The End of Equal Opportunities?
A Multilevel Analysis of the Luxembourg PISA 2003 Data

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Abstract

The competitiveness of a country depends on the ability to tap the full potential of its talents. Therefore, equal opportunities in its educational system are an important condition for this process. This study analyzes whether students in Luxembourg have the same chance to assess higher secondary education independently of the social-economic status (SES) of their parents. First of all, an explorative view on the between- and within-school variation of students' attainment in mathematics is presented showing that a strong contextual effect of the schools exists. Secondly, a selection model for the Luxembourg Educational Authorities' choice of the secondary school type is presented and tested with the Luxembourg PISA 2003 data set published by the OECD. It proves that the SES and primary school failure have a strong effect on the choice of grammar schools. Thirdly, a multilevel model is presented which controls this selection process. It predicts students' achievement in mathematics by exogenous variables on student and school level. It demonstrates that beside the school types the SES has a statistical significant effect on attainment in mathematics between and within schools. In contrast to the OECD (2006) findings the quality of teaching indicators have not a significant effect on the achievement in mathematics. These strong effects of the SES challenge equal opportunities in the Luxembourg educational system. Finally some improvements of the research design are proposed for further research.

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Key words: PISA 2003, Mathematical Attainment, Equal Opportunities, Multilevel Analysis

"Statistics can't work magic." Howard Wainer (1989b: 188)

1. Research questions

The competitiveness of a country depends on its ability to tap the full potential of its talents. Equal opportunities in the educational system is an important condition for this process. Therefore the following question has to be answered. Have Luxembourg children the same chance to assess higher secondary education independently of the social-economic status of their parents?

The thesis leads to the following research questions. Firstly, to which extent does the school context influence the mathematical performance of the students? Secondly, what are the selection criteria of the Educational Authorities for the secondary school types? Thirdly, how can the social and ethnical selectivity of the school types be controlled in a multilevel analysis of this performance? Fourthly, to which extent does the social-economic status of the parents influence the performance of their children?

2. The Luxembourg PISA 2003 data set

This study uses the official PISA 2003 data set published by the OECD in December 2004. The Luxembourg sample includes 3,923 of 4,204 students at the age of 15. They have been tested in their 29 schools.

This corresponds to a coverage rate of 93.27 % plus 1.6 % neutral drop out. These students have spoken neither German nor French or they have been truants at the testing day.

The international PISA team use a multimatrix-sampling–test design with a systematic rotation of 13 test blocks. 7 of them contain tests in mathematics. The others are reading, problem solving or natural sciences. Every student has to work up 4 of 13 test blocks within two hours. They consist of 50 % multiple choice questions and 50 % text exercises demanding short answers or drawings. Four trained persons coded the latter with an intercoder-reliability of 89.6 % in the French test version chosen by 20 % of students. In the German test version they reach a reliability of 93.6 %. 80 % of students have chosen the latter.

The mathematical competence - a latent variable - has been estimated by a two parametric Rasch- or Partial-Credit Model developed by Masters (1982). It estimates the person's parameter representing the test score and the difficulty-parameter of the item. For correct answers the PISA team demands a solution probability of at least 62.0 %. The used item–response models estimate the competence score of a person as a fair comparison which psychometricians call specific objectivity. For students work up only four of thirteen test blocks, non-tested blocks and their refusals have been replaced by the Plausible-Value technique developed by Mislevy & Sheehan (1992, 1997). They use the multiple imputation technique introduced by Rubin (1987). Both assume that respondents' refusals are at least missing at random. Per student and competence area five imputations have been made to get five plausible values.

Therefore the researcher has to estimate each model five times and to average the estimated coefficients. Afterwards he or she has to adjust the standard errors to the additional imputation variance of the dependent variable. Bryk & Raudenbush (2005) has developed the Hierarchical–Linear Models program which does this automatically in version 6. The average competence score is standardized for the OECD with a mean of 500 and a standard deviation of 100 points.

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1 OECD (2004a).

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3. Explorative analysis of the test results

Figure 1 gives a short look on the distribution of the mathematical test score of Luxembourg for the whole and the variation between and within the 29 schools.

On the whole Luxembourg students reach an average test score of 493.0 points, being under the OECD average of 500. The corresponding standard deviation is 92 points. In figure 1 the blue line represents the overall average of Luxembourg. To explore the variation between schools the reader has to compare the black bars within the red school box representing the median of the within-school distribution. The comparison of the black bars shows that there is a high variation of the test results between these 29 schools. The box and the whiskers present the variation of the test results within each school. Outliers are marked by cycles. To assess the extent of the contextual influence on the test scores a Random-Intercept-Only Model (RIOM) have been estimated taking the Plausible Values as the dependent variables. It has found that 31.3 % of the variation of the test score can be explained by school context. This shows that the school context itself is an important factor of the learning and achievement process.

Figure 1: Variation of the mathematical test results within and between the 29 Luxembourg schools 2003

4. Estimated Models

Two models have been developed and tested. The first one examines the allocation process of students within the educational system of Luxembourg. The second one predicts the attainment in mathematics by students and school characteristics.

4.1 The selection model for the Luxembourg school types

The allocation of students within an education system is not at all a random process. At the end of the primary education - normally at the age of 12 - the Luxembourg Educational Authority decides to what kind of secondary school a student should go. Parents have not the choice by themselves. Therefore a selection model has been developed predicting the choice of the school type by the following exogenous variables. The students' school career questionnaire has measured all of them retrospectively. Figure 2 presents this selection model with the exogenous variables used for prediction.

The international PISA team has measured the Economic-Social-Cultural Status with a Principle-Component Scale which uses the following four indicators:

- The highest Socio-Economic Index of the parents. Ganzeboom et.al. (1992) has developed this index for international comparative research.
- The highest educational degree of the parents measured in school years
- An Item-Response-Index of the cultural possessions of the household
- The number of books in the parents' household.

This Principle-Component scale has an OECD average of 0 and a standard deviation of 1. On the whole, Luxembourg students have a little bit higher mean of 0.187 and standard deviation of 1.089. For our selection model the ESCS-index has been centered at its grand-mean to anchor the estimation at the average Luxembourg family (c_escs).

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To assess the influence of the decision criteria on the choice of the school type a multinomial logit model is estimated with Stata using the vocational school (EST) as the reference category. It is a multi-equation model estimating the logit parameters for the three alternatives: grammar (ES) versus vocational school (EST), comprehensive (MIXED) versus vocational school (EST) and European (EE) vs. vocational school (EST). Assuming that the observation are independent from each other the following table presents its logit parameters, standard errors and t-tests.

The students have been tested at their schools. Therefore, the assumption of the independence of observations is seriously violated. They are building clustered sub-samples which are independent on the school level but not inside their school buildings. To correct the intra-class correlation within each school Long & Freese (2005) recommend to use robust standard errors to avoid statistical fallacies. Therefore, they calculate the Huber-White-sandwich estimator of the parameter covariances. Stata offers this possibility by the cluster-option of the mlogit-command. Instead of the conventional likelihood-ratio-chi-square test Stata uses now the Wald test to check the statistical significance of the multinomial logit model on the whole. Its zero hypothesis assumes that all logistic slopes are zero in the population. It is rejected with an error probability of less than 1 per thousand. The following table presents the logit parameters, robust standard errors and t-tests.

Figure 2: The selection model for the Educational Authority’s choice of the secondary school type
To assess the practical significance of the model the McKelvey & Zavoina Pseudo-R Square has been applied for each alternative comparison.

\[ \text{McKelvey & Zavoina (1975: 112), Veall & Zimmermann (1996: 250); Langer (2007).} \]

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To assess the practical significance of the model, the McKelvey & Zavoina Pseudo-R Square has been applied for each alternative comparison.
The reference category is marked by the value of zero. The independent variables explain 49.72% of the logit variation of the comparison grammar vs. vocational school, 69.96% of the choice between European and vocational school and only 4.47% of the choice between comprehensive and vocational school. Therefore, it fits very well for the first two alternatives but not for the last one. The McFadden- and Cragg & Uhler Pseudo-R-Squares assess the overall fit of the multinomial logit model with values of 17.22% and 37.70% respectively. For its interpretation McFadden has formulated the following rule of thumb: "Those unfamiliar with the $\rho^2$ index should be forewarned that its values tend to be considerably lower than those of the R squared index and should not be judged by the standards for a 'good fit' in ordinary regression analysis. For example, values of 0.2 to 0.4 for $\rho^2$ represent an excellent fit" (McFadden 1979: 307). Corresponding to McFadden’s rule the multinomial logit model has an excellent fit except for the alternative comparison of mixed and vocational school.

To evaluate the effect sizes of the exogenous variables for these choice alternatives the marginals for metric variables and the discrete probability change for dummy variables have been used.1 In figure 4 these effect sizes are presented by a plus-minus diagram. The reference group consists of Luxembourg boys grown up in core or greater family with the average ESCS and have no failure in the primary school. For them the following choice probabilities have been estimated for the four school types.

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These probabilities serve as baselines for the effect sizes of the exogenous variables in figure 4. This plus-minus diagram shows the estimated effects of the independent variables on the school type choice. The zero point of the y-axis is equivalent to these baseline probabilities. The bars on the x-axis represent the probability change of the different alternatives caused a unit-change of the exogenous variables which is measured in percentages. Thus, they are deviations or probability differences from the reference group - named „the average boys“. Corresponding to a common rule of thumb all effects or deviations within the range between minus five and plus five percent are not statistical significant. Following Long & Freese (2005) all effects has been tested with robust standard errors.

Figure 4: Estimated effects of the exogenous variables on the choice of the secondary school type

Figure 4 shows a strong effect of the Economic-Social-Cultural status (\(c_{escs}\)) on the choice of the secondary school type. A decrease of one standard deviation leads to an increase of the choice probability for the vocational school (EST) by +16.6 %. On the other side the probability for the grammar school (ES) is reduced by -13.6 %. An increase of one standard deviation improves the chance of being sent to grammar school (ES) by 21.8 %. Reversely it lowers the probability of the vocational school (EST) by -13.8 %. The chance of being accepted by the European school (EE) improves by +1.2 %. Immigrant students of the first and second generation (\(_{immig}_1, _{immig}_2\)) – especially the children of European Officials – have significant higher chances of +9.4 and +11.7 % respectively than the reference group to enter the European School. On the other hand their chances for the other school types decrease. The Educational Authority does not consider the gender (\(d_{girls}\)) or the family background of the student (\(d_{singlep}\)). A failure during primary school time (\(drisced1\)) leads to an increase of +16.8 % for the vocational and a decrease of -20.6 % of the grammar school. The chance of the comprehensive school improves by +4.0 %. The last three variables have not any effect on choice of the European School.

Figure 5 shows the results of a hierarchical model test of the multinomial logit to evaluate the relative importance of the exogenous variables for each alternative comparison. It demonstrates the overall influence of the parents’ Economic-Socio-Cultural Status on the choice of the school type followed by the primary school failure. The immigration background influences only the decision between the European (EE) and the vocational school (EST).

Summarising, the allocation of students to the different secondary school types is a systematic selection process which has to be controlled in the
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4.2 The multilevel model for the students’ performance in mathematics

Why is it necessary to use a multilevel model instead of a conventional regression model? Students within their schools build a hierarchical data structure. Therefore, the observations are not independent from each other which is assumed by standard statistical theory. Formally spoken the PISA data set consists of clustered samples which are very homogenous within themselves. Thus the use of classical regression models leads to biased standard errors of the exogenous student and school characteristics. Contextual school variables also do not vary within schools but only between schools. Therefore their degrees of freedom in a t-test have to be adjusted to the number of cluster and not to the number of students. Otherwise the results of the t-test are not reliable. The multilevel model allows also to test cross-level interaction between exogenous student and school variables. Figure 6 shows the causal structure of the estimated Intercept-as-Outcome Model.

The systematic selection within the education system is controlled by introducing the main selection criteria like the ESCS (MESCS) and Immigration background (PCTIMMIG) as causal factors at the school level. Therefore, the multilevel model includes the school mean and the percentage of immigrant students as exogenous contextual variables. Snijders & Bosker (1999), Raudenbush & Bryk (2002) and Langer (2004) give a useful introduction in the statistical fundamentals of multilevel analysis.

The multilevel model in figure 6 has been estimated by HLM version 6, developed by Raudenbush, Bryk, Cheong & Congdon (2004). It adjusts automatically the estimates of the fixed and random effects, their standard errors and deviance corresponding to the Plausible Value technique developed by Mislevy et. al. (1987, 1992).
The following student and school characteristics build the causal structure of the multilevel model. The dependent variable is the overall mathematical test score of student i within his/her school j. This maths score is predicted by school- and student-variables. On the school level there are the school types: vocational- (DEST), grammar- (DES) and comprehensive school excluding the European School from further analysis. To measure the quality of teaching this study use the same indicators like the OECD (2006):

- The students per maths teacher ratio (SMRATIO) following the hypothesis the more the students, the lower the quality of teaching. The mean is 100.38 with a standard deviation of 53.26.

- The percentage of full certified teachers (PERCCERT). The corresponding mean is 87.97 with a standard deviation of 12.76.

- The using of ability group (streaming) within the school (DABGROUP). The mean or percent is 0.56 with a standard deviation of 0.51.

All metric school variables have been centered at their grand-mean in order to test afterwards against the average comprehensive school in Luxembourg.

The following student variables have been used:

- The Economic-Social-Cultural-Status (ESCS) with a mean of 0.18 and a standard deviation of 1.08. This variable is also grand-mean-centered in order to test later against the „average boys“.

- Gender (DGIRLS): Girls versus Boys

- The Family Background (DSINGLEP): Single Parent versus Core or greater Family
- The Immigration Background (DIMMIG): first or second Generation Immigrants vs. Luxembourg students (natives)

- School Failure (DRISCED2): Repeating a class during secondary education.

- Grade difference (DISCED2U): Grade 10 vs. Grade 9. One third of the students in Luxembourg have been tested in grade 10 and two third in Grade 9. Therefore a substantial difference of their test scores is expected.

For the estimation of the multilevel model with HLM 6, 3,059 Students in 28 schools has been used. The European school have been excluded because it does not belong really to Luxembourg educational system.

The reference group consists of Luxembourg boys of grade 9, grown up in a core or greater family with an average ESCS. They have not any failure during their secondary school time and are named „the average-boys“. For these average boys the model has estimated a test score of 507.8 points. The reference context is a comprehensive school which does not build ability groups (no use of streaming). This school has the average student-maths teacher ratio of 100.38 and an average percentage of certified teachers of 87.97. It has a mean ESCS of 0.15 and a mean percentage of immigrant students of 28.87.

To assess the fit of the presented Intercept-as-Outcome-Model (IasOM) the Bryk & Raudenbush Proportional-Reduction-of-Error-R Square has been employed for the between- and within-regressions. Therefore two additional models have been estimated serving as baselines for the proportional reduction of the random-effect parameter variance. The Random-Intercept Model (RIM) estimates the maximum of the variation of the context-dependent intercepts representing the expected test score of the reference group. Otherwise the Random-Intercept-Only Model (RIOM) estimates the grand-mean of the test-score independently of students and school characteristics. Ignoring any students' variables it also estimates the maximum of the error variance of the within-regression model.

At the school level the used contextual characteristics explain 88.70 % of the between-school variation of the mathematics test score of the reference group - the average boys. The presented student characteristics explain 17.35 % of the pooled within-school variation of the test scores. This percentage can be easily increased by introducing some attitudes towards Mathematics like self efficacy or anxiety, but they have been measured directly after the attainment test. Therefore they are not independently measured so that they reflect rather the PISA test experience and not a stabile trait in the psychological sense of the term.

\[
\begin{align*}
\text{Level 2 - PRE - } R^2(b_{0j}) &= \frac{\sigma_{u_j}^2(M_{RIM}) - \sigma_{u_j}^2(M_{IasOM})}{\sigma_{u_j}^2(M_{RIM})} = \frac{1241.09 - 140.23}{1241.09} = 0.8870 \\
\text{Level 1 - PRE - } R^2 &= \frac{\sigma_{e_j}^2(M_{RIO}) - \sigma_{e_j}^2(M_{IasOM})}{\sigma_{e_j}^2(M_{RIO})} = \frac{5274.92 - 4359.64}{5274.92} = 0.1735
\end{align*}
\]

1. Bryk & Raudenbush PRE-R-Square of the between-school regression

2. Bryk & Raudenbush PRE-R-Square of the within-school regression

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The multilevel model in figure 5 is an Intercept-as-Outcome Model with the following equations.

Level-1 Model

\[ Y = B_0 + B_1 \times \text{ESCS} + B_2 \times \text{DGIRLS} + B_3 \times \text{DSINGLEP} + B_4 \times \text{DIMMIG} + B_5 \times \text{DRISCED2} + B_6 \times \text{DISCED2U} + R \]

Level-2 Model

\[ B_0 = G_{00} + G_{01} \times \text{SMRATIO} + G_{02} \times \text{MESCS} + G_{03} \times \text{PCTIMMIG} + G_{04} \times \text{DEST} + G_{05} \times \text{DES} + G_{06} \times \text{DABGROUP} + G_{07} \times \text{PERCCERT} + U_0 \]

For this model HLM 6 estimates the following fixed- and random-effect parameters with the corresponding standard errors and t-tests. Raudenbush & Bryk (2002: 64) use the chi-square test to decide whether or not the residual random-effects are significantly different from zero in the population. The residual variation of the context dependent intercepts is still significantly different from zero but compared with the Random-Intercept-Model it has been reduced about 88.7 % by the school characteristics.

The outcome variables are: PV1MATH, PV2MATH, PV3MATH, PV4MATH, PV5MATH

Final estimation of fixed effects:

<table>
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<th>Fixed Effect</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>T-ratio</th>
<th>d.f.</th>
<th>P-value</th>
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<tr>
<td>For INTRCPT1, B0</td>
<td>507.758941</td>
<td>8.822531</td>
<td>57.553</td>
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<td>ESCS slope, B1</td>
<td>-0.028424</td>
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<td>MESCS, G02</td>
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<td>PCTIMMIG, G03</td>
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Final estimation of variance components:

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<th>Variance Component</th>
<th>df</th>
<th>Chi-square</th>
<th>P-value</th>
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<td>4359.63582</td>
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Firstly, the focus of interest is the between-school-explanation of the multilevel model. It explains the between-school variation of the expected test score of the „average boys“ - the reference group - by the school characteristics still presented. Figure 7 shows the effect sizes of the school variables in a plus-minus diagram. In order to assess the effect sizes of the different metric school characteristics the bars show the increase or decrease of the maths test score caused by a standard deviation increase of the exogenous contextual variable. Therefore, the comparison applies a common metric for the effect sizes. For the dummy variables the difference of the estimated test scores is used directly. Statistical significant effect are marked by the red colour. A blue bar has no effect in the population. Of course each bar represents a partial effect controlled for the other exogenous school variables.

On vocational school the Luxembourg average boys attain 18.4 points less than their co-students going to the comprehensive school. On the other hand students of the grammar school attain on the average a significant 25.4 points higher test score than the comprehensive school. The three indicators of the teaching quality do not a have a statistical significant effect on the test score of the average boys. From the practical point of view the effects are very small even if the student- maths-teacher ratio or the percentage of qualified teachers increases a full standard deviation of its own (\( s_{\text{SMRATIO}} = 53.26 \) respectively \( s_{\text{PERCCERT}} = 12.76 \)). The corresponding test deviations are -1.5 respectively +3.8 points. The effect of the social selection of the school is statistically significant. An increase of one standard deviation (\( s_{\text{MESC}} = 0.51 \)) lead to an improvement of the test-score about 11.8 points of the test scale. In the contrast to this finding the ethnical selectivity measured by the percentage of immigrant students in the regarded school have no significant effect on test attainment. Its increase of standard deviation (\( s_{\text{PERIMMIG}} = 15.1 \)) reduce the test score only by 3.8 points.

Figure 8 presents the within-school explanation of the estimated multilevel model. As the baseline it uses also the expected test score of our reference group – the Luxembourg average boys. All causal effect are estimated as fixed effects which do not vary between schools. Now the test-score difference between students of the same school is explained by their exogenous variables. An increase of the Economic-Social&Cultural Status of a standard deviation (\( s_{\text{ESCS}} = 1.08 \)) improves the mathematical attainment by 10.1 points significantly. Girls achieve a 28.4 points lower test score than the boys which is a strong significant gender effect. The family background has no significant influence on attainment in mathematics. The 5.2 point group difference between single parent and core family students has no practical relevance. On the average immigrant students attain a 18.0 points lower test score than their Luxembourg classmates. Repeating one class during secondary education does not reduce significantly the maths test score. The estimated reduction of 5.7 points has no practical importance. One third of the Luxembourg student at age of fifteen has been tested in grade 10 instead of 9. They achieve a 49.4 points higher test score than their 9 grade schoolmates. This test difference is statistically significant. It is almost equivalent to one competence degree of the PISA-test (about 80 % of 65 points). This shows that the PISA-study tests rather the competence level of Luxembourg students in grade 10 instead of grade 9. This can be explained by the main focus of Luxembourg school system – the trilingual education.
Figure 7: The effect of the school variables on the average boys’ maths-test score (Between-school regression)

Figure 8: Effects of the student variables as deviation from the average boys’ score (Within-school regression)
5. Summary

Summarizing, against all expectations the quality of teaching indicators do not significantly improve or aggravate the test results. This disproves the OECD-study of 2006 which uses the same data set and the same variables. Also the test differences between the vocational (EST), the grammar (ES) and the comprehensive schools (ES+EST) remain statistically significant. This shows that there are additional organizational factors behind these school types not tested in the multilevel model. Unfortunately the number of 28 secondary schools is very small in Luxembourg. Therefore, few contextual effects can be tested. Normally the maximum-likelihood estimation needs at least 10 contextual units per parameter.

The social selection or segregation between the 28 school has still a significant influence on the test score. Within the 28 school the difference of parents' Economic-Social & Cultural Status has also a significant effect on mathematical attainment. Both effects - between- and within-schools - show that equal opportunities are threatened by the investigated selection process within the Luxembourg education system.

In this study the selection process has been analysed only between school types and not between the different educational programs like Modulaire, Enseignement Secondaire Technique and Enseignement Secondaire General. Under the roof of a comprehensive school the researcher finds the whole range of educational programs. Therefore he or she has to analyse the allocation to educational programs within schools. This focus leads to a tree-level model consisting of students within their educational program within their school. That's why the researcher has to estimate the effects of the different programs within a comprehensive school on its students' attainment in mathematics. Finally he or she has to analyse the PISA data very carefully to avoid statistical fallacies like those produced by the OECD research group.
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