Efficiency of Schools in the Visegrad Region, a StoNED Approach

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Abstract

The subject of school efficiency has attracted lots of literature attention, as school-level inefficiencies can have serious negative consequences on the development of human capital and the labor market. In this paper, we examine the efficiency of a sample of a combined 686 schools in the Visegrad countries using the 2018 PISA survey data. We employ an innovative nonparametric approach that combines both the benefits of Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA), namely the Stochastic Nonparametric Envelopment of Data (henceforth StoNED) developed in Kuosmanen and Kortelainen (2012). We construct four different models to control for return to scale, contextual (nondiscretionary) input variables, as well as the inclusion of undesirable variables, and accounting for multiple outputs. These models are applied country-wise and across all four countries to compare their efficiency frontiers and derive policy recommendations.

Introduction

In some empirical applications, researchers often seek to analyze the performance of certain Decision-Making Units (hereafter as DMU, eg: a school). These DMUs are often characterized by a production process that takes a certain level of resources (or inputs) and transforms them to a certain level of goods (or outputs). In this context researchers model productivity and efficiency as metrics of performance, by analyzing the production process which yields a production frontier. The frontier describes the feasible level of outputs for each level of inputs, this frontier reflects the state of technology for a given sector or industry.

Educational institutions can be considered (from an economic point of view) as production units (DMUs), and can be evaluated in terms of efficiency. Efficiency can be analyzed from various perspectives. School-level inefficiencies and mismanagement can have serious repercussions for human resource development and labor market outcomes as a recent study (Bhutoria and Aljabri 2022) highlights.

There are many papers that are measuring the efficiency within the sector of education, see for example the excellent review of Witte and López-Torres (2017). To the best of our knowledge, no paper among these concentrates on the Visegrad (V4) countries, although the countries are historically linked and followed similar development paths and it seems useful to compare their education policies and performance Pelle and Kuruczleki (2016). In this paper we focus on answering the question of what drives the efficiency of schools in the Visegrad countries in terms of standardized test performance? The efficiency analysis will be based on PISA 2018 data and the novel StoNED framework.

Methods

The early literature provided two major directions in performance analysis. The first is the "Stochastic Frontier Analysis" (SFA). The second direction is the non-parametric approach, leading to the development of "Data Envelopment Analysis" (DEA) and "Full Disposal Hull" (FDH). DEA and FDH gained a large theoretical and empirical literature grounds since they were introduced (DEA and FDH are considered the same technique, they are usually both referred to as DEA).

Both approaches have clear advantages and disadvantages. The main shortcoming of DEA is that all deviations from the frontier are treated as inefficiency. The strength of SFA is its probabilistic nature. It allows for decomposing deviations into an inefficiency term and noise term. However development on convex nonparametric least squares (CNLS) have led to the full integration of DEA and SFA into a unified framework of productivity analysis, which we refer to as Stochastic Nonparametric Envelopment of Data (StoNED). Johnson and Kuosmanen (2015)

Formulation of a StoNED model requires identifying input, output and enviromnetal variables, and solving an optimization algorithm, depending on various possible assumptions.

SOME UGLY ASS EQUATIONS MAYBE?

Creators of the StoNED framework provide GAMS and MATLAB code originally, there exists a Python package (REFERENCE) for implementing different models.

In the next chapter we use nonparametric envelopment techniques to estimate a production (education) frontier for each Visegrad country, and for the region as a whole (metafrontier what he called it?).

Data

Data is extracted from the 2018 PISA survey, it contains information on schools (and their environments), teachers, and students (and parental engagement). Data analysis and exploration, visualisation was done in R, while the frontiers were estimated in Python. In this

section we summarise and interpret our data mainly using graphical methods. We show the relationship of the variables we use later in the StoNED models.

Summary statistics of the data

Our sample is constituted of 623 schools from the V4 countries decomposed per the table below. Data is gathered on an individual level, so the first task was to aggregate that to a school level. This was done in two different ways: taking means and medians of the individual level results for each of the schools. Medians are more robust statistics of the central tendency, and not influenced so much by outliers. The models below were estimated using both summaries, but there were no big differences, so we just highlight results from the models using the mean.

country	n
CZE	187
HUN	99
POL	209
SVK	128

The variables and their names we initially decided to use based on the existing literature are the following:

NEED TO CLEAR THIS A BIT, redundant? It should match table of means!!!

- Students:
  - total number of students: `total_sudents`
  - gender characteristics: `students_male (number of)/students_female (number of)` THIS IS ALSO THERE FOR SCHOOLs???
  - parents: `ap_parental_eng` (proportion of parents who engage with the school staff regarding their children education) IS THIS STUDENT OR SCHOOL LEVEL DATA?
  - MATH, READ, SCIENCE RESUTLS?
- Schools:
  - School characteristcs: `ratio_f2m (ratio of female to male students), ratio_pt2ft (part time to full time tachers), ratio_t2s (students per teacher), dropout_rate, funding (percentage of government funding)`
- Teachers:
  - number of full and part time teachers: `teachers_ft`, `teachers_pt`

Table 1: Means of variables for each of the countries

name	CZE	HUN	POL	SVK
bol_location	0.369	0.212	0.469	0.391
bol_extra_acts	0.989	0.990	1.000	1.000
bol_competition	0.882	0.788	0.732	0.859
bol_career_guidance	0.717	0.616	0.383	0.523
funding	0.946	0.974	0.971	0.969
students_male	243.717	270.212	181.134	196.930
students_female	208.695	244.970	173.330	206.289
teachers_ft	34.545	46.020	38.943	29.148
teachers_pt	8.481	6.586	9.191	5.445
total_students	452.412	515.182	354.464	403.219
total_teachers	43.027	52.606	48.134	34.594
ratio_f2m	1.301	1.321	1.078	1.301
ratio_pt2ft	0.342	0.176	0.780	0.217
ratio_ft2pt	7.843	16.056	8.542	8.678
ratio_t2s	0.102	0.119	0.194	0.092
ratio_s2t	10.932	9.620	7.126	11.756
ap_parental_eng	0.256	0.212	0.376	0.284
dropout_rate	0.052	0.033	0.006	0.013
avg_math	7.735	8.602	7.645	5.145
avg_read	52.010	50.511	53.278	49.529
avg_science	11.392	13.003	11.812	7.920

  - `total_teachers` : Total number of teachers

- Context:
  - Location (`bol_locataion`): 1 - School is in Urban area, 0 - School is in Rural area
  - Extra activities (`bol_extra_acts`): 1 - Yes there are official extra activities in the curricilum, 0 - No
  - Competition (`bol_competition`): 1 - There's at least another school in the area, 0 - There's no other schools in the area
  - Career guidance (`bol_career_guidance`): 1 - There's an official career guidance curriculum in the school, 0 - There's not

Mean and standard deviation (DO WE NEED STDEV, can stay, but I woundt write about it!!!) tables for each variable per country is depicted as follows:

Table 2: Standard deviations of variables for each of the countries

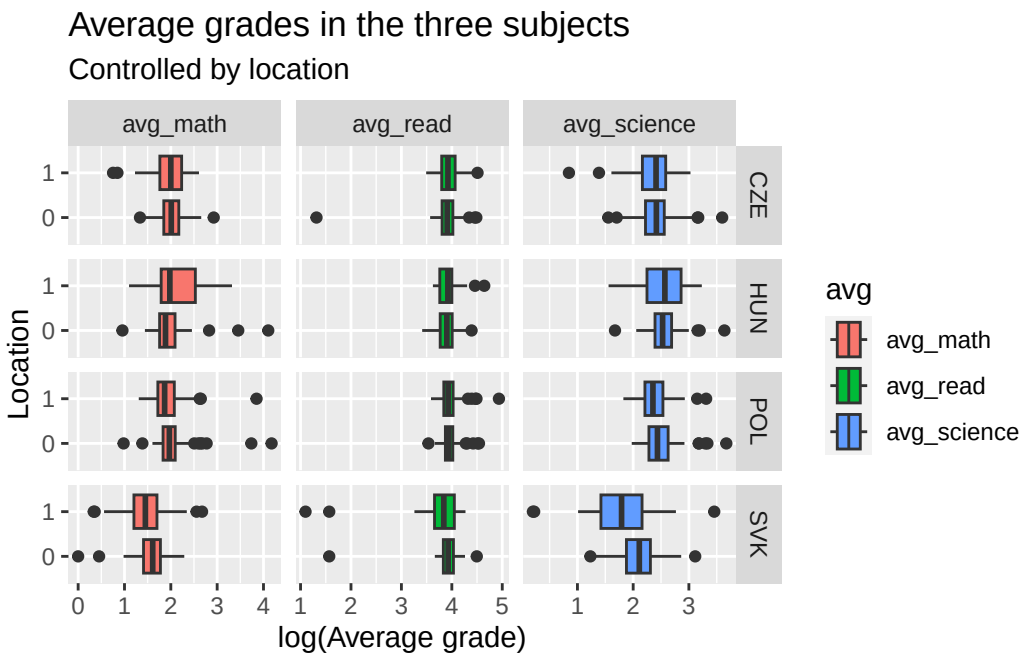
name	CZE	HUN	POL	SVK
bol_location	0.484	0.411	0.500	0.490
bol_extra_acts	0.103	0.101	0.000	0.000
bol_competition	0.323	0.411	0.444	0.349
bol_career_guidance	0.452	0.489	0.487	0.501
funding	0.101	0.077	0.090	0.068
students_male	183.576	230.992	141.259	117.215
students_female	134.320	170.437	130.440	128.833
teachers_ft	20.197	22.383	25.130	13.879
teachers_pt	8.922	6.830	7.776	4.913
total_students	232.565	290.519	261.044	196.683
total_teachers	22.588	24.300	25.650	16.051
ratio_f2m	1.337	1.214	0.936	1.106
ratio_pt2ft	0.576	0.227	2.622	0.184
ratio_ft2pt	8.047	17.792	11.112	7.800
ratio_t2s	0.042	0.062	0.192	0.032
ratio_s2t	3.313	2.897	2.844	2.883
ap_parental_eng	0.137	0.158	0.163	0.162
dropout_rate	0.072	0.057	0.035	0.036
avg_math	2.392	7.116	5.872	2.211
avg_read	11.115	10.893	11.015	11.774
avg_science	3.935	4.878	4.206	3.970

Based on the summary values we can see, that Poland has the highest proportion of urban schools in the sample (47%) whereas Hungary the lowest (only 21%). Official extra activities are so widely available that almost all institutions responded with yes, we can conclude that probably there is not enough variance in the data to find any effect in the models. Proportion of competing schools are similar across countries, however career guidance proportions are varying between 38% (Poland) and 72% (Czech Republic). Dropout rates are relatively low, but highest in the Czech Republic.

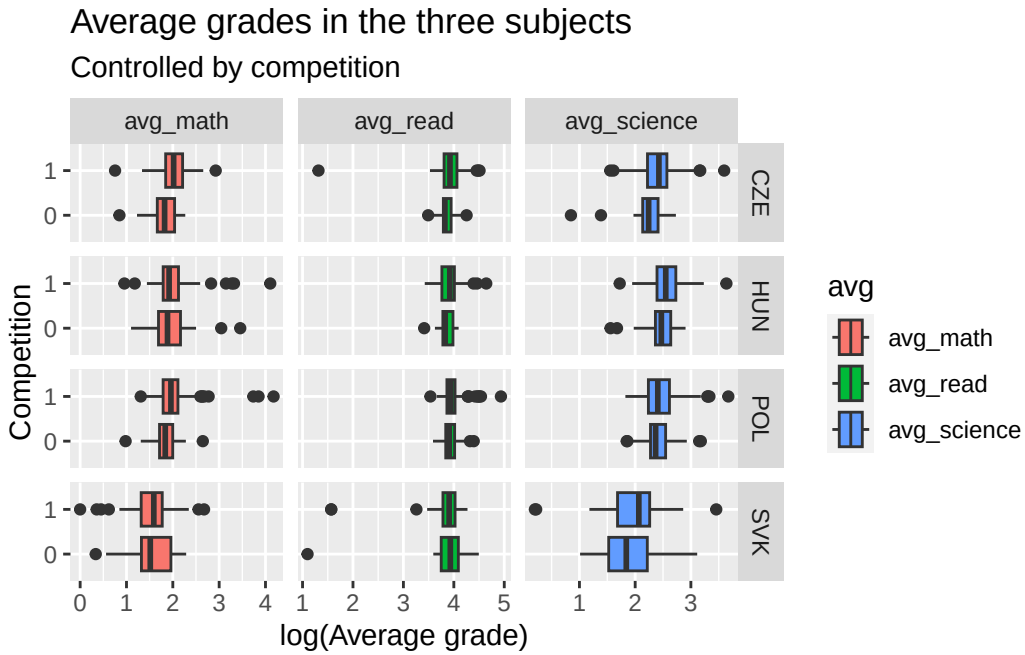
FUNDING IS IN TABLE BUT NOT EARLIER!

Visualisations

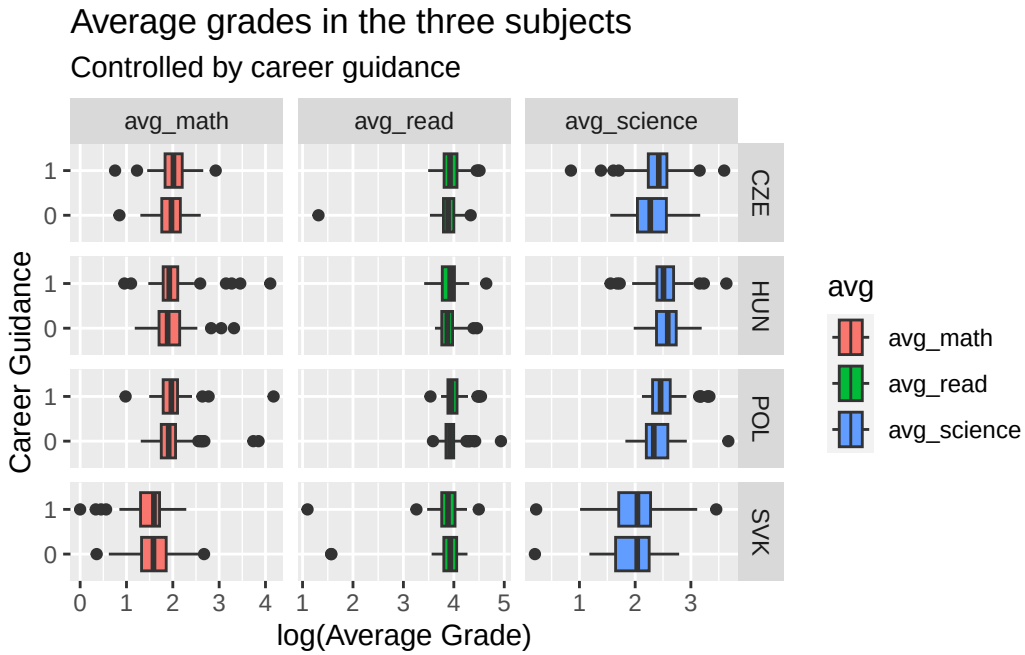
In this subsection we discover the patterns in the data using visual techniques. The following chart shows the average results in the three tests for each country, grouped by location. We can see some extreme outliers in almost all cases. Urban schools seem to slightly outperform rural schools in math scores in Hungary, but the opposite seems to be the situation in Slovak Republic. Interestingly science score on average are higher in rural located schools in general. Heterogeneity in terms of interquartile range is usually larger for urban schools, while rural school averages are more similar to each other. This seems to be the case for all V4 countries and all subjects. (Note that results are on a log scale!)



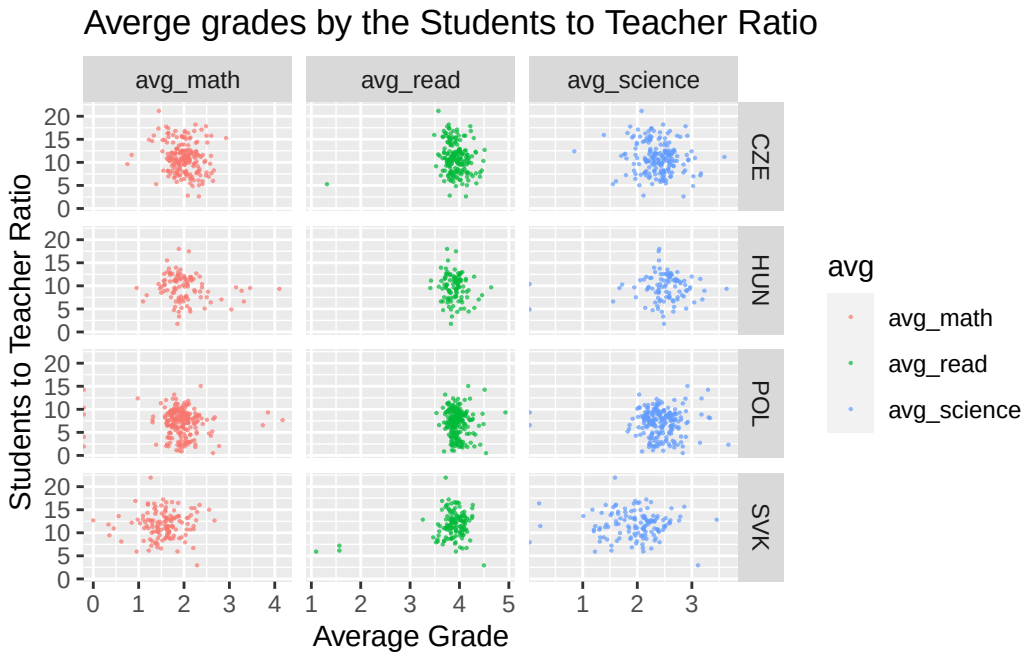
Next we checked for differences in terms of competition and performance. It seems to be evident that if institutions stated that there is competition, average results are better or similar. This conclusion holds through all countries and subjects as can be seen on the following graph.

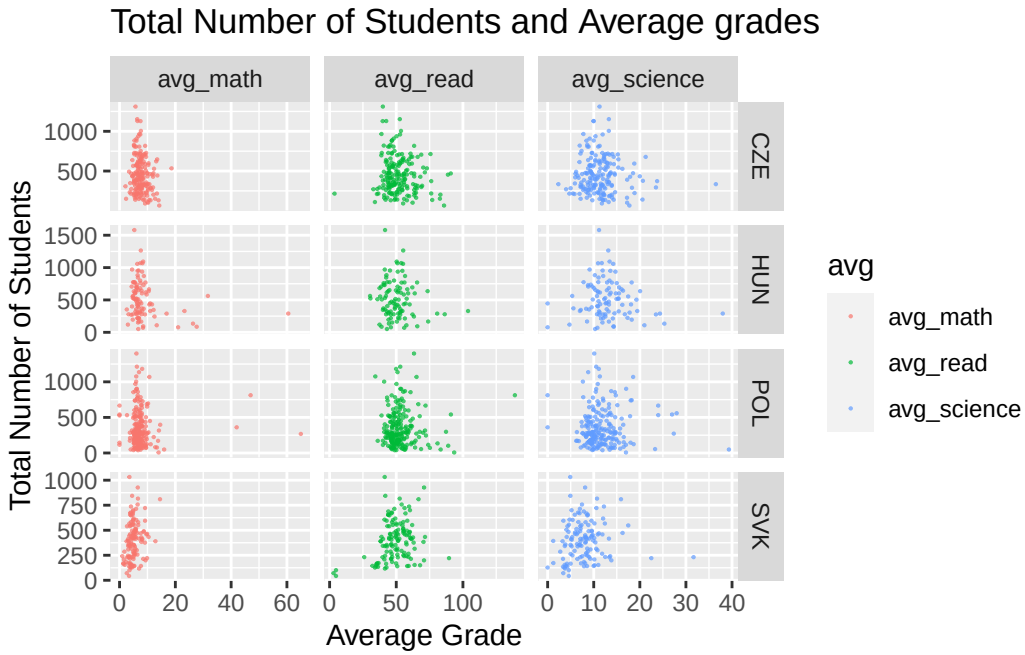


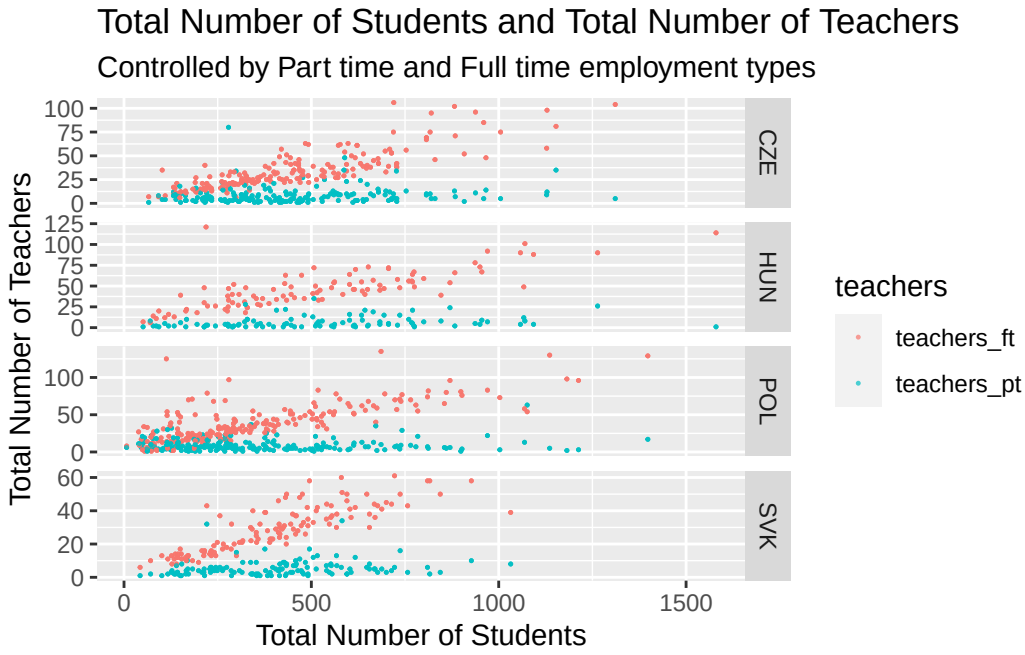
Career guidance might improve grades on its own as well, but it also shows how important it is for the schools to develop their students' abilities according to their needs. Our data does not show a systematic relationship between performance (grades) and career guidance availability. Guidance might help and has an influence on later success of students, not the actual observable scores achieved.

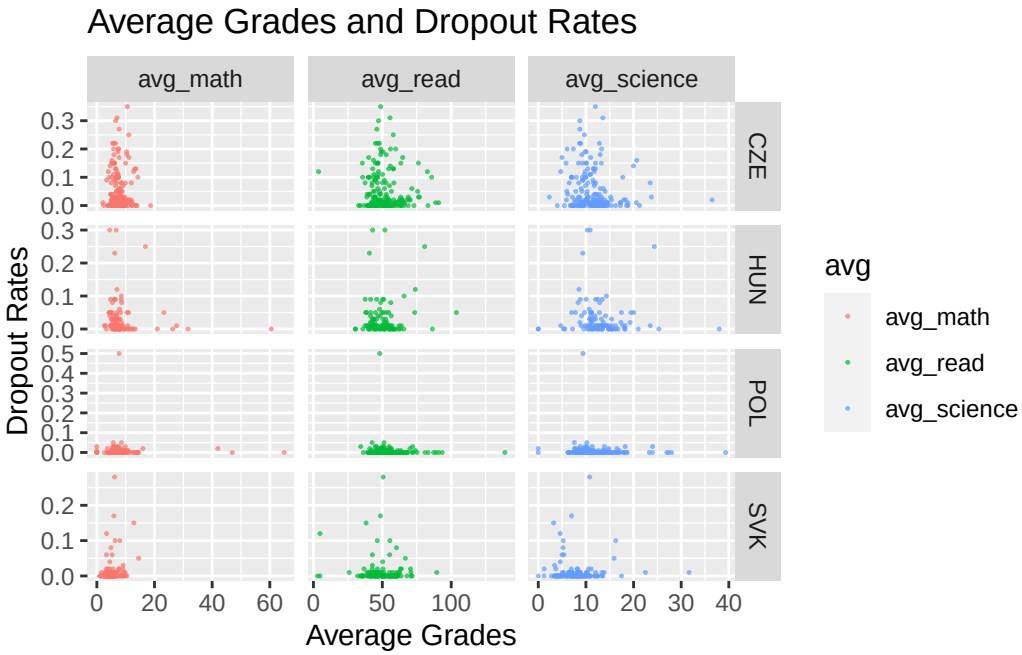


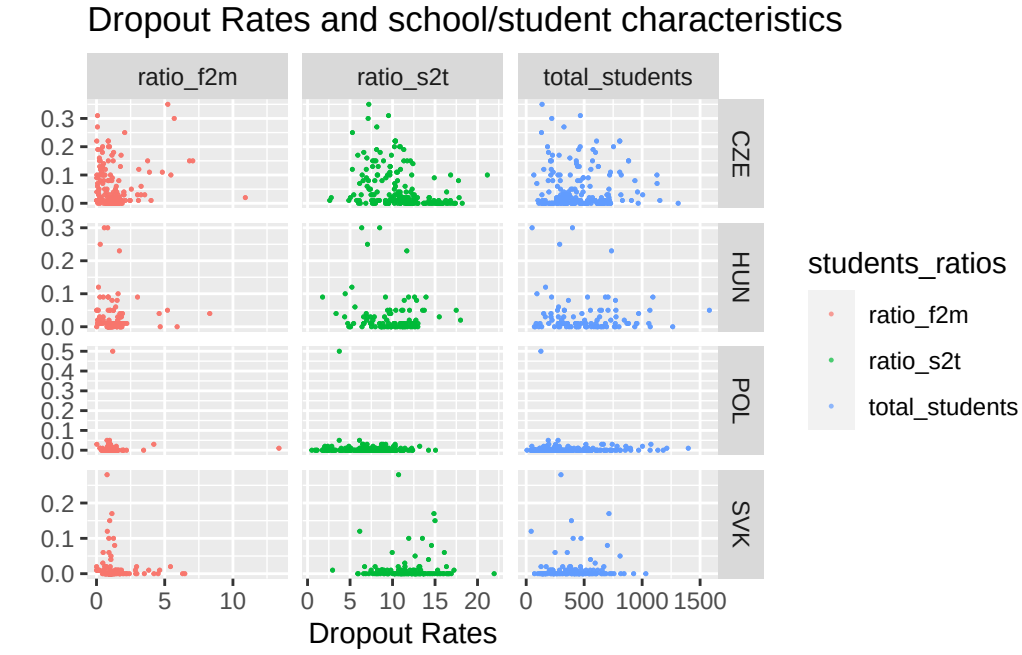
Student to teachers ratios are one way to measure the quality of teaching. In general we observe low ratios in Polish schools, compared to the other three countries. In general, lower ratios indicate a somewhat better average result, however, the strength of the relationship seems to be weak.

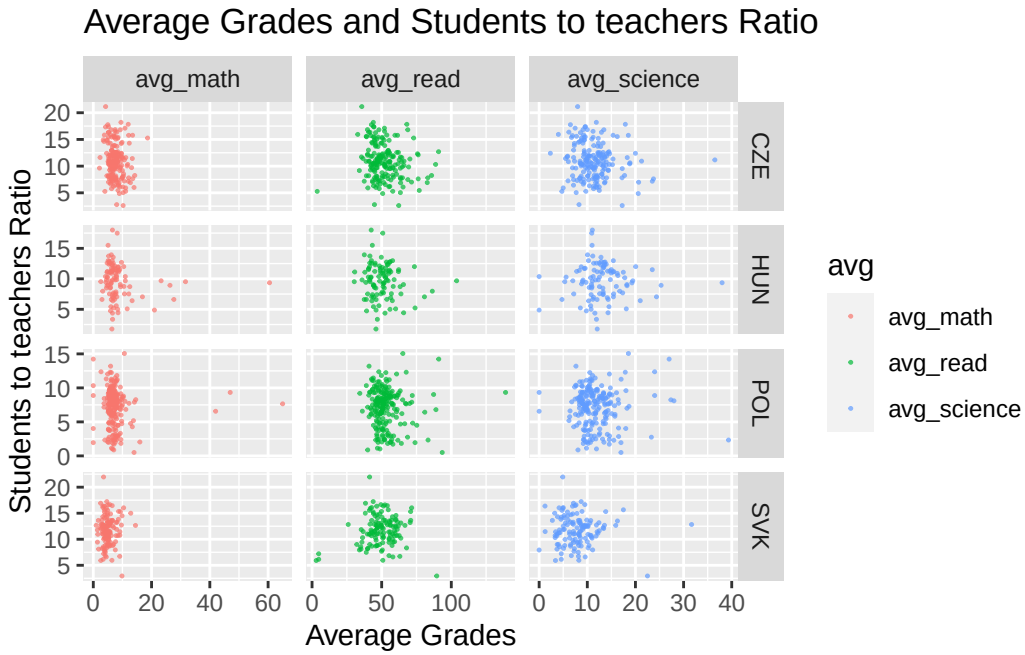



Total Number of Students and Average grades
avg_math
avg_read
avg_science
CZE
HUN
POL
SVK
Total Number of Students
Average Grade
avg
avg_math
avg_read
avg_science


Total Number of Students and Total Number of Teachers
Controlled by Part time and Full time employment types
CZE
HUN
POL
SVK
Total Number of Teachers
Total Number of Students
teachers
teachers_ft
teachers_pt


Average Grades and Dropout Rates
avg_math
avg_read
avg_science
CZE
HUN
POL
SVK
Dropout Rates
Average Grades
avg
avg_math
avg_read
avg_science


Dropout Rates and school/student characteristics
ratio_f2m
ratio_s2t
total_students
CZE
HUN
POL
SVK
Dropout Rates
students_ratios
ratio_f2m
ratio_s2t
total_students



Results and discussion

```
# A tibble: 16 x 6
   country model  total_students ratio_f2m ratio_s2t ratio_ft2pt
   <chr>   <glue>          <dbl>     <dbl>     <dbl>       <dbl>
 1 hun     res1          0.00552     10.2      1.08        0.213
 2 hun     res2          0.00449      4.98     0.862       0.221
 3 hun     res3          0.00161      1.55     0.178       0.109
 4 hun     res4          0.00163      1.56     0.173       0.108
 5 pol     res1          0.0117       9.97     0.515      18.3
 6 pol     res2          0.00537      3.28     0.166      16.7
 7 pol     res3          0.00429      2.09     0.132       8.17
 8 pol     res4          0.00449      2.11     0.147       8.82
 9 svk     res1          0.0117       2.93     0.889       0.0847
10 svk     res2          0.0124       2.38     0.211       0.103
11 svk     res3          0.00428      0.732    0.0732      0.0899
12 svk     res4          0.00428      0.749    0.0742      0.0915
13 cze     res1          0.00443      3.04     0.709       0.0853
14 cze     res2          0.00106      1.82     0.0494      0.0403
15 cze     res3          0.000147     0.509    0.0129      0.0203
16 cze     res4          0.000140     0.512    0.0125      0.0207
```

```
# A tibble: 4 x 5
  model    total_students ratio_f2m ratio_s2t ratio_ft2pt
  <chr>             <dbl>     <dbl>     <dbl>       <dbl>
1 res1_all       0.00747      4.08    0.566        0.129
2 res2_all       0.000730     1.97    0.0132       0.0263
3 res3_all       0.000241     0.699   0.00673      0.0221
4 res4_all       0.000185     0.846   0.00596      0.0565
```

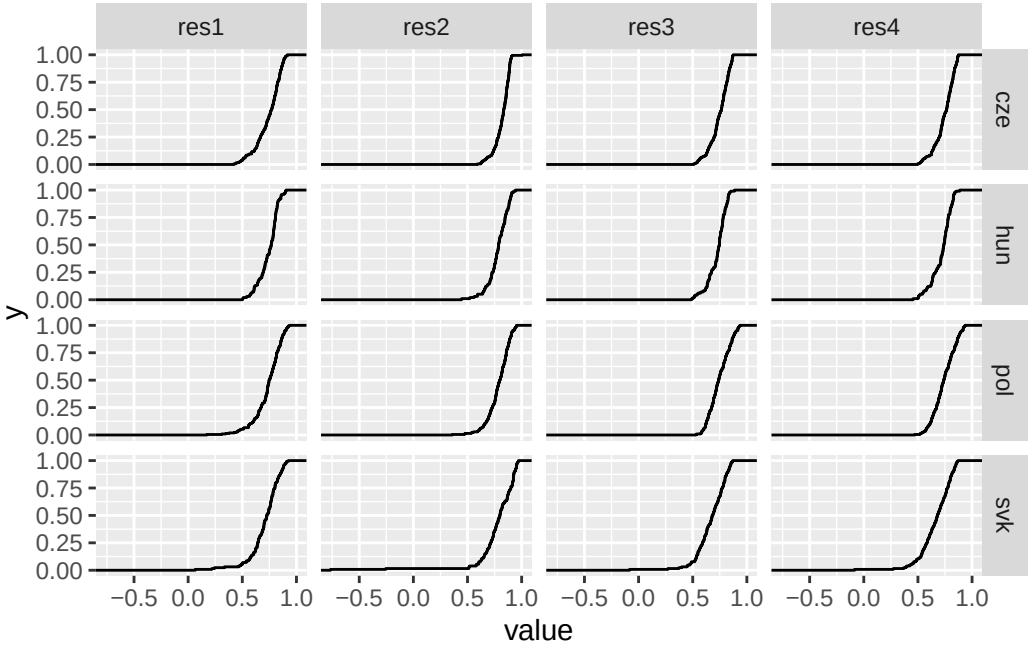
```
# A tibble: 8 x 4
  country model    z1     z2
  <chr>   <chr> <dbl>  <dbl>
1 svk     res1   3.29  1.41
2 svk     res2  -1.79 -1.61
3 hun     res1   7.30  8.62
4 hun     res2   2.63  3.90
5 cze     res1  11.6   3.27
6 cze     res2   2.94  0.306
7 pol     res1   5.76  4.88
8 pol     res2   1.30  0.677
```

```
# A tibble: 2 x 3
  model       z1     z2
  <chr>    <dbl>  <dbl>
1 res1_all  9.65  5.90
2 res2_all  1.04 -0.162
```

```
# A tibble: 16 x 4
   country model  value_mean value_sd
   <chr>   <glue>      <dbl>    <dbl>
 1 hun     res1        0.744   0.0883
 2 hun     res2        0.782   0.0915
 3 hun     res3        0.726   0.0834
 4 hun     res4        0.719   0.0907
 5 pol     res1        0.736   0.124
 6 pol     res2        0.787   0.0985
 7 pol     res3        0.746   0.0950
 8 pol     res4        0.742   0.101
 9 svk     res1        0.710   0.137
10 svk     res2        0.777   0.200
11 svk     res3        0.671   0.136
12 svk     res4        0.665   0.141
13 cze     res1        0.742   0.113
```

```
14 cze     res2        0.821   0.0692
15 cze     res3        0.747   0.0864
16 cze     res4        0.745   0.0892

# A tibble: 4 x 3
  model     mean     sd
  <chr>    <dbl>  <dbl>
1 res1_all 0.675 0.138
2 res2_all 0.799 0.0706
3 res3_all 0.614 0.102
4 res4_all 0.614 0.103
```




```
$x
[1] "inefficiency level"

$y
[1] "CDF"

$title
[1] "Cumulative distribution of the inefficiency estimate per model"

attr(,"class")
[1] "labels"
```

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