratio estimated with a smaller sample had a small, statistically significant positive coefficient in random effects and true fixed effects model.

The length of studies affected the test results negatively. A longer stay in upper secondary school seems not to improve the grades. And neither does the decentralization of test taking. The more students decentralize test taking in matriculation examination the worse they perform. Larger schools perform worse but the effect is very close to zero.

The inefficiency varied depending on the stochastic frontier model. The average inefficiency was between 3–17 percent depending on the model and the year. Taking into account the unmeasured heterogeneity with the true random and true fixed effects models reduces the inefficiency. Random and fixed effects models produce slightly different estimates for efficiency. Therefore, the choice of the model matters.

Also the ranking of schools based on their inefficiency score changes considerably in true random and true fixed effects models compared to other models. As for the random and fixed effects, they remained stable between random effects and true random effects models as well as between fixed and true fixed effects models. Only the size of the effects was somewhat diminished in true random and true fixed effects. Based on these results, the identified inefficiency is something different in random and fixed effects models compared to true random and true fixed effects models. The puzzle of choosing the appropriate model remains partly unresolved. The advantage of true random and true fixed effects models is, however, that they allow the separate identification and investigation of time constant effects and inefficiency.

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Appendix

Appendix 1   Summary statistics of the variables in Model A.

		Mean	Std.	Min.	Max.	Observations
Grades in compulsory subjects/student	Overall	16.67	1.77	10.71	23.48	N = 2133
	Between		1.62	11.93	23.13	n = 436
	Within		0.76	13.19	19.74	T-bar = 4.89
Grades in all subjects/student	Overall	20.95	2.94	11.23	34.69	N = 2133
	Between		2.72	12.73	33.72	n = 436
	Within		1.22	16.28	27.06	T-bar = 4.89
Grade point average (GPA)	Overall	8.31	0.30	7.20	9.55	N = 2133
	Between		0.27	7.48	9.46	n = 436
	Within		0.13	7.27	8.80	T-bar = 4.89
Parents' education	Overall	389.30	81.55	186.00	754.50	N = 2133
	Between		72.25	258.30	720.10	n = 436
	Within		30.17	172.89	534.50	T-bar = 4.89
Percentage white collar workers	Overall	20.69	10.36	0.00	66.20	N = 2133
	Between		9.62	4.28	60.76	n = 436
	Within		4.11	-6.75	46.05	T-bar = 4.89
Percantage single parents	Overall	13.95	6.35	0.00	66.70	N = 2133
	Between		4.67	2.92	30.06	n = 436
	Within		4.31	-0.79	50.59	T-bar = 4.89
SD of grades in matriculation examination	Overall	4.69	0.68	2.34	8.19	N = 2133
	Between		0.48	3.04	6.08	n = 436
	Within		0.49	2.57	8.24	T-bar = 4.89
Percentage females	Overall	0.57	0.10	0.11	1.00	N = 2133
	Between		0.07	0.32	0.81	n = 436
	Within		0.07	0.25	0.89	T-bar = 4.89
Percentage Swedish speaking	Overall	0.06	0.22	0.00	1.00	N = 2133
	Between		0.22	0.00	0.97	n = 436
	Within		0.02	-0.18	0.37	T-bar = 4.89
Teaching expenditures/students	Overall	3495.08	987.50	1819.50	12991.63	N = 2133
	Between		975.92	1985.74	11120.66	n = 436
	Within		237.79	1395.40	5368.72	T-bar = 4.89
Other expenditues/student	Overall	1085.40	352.38	383.34	3276.37	N = 2133
	Between		360.29	434.89	3118.31	n = 436
	Within		116.08	448.48	1700.16	T-bar = 4.89
Ave. length of studies	Overall	3.11	0.11	2.53	3.75	N = 2133
	Between		0.09	2.93	3.59	n = 436
	Within		0.06	2.66	3.51	T-bar = 4.89
Ave. participation in test periods	Overall	1.79	0.28	1.00	3.00	N = 2133
	Between		0.22	1.26	2.45	n = 436
	Within		0.17	1.10	2.68	T-bar = 4.89

Appendix 1 continues

School size	Overall	252.76	149.43	23.00	879.00	N = 2133
	Between		147.51	28.00	840.00	n = 436
	Within		17.69	72.16	477.16	T-bar = 4.89
Languages	Overall	0.01	0.09	0.00	1.00	N = 2133
	Between		0.08	0.00	1.00	n = 436
	Within		0.03	-0.79	0.41	T-bar = 4.89
Mathematics and science	Overall	0.03	0.17	0.00	1.00	N = 2133
	Between		0.17	0.00	1.00	n = 436
	Within		0.00	0.03	0.03	T-bar = 4.89
Music and arts	Overall	0.04	0.19	0.00	1.00	N = 2133
	Between		0.19	0.00	1.00	n = 436
	Within		0.03	-0.76	0.64	T-bar = 4.89
Sports	Overall	0.03	0.17	0.00	1.00	N = 2133
	Between		0.16	0.00	0.00	n = 436
	Within		0.00	0.03	0.03	T-bar = 4.89
Private schools	Overall	0.06	0.23	0.00	1.00	N = 2133
	Between		0.23	0.00	1.00	n = 436
	Within		0.02	-0.54	0.46	T-bar = 4.89
State owned	Overall	0.01	0.11	0.00	1.00	N = 2133
	Between		0.15	0.00	1.00	n = 436
	Within		0.00	0.01	0.01	T-bar = 4.89
Densely populated area	Overall	0.20	0.40	0.00	1.00	N = 2133
	Between		0.40	0.00	1.00	n = 436
	Within		0.00	0.20	0.20	T-bar = 4.89
Rural area	Overall	0.33	0.47	0.00	1.00	N = 2133
	Between		0.47	0.00	1.00	n = 436
	Within		0.00	0.33	0.33	T-bar = 4.89

Appendix 2   Summary statistics for variables in Model B

		Mean	Std. Dev.	Min	Max	Observations
Grades in compulsory subjects/student	Overall	16.59	1.66	10.71	23.30	N = 1798
	Between		1.51	11.93	22.68	n = 376
	Within		0.73	13.68	19.37	T-bar = 4.78
Grades in all subjects/student	Overall	20.82	2.69	11.23	33.89	N = 1798
	Between		2.47	12.73	32.78	n = 376
	Within		1.18	17.27	25.74	T-bar = 4.78
Grade point average (GPA)	Overall	8.30	0.28	7.20	9.55	N = 1798
	Between		0.25	7.48	9.48	n = 376
	Within		0.13	7.26	8.77	T-bar = 4.78
Parents' education	Overall	381.30	74.38	186.00	702.50	N = 1798
	Between		70.17	261.70	673.60	n = 376
	Within		28.39	237.70	514.40	T-bar = 4.78
Percentage white collar workers	Overall	19.64	9.56	0.00	59.90	N = 1798
	Between		8.97	4.28	55.08	n = 376
	Within		3.81	-0.89	36.86	T-bar = 4.78
Percentage single parents	Overall	13.34	5.93	0.00	37.80	N = 1798
	Between		4.35	2.92	27.55	n = 376
	Within		4.07	-1.40	30.22	T-bar = 4.78
SD of grades in matriculation examination	Overall	4.72	0.66	2.71	7.61	N = 1798
	Between		0.47	3.32	6.08	n = 376
	Within		0.47	2.90	6.93	T-bar = 4.78
Percentage female students	Overall	56.71	9.92	14.29	93.65	N = 1798
	Between		7.19	32.32	80.57	n = 376
	Within		6.99	27.90	81.03	T-bar = 4.78
Percentage Swedish speaking	Overall	6.17	22.02	0.00	100.00	N = 1798
	Between		22.17	0.00	97.06	n = 376
	Within		1.14	-9.39	13.48	T-bar = 4.78
Student-teacher ratio	Overall	17.98	3.85	5.90	29.88	N = 1798
	Between		3.62	6.03	28.43	n = 376
	Within		1.44	10.93	24.93	T-bar = 4.78
Other expenditures/student	Overall	1058.37	307.45	383.34	2971.37	N = 1798
	Between		293.78	449.33	2377.88	n = 376
	Within		105.91	430.74	1673.13	T-bar = 4.78
Ave. length of studies	Overall	3.11	0.10	2.53	3.65	N = 1798
	Between		0.09	2.93	3.59	n = 376
	Within		0.06	2.66	3.51	T-bar = 4.78
Ave. participation in test periods	Overall	1.78	0.28	1.00	2.78	N = 1798
	Between		0.23	1.18	2.45	n = 376
	Within		0.16	1.17	2.59	T-bar = 4.78

Appendix 2 continues

School size	Overall	253.40	150.43	24.00	879.00	N = 1798
	Between		149.77	27.88	839.90	n = 376
	Within		18.34	72.20	477.70	T-bar = 4.78
Sports	Overall	0.03	0.16	0.00	1.00	N = 1798
	Between		0.16	0.00	1.00	n = 376
	Within		0.00	0.03	0.03	T-bar = 4.78
Languages and communication	Overall	0.00	0.06	0.00	1.00	N = 1798
	Between		0.06	0.00	1.00	n = 376
	Within		0.03	-0.60	0.40	T-bar = 4.78
Music and arts	Overall	0.04	0.20	0.00	1.00	N = 1798
	Between		0.20	0.00	1.00	n = 376
	Within		0.00	0.04	0.04	T-bar = 4.78
Mathematics and science	Overall	0.02	0.15	0.00	1.00	N = 1798
	Between		0.15	0.00	1.00	n = 376
	Within		0.00	0.02	0.02	T-bar = 4.78

Appendix 3   Results of panel data stochastic frontier estimations using grades in all subjects in matriculation examination as the dependent variable. Model A

	Pooled panel data model	Random effects model		Fixed effects model	True fixed effects model
GPA	2.210	2.296		2.271	2.258
	(35.25)**	(44.54)**		(18.51)**	(39.57)**
Parents' education	0.165	0.088		0.047	0.179
	(8.25)**	(5.23)**		(2.09)*	(11.38)**
% white collar workers	0.001	0.001		0.001	0.001
	(3.39)**	(3.14)**		(2.55)*	(3.11)**
% single parents	-0.001	-0.0004		-0.0001	-0.002
	(-4.47)**	(-1.59)		(-0.18)	(-7.59)**
Teaching expenditures/students	-0.013	-0.019		0.025	-0.012
	(-1.07)	(-1.25)		(0.79)	(-1.46)
Other expenditures/student	0.001	0.012		0.030	0.010
	(0.19)	(1.40)		(2.13)*	(2.12)*
SD of matriculation examination	-0.085	-0.053		-0.017	-0.089
	(-6.39)**	(-4.76)**		(-1.35)	(-7.82)**
% female	0.001	0.001		0.0004	0.001
	(5.64)**	(3.58)**		(2.54)*	(7.00)**
% Swedish speaking	0.001	0.001		0.0002	0.001
	(12.10)**	(7.54)**		(0.19)	(17.48)**
Ave. length of studies	-0.292	-0.082		-0.070	-0.274
	(-4.81)**	(-1.84)		(-1.12)	(-6.42)**
Ave. participation in exam periods	-0.114	-0.090		-0.108	-0.112
	(-9.79)**	(-7.97)**		(-6.62)**	(-13.50)**
School size	-0.014	-0.018		-0.017	-0.018
	(-2.72)**	(-3.05)**		(-0.82)	(-5.50)**
Languages and communication	0.049	0.036		-0.010	0.042
	(2.55)*	(4.22)**		(-0.25)	(3.30)**
Mathematics and sciences	-0.011	-0.018			
	(-1.09)	(-1.25)			
Music and arts	-0.008	-0.001		0.014	-0.013
	(-0.79)	(-0.07)		(0.51)	(-2.10)*
Sports	0.028	0.007			
	(2.50)*	(0.49)			
Private schools	-0.002	0.028			
	(-0.23)	(3.15)**			
State owned schools	0.071	0.136			
	(4.05)**	(11.97)**			
Densely populated area	0.020	-0.006			
	(3.90)**	(-0.67)			

Appendix 3 continues

Rural area	0.017	-0.014		
	(2.57)*	(-1.60)		
Year	0.002	0.003	0.001	0.003
	(1.22)	(3.46)**	(0.75)	(34.69)**
Constant	-5.213	-8.220	-4.712	
	(-1.97)*	(-4.68)**	(1.48)	
Lambda	0.872	0.234		0.878
	(15.05)**	(17.07)**		(12.00)**
Sigma(v)	0.068	0.489		0.078
Sigma(u)	0.059	0.114		0.088
Het: School size		-0.883		
		(-21.76)**		
Log-L	2451.86	3004.05		2718.55
No. of obs.	2133	2133	2133	2133
No. of schools	436	436	436	436

t-values in parentheses, robust t-values in fixed effects model
* Significant at 5%
** Significant at 1 %
All explanatory variables in logarithmic form except ratios

Appendix 4   *Results of panel data stochastic frontier estimations using grades in all subjects in matriculation examination as the dependent variable. Model B*

	Pooled panel data model	Random effects model	True random effects model	Fixed effects model	True fixed effects model
GPA	2.220	2.258	2.263	2.208	2.249
	(32.48)**	(39.94)**	(58.17)**	(16.49)**	(36.72)**
Parents' education	0.129	0.086	0.068	0.046	0.134
	(5.98)**	(4.59)**	(5.32)**	(1.96)*	(8.21)**
% white collar workers	0.001	0.001	0.001	0.001	0.001
	(3.02)**	(2.507)*	(5.11)**	(2.54)*	(2.94)**
% single parents	-0.001	-0.0004	-0.0002	0.0001	-0.002
	(-3.46)**	(-1.50)	(-0.78)	(0.41)	(-6.16)**
Student-teacher ratio	0.001	0.027	-0.004	0.015	0.007
	(0.14)	(2.72)**	(-0.71)	(0.80)	(1.18)
Other expenditures per student	0.007	0.021	0.015	0.031	0.008
	(0.95)	(2.20)*	(2.87)**	(1.96)*	(1.55)
SD of matriculation examination scores	-0.081	-0.044	-0.022	-0.003	-0.091
	(-5.55)**	(-3.69)**	(-2.38)*	(-0.22)	(-7.67)**
% female	0.001	0.001	0.001	0.001	0.001
	(4.52)**	(3.42)**	(4.70)**	(2.57)**	(5.61)**
% Swedish speaking	0.001	0.001	0.001	0.0003	0.001
	(11.88)**	(7.95)**	(21.47)**	(0.35)	(17.50)**
Ave. length of studies	-0.260	-0.075	-0.178	-0.137	-0.217
	(-3.99)**	(-1.60)	(-4.33)**	(-2.08)*	(-4.84)**
Ave. participation in exam periods	-0.118	-0.093	-0.103	-0.106	-0.118
	(-9.47)**	(-7.69)**	(-13.53)**	(-6.04)**	(-13.62)**
Densely populated area	0.019	-0.005	0.012		
	(3.48)**	(-0.69)	(3.31)**		
Rural area	0.015	-0.013	0.006		
	(2.16)*	(-1.41)	(1.30)		
School size	-0.002	-0.013	-0.001	-0.050	-0.009
	(-0.39)	(-1.85)	(-0.31)	(-2.16)*	(-2.93)**
Languages and communication	0.015	-0.042	-0.027	-0.066	0.015
	(0.52)	(-1.91)	(-1.33)	(-3.81)**	(0.79)
Mathematics and sciences	-0.016	-0.005	-0.018		
	(-1.36)	(-0.30)	(-2.18)*		
Music and arts	-0.009	0.001	-0.001		
	(-0.87)	(0.10)	(-0.17)		
Sports	0.025	0.015	0.007		
	(2.08)*	(1.14)	(0.85)		
Year	0.002	0.002	0.002	0.001	0.003
	(1.19)	(2.37)*	(2.12)*	(0.84)	(36.79)**

Appendix 4 continues

Constant	-5.344	-6.590		-4.037	
	(-1.91)	(-3.55)**		(-1.42)	
Lambda	1.044	0.208	0.881		1.208
	(15.94)**	(15.57)**	(5.95)**		(15.34)**
Sigma(v)	0.066	0.513	0.044		0.080
Sigma(u)	0.063	0.107	0.038		0.097
Het: School size		-0.907			
		(-19.59)**			
Log-L	2110.30	2574.50	-2480.68		2329.63
No. of obs.	376	376	376	376	376
No. of schools	1798	1798	1798	1798	1798

t-values in parentheses, robust t-values in fixed effects model
* Significant at 5%
** Significant at 1 %
All explanatory variables in logarithmic form except ratios

Appendix 5   *Average inefficiency, standard deviation, minimum and maximum in panel data models using grades in compulsory subjects in matriculation examination as the dependent variable. Model A*

	Average	Standard deviation	Minimum	Maximum
Pooled panel data model				
2000	0.044	0.021	0.009	0.159
2001	0.044	0.023	0.008	0.143
2002	0.047	0.023	0.010	0.131
2003	0.045	0.023	0.011	0.171
2004	0.044	0.020	0.010	0.142
Random effects model				
2000	0.064	0.042	0.002	0.252
2001	0.064	0.042	0.002	0.252
2002	0.064	0.042	0.002	0.252
2003	0.064	0.041	0.002	0.252
2004	0.064	0.042	0.002	0.252
True random effects model				
2000	0.027	0.010	0.005	0.102
2001	0.027	0.010	0.010	0.071
2002	0.029	0.010	0.010	0.084
2003	0.027	0.010	0.009	0.095
2004	0.026	0.011	0.010	0.087
Fixed effects model				
2000	0.155	0.046	0.000	0.295
2001	0.155	0.046	0.000	0.295
2002	0.155	0.046	0.000	0.295
2003	0.154	0.046	0.000	0.295
2004	0.154	0.046	0.000	0.295
True fixed effects model				
2000	0.055	0.014	0.020	0.143
2001	0.055	0.014	0.023	0.115
2002	0.059	0.014	0.026	0.132
2003	0.056	0.014	0.025	0.136
2004	0.056	0.015	0.024	0.134

Appendix 6   *Average inefficiency, standard deviation, minimum and*
maximum in panel data models using grades in all subjects in
matriculation examination as the dependent variable. Model A

	Average	Standard deviation	Minimum	Maximum
Pooled panel data model				
2000	0.048	0.017	0.010	0.125
2001	0.047	0.018	0.015	0.131
2002	0.049	0.018	0.017	0.120
2003	0.049	0.019	0.016	0.187
2004	0.047	0.017	0.017	0.148
Random effects model				
2000	0.094	0.058	0.003	0.347
2001	0.094	0.058	0.003	0.347
2002	0.094	0.058	0.003	0.347
2003	0.096	0.060	0.003	0.347
2004	0.096	0.060	0.003	0.347
True random effects model				
Fixed effects model				
2000	0.273	0.054	0.104	0.426
2001	0.273	0.056	0.000	0.426
2002	0.273	0.056	0.000	0.426
2003	0.272	0.055	0.000	0.426
2004	0.272	0.055	0.000	0.426
True fixed effects model				
2000	0.056	0.010	0.024	0.116
2001	0.056	0.009	0.031	0.097
2002	0.058	0.009	0.031	0.100
2003	0.058	0.009	0.037	0.120
2004	0.057	0.011	0.028	0.112

Appendix 7   *Average inefficiency, standard deviation, minimum and maximum in panel data models using grades in compulsory subjects in matriculation examination as the dependent variable. Model B*

		Average	Standard deviation	Minimum	Maximum
Pooled panel data model					
	2000	0.026	0.008	0.010	0.066
	2001	0.026	0.008	0.009	0.068
	2002	0.027	0.007	0.010	0.055
	2003	0.026	0.008	0.011	0.061
	2004	0.026	0.007	0.011	0.052
Random effects model					
	2000	0.064	0.041	0.002	0.214
	2001	0.065	0.043	0.002	0.214
	2002	0.065	0.043	0.002	0.214
	2003	0.065	0.042	0.002	0.214
	2004	0.065	0.042	0.002	0.214
True random effects model					
	2000	0.029	0.012	0.006	0.120
	2001	0.030	0.014	0.009	0.091
	2002	0.032	0.012	0.012	0.099
	2003	0.030	0.013	0.008	0.105
	2004	0.029	0.013	0.010	0.103
Fixed effects model					
	2000	0.175	0.054	0.000	0.315
	2001	0.175	0.057	0.000	0.315
	2002	0.176	0.057	0.000	0.315
	2003	0.174	0.057	0.000	0.315
	2004	0.174	0.057	0.000	0.315
True fixed effects model					
	2000	0.055	0.014	0.020	0.146
	2001	0.056	0.014	0.024	0.119
	2002	0.059	0.013	0.027	0.132
	2003	0.057	0.015	0.025	0.138
	2004	0.056	0.015	0.024	0.135

Appendix 8   *Average inefficiency, standard deviation, minimum and maximum in panel data models using grades in all subjects in matriculation examination as the dependent variable. Model B*

		Average	Standard deviation	Minimum	Maximum
Pooled panel data model					
	2000	0.053	0.022	0.009	0.154
	2001	0.052	0.023	0.014	0.157
	2002	0.053	0.022	0.018	0.140
	2003	0.054	0.024	0.016	0.220
	2004	0.051	0.021	0.015	0.174
Random effects model					
	2000	0.088	0.053	0.003	0.291
	2001	0.089	0.056	0.003	0.291
	2002	0.089	0.056	0.003	0.291
	2003	0.089	0.055	0.003	0.291
	2004	0.088	0.055	0.003	0.291
True random effects model					
	2000	0.030	0.010	0.007	0.107
	2001	0.030	0.010	0.011	0.079
	2002	0.031	0.009	0.012	0.075
	2003	0.031	0.011	0.013	0.107
	2004	0.029	0.011	0.011	0.096
Fixed effects model					
	2000	0.179	0.061	0.000	0.341
	2001	0.179	0.064	0.000	0.341
	2002	0.179	0.064	0.000	0.341
	2003	0.179	0.064	0.000	0.341
	2004	0.179	0.063	0.000	0.341
True fixed effects model					
	2000	0.068	0.015	0.024	0.167
	2001	0.068	0.015	0.032	0.134
	2002	0.070	0.014	0.032	0.140
	2003	0.070	0.016	0.040	0.175
	2004	0.068	0.016	0.031	0.161

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