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an Application to Educational Outcomes  
in PISA***

Ricardo Martínez  
Universidad de Granada

Antonio Villar  
Universidad Pablo de Olavide and IVIE

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**JEL Classification:** H7, I2, I3, J1



**Department of Economics**

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# MULTILEVEL PROFICIENCY COMPARISONS WITH AN APPLICATION TO EDUCATIONAL OUTCOMES IN PISA\*

Ricardo Martínez<sup>†</sup>  
Universidad de Granada

Antonio Villar<sup>‡</sup>  
Universidad Pablo de Olavide and IVIE

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## Abstract

We propose in this paper a general framework for evaluation problems in which the outcome range of the variable can be partitioned into a series of levels that may have different meaning or importance, as they may represent qualitatively different results. Measures of poverty, excellence, inclusion or overall performance indicators are particular cases of this type of problems. We focus on the case of additive functions, to facilitate the discussion. This framework is applied to the analysis of educational poverty, excellence and overall performance of 15-year old students, according to the PISA 2015 data for all 68 participating countries and large economies. The analysis provides insights on the differences between countries that are not captured by the average test scores.

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<sup>†</sup>**Corresponding author.** Departamento de Teoría e Historia Económica. Universidad de Granada. 18011 Granada. Spain. E-mail: ricardomartinez@ugr.es.

<sup>‡</sup>Department of Economics, Universidad Pablo de Olavide, Ctra. Utrera km 1, 41013 Seville, Spain. Email: avillar@upo.es

## 1 Introduction.

This paper proposes an evaluation protocol that applies to a family of problems regarding the comparison of different societies (e.g. countries, firms, institutions) as a function the distribution of their members' outcomes, which are measured by a scalar quantitative variable. This is a common evaluation problem, examples of which are the comparison of income distributions, school achievements, unemployment duration, or scientific influence, to mention just four relevant instances. In the first case the variable is income, in the second one we can think of the scores of some test, the third can be linked with the number of months unemployed, and in the last one with the number of citations of scientific publications. We shall keep these examples as a reference along the paper to facilitate the discussion.

The novelty of our contribution is that we use a *multilevel* approach for the evaluation. By that we mean that the range of variation of the outcome variable that measures individual achievements can be sensibly divided into a number of levels or categories, defined by a partition in terms of intervals of the outcome range. Those categories indicate differences not only in the levels of achievements but also in their meaning or importance.

There are two main reasons why this approach is relevant. First and foremost because there are evaluation problems in which quantitative differences entail qualitative disparities. That is, different parts of the outcome distribution represent different aspects of that distribution from a descriptive or normative viewpoint. In the case of income distributions, for instance, values below 60% of the median identify the set of the poor, who are regarded as defining a particular category of agents. When measuring the scientific influence, publications in the top 1% or top 10% of the citation distribution represent contributions that are regarded as qualitatively different (e.g. the evaluation protocol of citation impact known as the NSF6).<sup>1</sup> Unemployment studies usually consider long-term unemployment (i.e. more than 12 months unemployed) as qualitatively different. The evaluation of scholastic performance in the OECD's PISA reports (OECD (2016), for instance) considers seven different levels of proficiency, defined by intervals of the test scores, which are regarded as qualitatively different (see OECD (2014)). Allmendinger and Leibfried (2003) document the relation between education and social policy, suggesting that pupils below a certain level of proficiency in their PISA scores should be

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<sup>1</sup>This is a procedure applied by the National Science Foundation in which there are six categories defined in terms of the following percentiles of the citation distribution: (1) Publications in the interval 1, 50th; (2) Publications in the interval (50th, 75th); (3) Publications in the interval (75th, 90th); (4) Publications in the interval (90th, 95th); (5) Publications in the interval (95th, 99th); and (6) Publications in the interval (99th, 100th).

considered as educationally poor.

Second, there are also cases in which we would like to get a finer discrimination than that derived from comparing average values (or even the mean and variance of the distributions). This becomes important when the outcome distributions of the groups we are comparing are very different or when the distributions within the groups are asymmetric. In those cases average (or mean and variance) comparisons may hide important structural differences between the groups and are not very informative. A multilevel evaluation permits one taking into account the differences in diverse parts of the distribution.

In summary, multilevel evaluation can be regarded as an intermediate step between comparing summary statistics and entire distributions, which permits one attaching different values to different parts of the distributions. Or, put differently, it provides a simplified way of comparing distributions in a non-symmetric step-wise manner.

We apply the multilevel approach to the analysis of educational outcomes for 15-year old students, according to PISA 2015, for 68 countries and large economies. This is a case in which average scores hide substantial differences in the outcome distributions between countries and where our approach can help uncovering the existing disparities in a systematic way. We propose here three different measures to complement the evaluation of the educational achievements in terms of average scores. First, a measure of low performance that tries to capture the extent of the students who do not achieve a minimal proficiency threshold. It can be regarded as a measure of educational poverty. Second, a measure of high performance that evaluates the success of educational systems in producing students with top outcomes. This can be interpreted as a measure of excellence. And third, an indicator of the overall performance that combines all levels of proficiency giving higher weights to better outcomes and hence taking into account the differences in the distributions. We shall show that these three evaluations provide new insights on the differences between educational systems and that the measures of educational poverty and excellence yield rankings that differ significantly from those in terms of mean scores.

The rest of the paper is organized as follows. In Section 2 we present the theoretical framework the propose the evaluation formulas that permit define the notions of poverty, excellence and overall performance. In Section 3 provide an empirical application regarding educational outcomes according to PISA 2015. In Section 4 we conclude with some final remarks.

## 2 Theoretical framework

Let us assume that we have a society of  $n$  agents,  $N = \{1, 2, \dots, n\}$ , whose performance relative to a given aspect has to be evaluated as a function of its members' outcomes. Agent  $i$ 's individual outcome is denoted by  $y_i \in D$ , where  $D$  is a connected subset of the real numbers. The vector  $y = (y_1, \dots, y_n) \in D^n$  give us the outcome distribution of the whole society. We consider, without loss of generality, that the elements of this vector are ordered so that  $y_1 \leq y_2 \leq \dots \leq y_n$ .

Let us assume that the domain  $D \subset \mathbb{R}_+$  can be divided into a set of categories, which gives us the possibility to treat agents differently depending on the category they belong to. To formalize this idea, let  $C = \{C_1, \dots, C_k\}$  be a partition of  $D$  into connected subsets  $C_h$ , which amounts to say that  $\bigcup_{h=1}^k C_h = D$ , and  $C_h \cap C_g = \emptyset$  for all  $g \neq h$ . Without loss of generality we take those categories as intervals open from the right, that is,  $C_1 = \{x \in D | q_0 \leq x < q_1\}$ ,  $C_2 = \{x \in D | q_1 \leq x < q_2\}$ , ...,  $C_k = \{x \in D | x \geq q_{k-1}\}$ . We denote by  $\mathbb{C}$  the set of all possible partitions of  $D$ .

For a given category  $h$ , let  $N_h$  the set of agents whose outcomes lie in  $C_h$ ,  $N_h = \{i \in N | y_i \in C_h\}$ , and  $n_h$  its cardinality. Obviously,  $\sum_{h=1}^k n_h = n$ .

For each category  $C_h$  we can define a **partial evaluation function** (PEF, for short), relative to this category, as a mapping  $f_h : D^n \rightarrow \mathbb{R}$  that measures the performance of those agents whose outcomes lie within  $C_h$ .

**Example 1.** *The following expressions are particular instances of partial evaluation functions that are frequent in the literature:*

(a) *Here we evaluate a category in terms of incidence, that is, in terms of the corresponding population share.*

$$f_h(y) = \frac{n_h}{n}$$

(b) *In this case the performance is evaluated in terms of the cumulative deviations with respect to the upper limit of the interval, so that this is a measure of relative loss (and hence decreasing in the outcome), powered by a sensitivity parameter  $\nu$ .*

$$f_h(y) = \frac{1}{n} \sum_{i \in N_h} \left[ \frac{q_h - y_i}{q_h} \right]^\nu$$

(c) *Using the dual idea, now performance is evaluated in terms of the relative gains with respect to the lower limit of the interval (and hence increasing in the outcome).*

$$f_h(y) = \frac{1}{n} \sum_{i \in N_h} \left[ \frac{y_i - q_{h-1}}{q_{h-1}} \right]^\nu$$

(d) This evaluation formula corresponds to a generalised mean of the outcomes in category  $h$ . The case  $\nu = 1$  yields the arithmetic mean and the case  $\nu = 0$  the geometric mean.

$$f_h(y) = \left[ \frac{1}{n_h} \sum_{i \in N_h} y_i^\nu \right]^{\frac{1}{\nu}}$$

(e) Finally, the next evaluation corresponds to the ratio between the mean outcome of the agents in category  $C_h$  and the mean outcome of the whole society  $N$ . The parameter  $\nu$  stands for the sensitivity of the measure to deviations with respect to the entire population. For  $\nu \in (0, 1)$  the PEF is increasing and concave whereas for values  $\nu > 1$  it is increasing and convex.

$$f_h(y) = \left[ \frac{\mu_h(y)}{\mu(y)} \right]^\nu,$$

where  $\mu_h(y)$  is the mean of category  $C_h$ , and  $\mu(y)$  is the mean of the whole society  $N$ .

Given a partition  $C = \{C_1, \dots, C_k\} \in \mathbb{C}$ , a **multilevel evaluation function** (or MEF, for short) is a mapping  $F : D^n \rightarrow \mathbb{R}$  that measures the overall performance of the agents in  $N$ , taking into account the existence of different categories of outcomes. That is,

$$F(y) = \phi(f_1(y), \dots, f_k(y))$$

We shall focus here on the family of multilevel evaluation functions that adopt the additive form, that is:<sup>2</sup>

$$F(y) = \alpha_1 f_1(y) + \dots + \alpha_k f_k(y), \quad (1)$$

with  $\alpha_h \geq 0$  for all  $h$  and  $\sum_{h=1}^k \alpha_h = 1$ . As these coefficients determine the relative importance of each category in the evaluation, there will often correspond to population shares,  $\frac{n_h}{n}$ .

**Example 2** (Overall performance). *This is an example in which our normative criteria are such that outcomes in the higher categories are given pre-eminence. We take the mean ratio as the appropriate partial evaluation function (Case (e) in Example 1 with  $\nu = 2$ ), and  $\alpha_h = \frac{n_h}{n}$*

$$F(y) = \sum_{h=1}^k \frac{n_h}{n} \left[ \frac{\mu_h(y)}{\mu(y)} \right]^2 \quad (2)$$

<sup>2</sup>Needless to say the additive format is a very particular case of that type of functions. Yet it provides a general and intuitive evaluation framework that suffices for our purposes.

Notice that the case in which  $\mu_h(y) = \mu(y)$  for all  $h$  (an egalitarian distribution) the MEF  $F$  takes the value  $F(y) = 1$ , which is a good point of reference to interpret the values of the index. That is, values above 1 indicate that the actual distribution is better than the egalitarian one, and vice-versa.

Note that Equation 2 can be rewritten as:

$$F(y) = \sum_{h=1}^k \frac{Y_h}{Y} \frac{\mu_h(y)}{\mu(y)},$$

where  $Y_h = n_h \mu_h(y)$  and  $Y = n \mu(y)$  are the aggregate realizations of category  $h$  and of the whole society. That is, the evaluation corresponds to the weighted sum of the mean shares, with weights given by the corresponding relative total achievements.

This evaluation approach is very flexible as it allows for different modeling choices regarding the design of the categories and the choice of the PEF's. In some cases the partition of the range of the variable into categories derives from some external consideration. An example is that of the levels of proficiency in the PISA reports, that are defined in terms of the achievement of certain competencies and then parameterised by intervals of the test scores. Similarly, the classification of the National Science Foundation citation impact obtains from a wide consensus among specialists, based on the shape of the citation distribution. When dealing with income distributions one usually refers to particularly relevant percentiles, such as 99, 80, 50 etc. The threshold defined by the 60% of the median income to define poverty is still another example of consensus. In other cases, though, there are less compelling reasons to choose a specific partition  $C$ .

In many situations, the society's performance is evaluated by the achievements of those individuals at the tails of the distribution, by focusing on low or high performers. A case in point is that of poverty indices, where only incomes below the poverty line are relevant. Another example is PISA, which considers that Level 2 as the minimum admissible one, and those students below the threshold that defines this level are considered as low performers (*educationally poor*).

**Example 3 (Poverty).** Let us consider Equation 1 when  $\alpha_1 = 1$  and  $\alpha_h = 0$  for any  $h > 1$ . If we take the PEF of Case (b) in Example 1, we obtain the following multilevel evaluation function:

$$F(y) = \frac{1}{n} \sum_{i \in N_1} \left[ \frac{q_1 - y_i}{q_1} \right]^\nu \quad (3)$$

This formula corresponds to the FGT family of poverty measures (see Foster et al. (1984)), which yields the well known poverty gap for the case  $\nu = 1$ .

A dual exercise is that of evaluating society's performance from the point of view of the excellence, that is, focusing on the high performers. Think, for instance, of the evaluation of citation impact by comparing institutions in terms of their shares in the top 10% (or even top 1%) of the distribution of total citations in a discipline. Here high performers are usually defined by a top percentile of the outcome distribution, to be interpreted as the threshold for excellence (see Albarrán et al. (2011)). Another relevant case is that in which we deal with the evaluation of the social cost of unemployment. Here we focus on those workers unemployed for more than one year, say, and obtain a measure of the unemployment that combines incidence and intensity (in terms of duration). See Gorjón et al. (2018) for an application to the Spanish labour market.

**Example 4** (Excellence). *Again, by selecting properly the multilevel evaluation function we can obtain a measure of high performance (excellence, but also inclusion) that is dual to the concept of poverty. Hence, if we take  $\alpha_k = 1$  and  $\alpha_h = 0$  for any  $h < k$  in Equation 1, and if we consider the PEF of Case (c) in Example 1, we can construct the following MEF:*

$$F(y) = \frac{1}{n} \sum_{i \in N_k} \left[ \frac{y_i - q_{k-1}}{q_{k-1}} \right]^\nu \quad (4)$$

The analysis of poverty and excellence represent an extreme case of evaluation in which we focus on just one of all the possible categories. We can think of the other extreme case in which each outcome in the support represents a category, which is the case for many inequality measures (e.g. Gini (1921), Theil (1967), Atkinson (1970)).

### 3 An empirical application: PISA 2015

The Program for International Student Assessment (PISA) is a worldwide study carried out by the OECD every three years, whose goal is to help improving educational systems based on the evidence regarding the outcomes they produce. Sixty eight countries and large economies participated in the 2015 wave that we take as reference. The key outcome variable is the scoring of a test designed so that it could be compared internationally, realized by 15 year old students. The score range is  $[0, 1000]$  with mean and standard deviation set initially at 500 and 100, respectively. Besides the test scores there is a rich information about the students' environment that helps understanding the outcomes and devising policies to improve them. There are three different fields of competence evaluated in each occasion, reading comprehension, mathematics and science, with a leading one that rotates. Science was the key field in 2015 and we shall refer to this dimension here.

The OCDE classifies the students' performance in seven different levels of proficiency, parameterised by critical values of the test scores. So we find here a partition of the domain  $D = [0, 1000]$  into seven categories that correspond to differential abilities. Special significance have the levels 2 and 5, which are considered the categories that define low and high performance. Table 1 provides the thresholds of the different levels for science. All the data that are presented below come from the 2015 PISA study, as supplied by the OECD.

Level	Interval of scores
$L_0$	$[0, 335[$
$L_1$	$[335, 410[$
$L_2$	$[410, 484[$
$L_3$	$[484, 559[$
$L_4$	$[559, 633[$
$L_5$	$[633, 708[$
$L_6$	$[708, 1000]$

Table 1: Levels and cutoffs in PISA 2015.

The diversity of the students' performance among countries is quite significant, as one should expect, even though such a diversity is partly hidden when comparing average scores. Figure 1 depicts the score distributions of five selected countries: the Dominican Republic, Singapore, Spain, Turkey and the United States. Singapore and the Dominican Republic are the extreme cases of good and bad results. Note that besides the difference in the overall average values, the distributions exhibit very different shapes, especially regarding the tails.

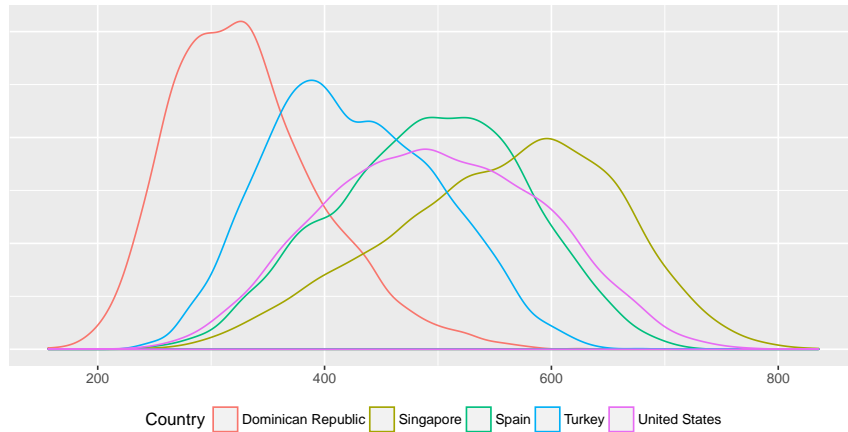


Figure 1: Distribution of scores.

Table 2 contains the main summary statistics regarding the scores. We observe that the coefficient of variation is rather low (0.11), which would indicate that the results in PISA 2015 do not exhibit large disparities. Figure 2, which represents the mean scores for all the countries and large economies participating in PISA 2015, illustrates further this aspect (the dashed line in the figure corresponds to the global mean). In particular, the average score of Singapore (the country with the highest value) is just 1.6 times that of the Dominican Republic (the country with the lowest score). Yet, Figure 1 suggests that the performances of Singapore and the Dominican Republic are extremely different. Which indicates that average scores are not very good measures of the differences that exist between educational systems, or at least that they should be complemented with other indicators.

Statistic	Value
Min	331.6
Median	476.1
Mean	464.9
Max.	555.6
Coeff. of Variat.	0.11

Table 2: Descriptive statistics for the scores in science.

Comparing the countries' educational outcomes in terms of the average scores is too crude an approach. We shall, therefore, analyse the data from a multilevel perspective, applying some of the formulae presented above. In order to keep the discussion within reasonable bounds we shall evaluate three aspects within each country: the extent of

low performance (educational poverty), the extent of high performance (educational excellence), and a multilevel measure of overall performance.

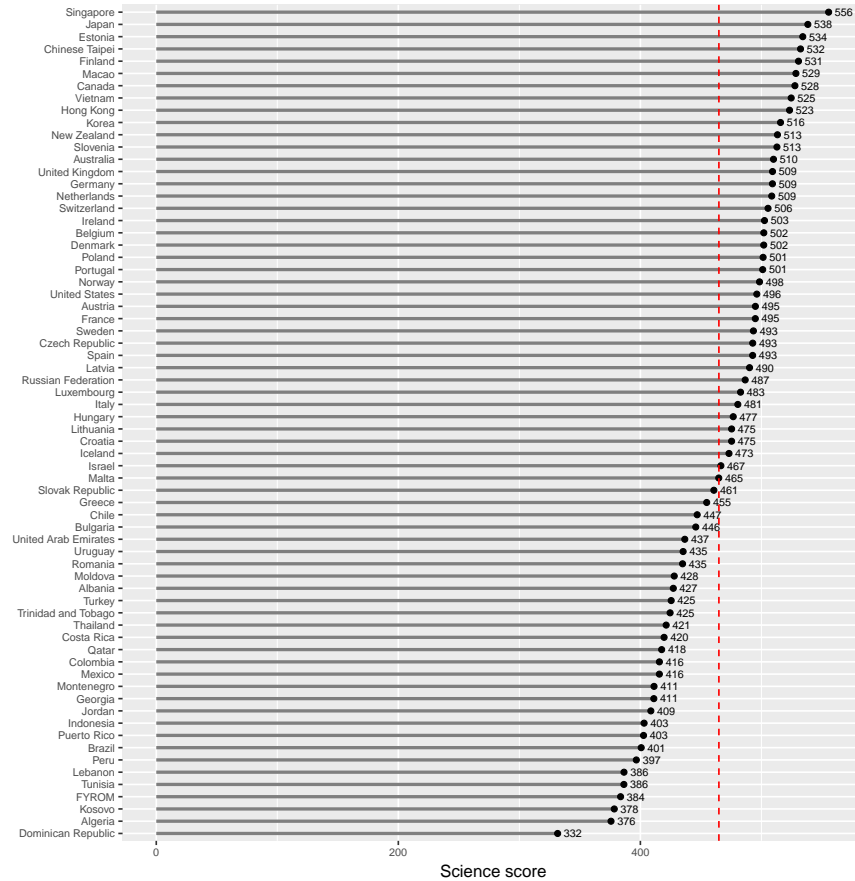


Figure 2: Distribution of science scores.

Table 6 in the Appendix contains, for each level and country, both the population share (Columns 2 to 8) and the average score (Columns 9 to 15) within that level.

### 3.1 Educational poverty

According to the PISA 2015 report (OECD 2016, vol. I, p. 60), “At Level 2, students are able to draw on everyday content knowledge and basic procedural knowledge to identify an appropriate scientific explanation, interpret data, and identify the question being addressed in a simple experimental design. They can use basic or everyday scientific knowledge to identify a valid conclusion from a simple data set. Level 2 students

demonstrate basic epistemic knowledge by being able to identify questions that can be investigated scientifically.” There is evidence, particularly longitudinal studies developed in Australia, Canada, Denmark and Switzerland, showing that students who perform below Level 2 often face severe disadvantages in their transition into higher education and the labour force in subsequent years (see Bertschy et al. (2009) and Mueller and Wolter (2011)). Consequently, “the proportion of students who perform below this baseline proficiency level thus indicates the degree of difficulty countries face in providing their populations with a minimum level of competencies.” (cf. OECD 2014, vol. I, p. 68)).

To provide a measure of educational poverty we thus propose to use Equation 3 with  $\nu = 1$ . This formula corresponds to the product of the head count ratio and the intensity of poverty, measured by 1 minus the ratio between the average score of those below level 2 and the threshold of level 2. That is,

$$F_P(y) = \frac{1}{n} \sum_{i \in L_0 \cup L_1} \frac{410 - y_i}{410} \quad (5)$$

It is worth noting that this measure of educational poverty uses the students’ competences as inputs. Other authors (such as Bourguignon and Chakravarty (2003), Baulch and Masset (2003), or Saccone (2008)) propose different alternatives based on primary school attainment. See also Villar (2017a) for more details on the measurement of poverty.

The summary statistics of this measure show, in particular, a large diversity of situations between the participating countries, with a coefficient of variation close to 0.8 (more than seven times higher than the coefficient of variation of the score). The highest value (Dominican Republic) is 52 times larger than the lowest one (Vietnam), in a sharp contrast with the corresponding ratio of average scores.

Statistic	Value
Min	0.003
Median	0.032
Mean	0.048
Max.	0.207
Coeff. of Variat.	0.780

Table 3: Descriptive statistics for poverty.

Educational poverty thus exhibits a behaviour that differs substantially from that of

average scores. Indeed, the Kendall’s  $\tau$ -test (with  $p$ -value smaller than 0.05) indicates that the raking of countries generated by this measure varies with respect to the ranking of the scores used in PISA.<sup>3</sup> Vietnam, that is in the eighth position regarding average scores, is the country with the best performance in educational poverty. In contrast, Singapore jumps down six positions (from the top position to the sixth). We do not observe significant changes at the lower tail. Yet, there are other countries whose positions change more drastically. Such is the case of New Zealand, Australia, Belgium (worsen) Latvia, or Russia (improve), that move more than ten positions. The full details of the rankings are in Table 8.

### 3.2 Educational excellence

Excellence refers to the extent of high performance in the population of 15-year old students (i.e. the thickness of the right hand tail of the distribution of the test scores). The implicit assumption is that the fraction of students with high levels of performance is a predictor of those who will get higher education and more likely to exert social leadership. We take level 5 as the threshold of high performance, following the OECD valuation. According to PISA: “At Level 5, students can use abstract scientific ideas or concepts to explain unfamiliar and more complex phenomena, events and processes involving multiple causal links. They are able to apply more sophisticated epistemic knowledge to evaluate alternative experimental designs and justify their choices and use theoretical knowledge to interpret information or make predictions. Level 5 students can evaluate ways of exploring a given question scientifically and identify limitations in interpretations of data sets including sources and the effects of uncertainty in scientific data.” (OECD (2016), vol. I, p. 60)). So, Equation 4 is a good candidate to measure high performance.

We propose the following formula for the evaluation of excellence (the mirror image of that corresponding to poverty):

$$F_E(y) = \frac{1}{n} \sum_{i \in L_5 \cup L_6} \frac{y_i - 633}{633} \quad (6)$$

Here we find huge differences between countries, much larger than those regarding poverty (the corresponding coefficient of variation is 38% larger). The country with better results (Singapore) has an index 8000 times that of the country with worst results (Kosovo).

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<sup>3</sup>As for the ordering of the countries according to educational poverty, we have considered that the less poverty the better, and thus, the top positions are for less educationally poor nations.

Statistic	Value
Min	$2.3 \cdot 10^{-6}$
Median	0.0020
Mean	0.0033
Max.	0.0191
Coeff. of Variat.	1.080

Table 4: Descriptive statistics for excellence.

The comparison of educational excellence and average scores shows that the coefficient of variation of the former is 9.8 times larger than that of the latter. Besides, the relative ratio of the maximum with respect to the minimum increases from 1.68 in the case of score to 8304 (almost 5000 times). That is, the educational excellence exhibits a much uneven distribution than average scores. Also in this case the Kendall's  $\tau$ -test (with  $p$ -value smaller than 0.05) evidences the existence of a significant differences between the orderings generated by those two criteria (see Table 8). For instance, Hong Kong goes down 22 positions if we consider the educational excellence, while Malta jumps up 24. Other countries (such as Brazil, Sweden, Switzerland, or Vietnam) also present important changes in the ordering. Singapore Japan, Estonia, Chinese Taipei, and Finland perform very well with respect to both measures.

### 3.3 A multilevel measure of overall performance.

In order to provide a more complete analysis, we propose here a measure of scholastic performance that takes into account all levels of proficiency. That is, for each participating country or large economy,  $i$ , we shall have:

$$F_{OP}(y) = \sum_{h=0}^6 \frac{n_h}{n} \left( \frac{\mu_h(y)}{\mu(\bar{y})} \right)^2, \quad (7)$$

where  $\mu_h(y)$  is the mean score of level  $L_h$  (with  $h \in \{0, 1, \dots, 6\}$ ) for the given country and  $\mu(\bar{y})$  is the mean score of all the participating countries. So we measure here the deviations of the average values of the different proficiency levels of each country with respect to the overall average of all countries and all levels. We obtain in this way an evaluation not only on how different are the means of the countries but also on how different are their distributions, under the implicit ethical assumption that higher outcomes are desirable and lower outcomes are not.

The basic statistics of this multilevel measure of overall performance are summarized in Table 5. We observe that the distribution of this variable is much smoother than that

of poverty or excellence, with a coefficient of variation of 0.21 and a much smaller gap between the top and bottom performers (2.8 times). Yet it is worth noting that this index discriminates much more than the average scores as its coefficient of variation is almost twice that of the average scores.

Note that, by construction, the overall performance measure generates the same ranking as that of average scores because it is obtained by a change of units (dividing by the global mean) and an increasing transformation (squaring the values).

Statistic	Value
Min	0.539
Median	1.109
Mean	1.068
Max.	1.505
Coeff. of Variat.	0.209

Table 5: Descriptive statistics for overall performance.

### 3.4 A comparison of the three measures.

In this section we compare the results we have obtained for the three measures presented above.

Table 7 in the Appendix contains the values for educational poverty, excellence and overall performance, respectively. Columns 2 to 4 show the absolute values of those measures (according to Expressions 5, 6, 7). Columns 5, 6, and 7 present the same data normalised as percentages of the OECD global average. The data show that the differences in the overall performance of the participating countries are moderate but much larger than those of the average values. Differences in educational poverty are much more acute, whereas disparities in excellence are huge. In particular, more than 20 countries are below the 10% of the OECD mean of excellence, with some of them barely reaching 1%. Top performers in excellence are very much alike, with the exception of Singapore that exhibits outstanding results.

Figure 3 presents the distribution of the countries ordered according to their average scores, poverty, excellence, and overall performance measures, arranged from top to bottom values. In order to facilitate the comparison of the distribution of those measures, we let the highest value of each indicator equal to 1. Mind that the same point in the horizontal axis is typically linked with different countries in the vertical axis, depending on the chosen variable. The graphic shows how different those distributions are. The

shape of the distribution of the overall performance is similar to that of the average scores, even though with sharper differences. The distributions of the poverty and excellence measures, however, show a very different pattern with much larger disparities. Both measures decrease sharply at the top and reach very low values at the bottom. It is remarkable that even though poverty and excellence are somehow dual variables, they exhibit a similar distribution. It is also worth noting that the distributions of educational poverty and excellence across countries exhibit the same pattern as the distribution of the GDP per capita (indeed they show even larger inequalities between countries).<sup>4</sup> This may serve to give an idea on how unequal are the countries regarding educational outcomes of high and low performers, an aspect that is not captured by average values.

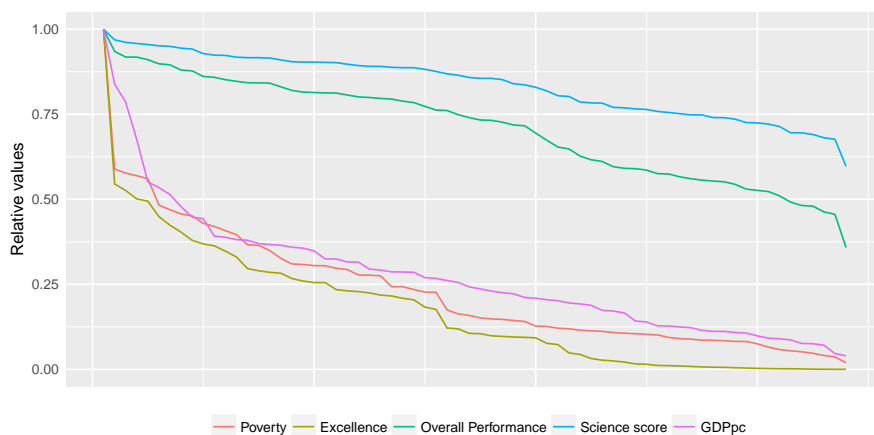


Figure 3: Distribution of the average scores, overall performance, poverty and excellence measures, together with the GDPpc.

In Figure 4 we represent the joint distributions of each pair of measures. Each dot represents one country and the dashed lines describe the mean values of the corresponding measures. Educational poverty and excellence are negatively correlated, as one would expect, with a value  $\rho = -0.64$ . Even though most of the countries with low scores in excellence exhibit high levels of poverty, there are many different combinations, as illustrated in Table 3 in the Appendix. The correlations between overall performance and poverty, and between overall performance and excellence, are stronger with values  $\rho = -0.92$  and  $\rho = 0.85$ , respectively. Note that, besides the differences in the coefficients of correlation, joint distributions differ in shape. Excellence and poverty are distributed as a hyperbola with negative slope. Poverty and overall performance also

<sup>4</sup>Note that this does not mean that the educational poverty or excellence are closely related to the distribution of per capita GDP. Indeed the coefficients of correlation between GDP per capita and educational poverty, excellence and overall performance, are -0.4, 0.48 and 0.51, respectively.

exhibit a negative slope but their joint distribution follows closely a linear pattern. Excellence and overall performance are positively related with a joint distribution that has the shape of a logarithmic function.

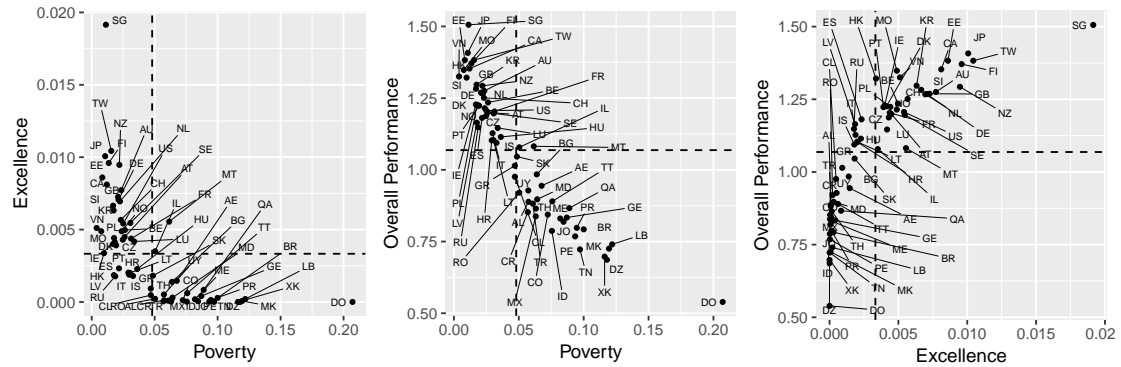


Figure 4: Correlations between educational poverty, excellence and overall performance.

#### 4 Final remarks.

We have presented in this paper a general framework to address those evaluation problems in which the outcome range can be regarded as consisting of different levels, which represent qualitatively different situations. The focus has been on those multilevel measures that can be expressed as weighted averages of the different partial evaluation functions. Even though this is a very particular family of indicators, it is flexible enough to encompass a rich family of problems and turns out to be very intuitive. Regarding the partial evaluation functions we also have discussed a small sample of cases which, nevertheless, cover the most usual indicators.

We have applied this framework to the analysis of educational outcomes for 15 year-old students, according to PISA 2015. The results show that a multilevel analysis provides a much richer picture of the countries' diversity.

Let us also mention that this approach also permits combining the data in order to devise richer indicators (a sort of boot-strapping exercise). An example is that Villar (2017b) where an elementary index of educational achievements is proposed, by combining three different aspects of the distribution of educational outcomes in PISA 2015: performance, inclusion and excellence. Performance is measured by the average scores, inclusion by the incidence of those students with levels 2 or above, and excellence by the share of students with levels 5 or above.

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## 5 Appendix: Tables

Country	Frequencies						Means							
	$L_0$	$L_1$	$L_2$	$L_3$	$L_4$	$L_5$	$L_6$	$L_0$	$L_1$	$L_2$	$L_3$	$L_4$	$L_5$	$L_6$
Albania	0.119	0.301	0.343	0.190	0.045	0.003	0.000	297.8	375.9	445.4	515.6	583.5	651.2	717.7
Algeria	0.280	0.429	0.225	0.056	0.009	0.000	0.000	295.6	372.1	439.9	512.1	580.4	644.4	0.0
Australia	0.048	0.129	0.214	0.274	0.221	0.092	0.020	299.0	377.1	449.3	522.1	592.7	662.8	738.5
Austria	0.050	0.160	0.237	0.282	0.194	0.068	0.009	301.8	376.8	448.6	520.9	591.7	661.5	731.2
Belgium	0.054	0.145	0.218	0.269	0.223	0.081	0.010	301.7	376.0	448.9	522.0	592.9	660.2	731.9
Brazil	0.242	0.325	0.251	0.132	0.042	0.007	0.000	291.1	372.5	444.0	516.3	587.0	657.4	726.8
Bulgaria	0.151	0.229	0.250	0.227	0.113	0.027	0.002	291.6	373.8	447.2	519.8	589.1	657.7	730.9
Canada	0.020	0.092	0.201	0.304	0.259	0.105	0.020	304.8	378.9	450.9	522.4	592.9	662.2	737.8
Chile	0.098	0.252	0.308	0.239	0.090	0.012	0.000	300.3	376.4	446.4	518.3	587.2	654.6	723.3
Chinese Taipei	0.030	0.095	0.179	0.272	0.269	0.128	0.027	300.3	377.9	450.6	523.4	594.1	662.8	737.8
Colombia	0.162	0.330	0.303	0.160	0.041	0.003	0.000	300.1	374.1	444.7	515.3	585.1	653.3	718.0
Costa Rica	0.108	0.358	0.352	0.153	0.027	0.001	0.000	306.0	376.2	443.9	514.3	582.1	650.4	722.6
Croatia	0.055	0.193	0.292	0.276	0.143	0.036	0.004	304.4	378.1	448.0	519.7	589.9	658.8	730.2
Czech Republic	0.046	0.162	0.257	0.279	0.183	0.064	0.009	304.9	377.4	448.6	520.6	591.2	661.0	731.7
Denmark	0.033	0.127	0.257	0.312	0.200	0.062	0.009	301.8	379.0	449.5	521.3	590.8	661.1	733.3
Dominican Republic	0.554	0.305	0.112	0.026	0.003	0.000	0.000	280.0	367.6	439.5	512.1	579.7	653.1	0.0
Estonia	0.013	0.076	0.199	0.308	0.267	0.117	0.019	311.5	381.0	451.3	522.7	592.9	662.6	735.9
Finland	0.026	0.090	0.189	0.293	0.258	0.120	0.024	301.9	379.1	450.3	522.6	593.6	662.4	738.2
France	0.067	0.154	0.219	0.266	0.213	0.072	0.008	297.5	375.9	449.2	521.5	592.4	660.0	734.0
Georgia	0.203	0.307	0.280	0.153	0.049	0.008	0.001	288.3	374.2	444.9	516.1	587.1	657.5	728.0
Germany	0.042	0.129	0.226	0.278	0.218	0.089	0.018	302.3	377.6	449.5	521.4	592.1	662.5	737.4
Greece	0.103	0.226	0.281	0.253	0.115	0.020	0.001	298.4	375.7	447.5	519.0	588.5	656.0	726.9
Hong Kong	0.016	0.079	0.196	0.363	0.272	0.070	0.004	307.4	380.4	452.1	523.2	591.1	657.5	728.6
Hungary	0.076	0.185	0.253	0.275	0.165	0.043	0.003	300.2	375.2	448.3	520.5	590.4	659.0	729.4
Iceland	0.066	0.189	0.288	0.274	0.145	0.035	0.003	299.4	377.3	448.4	519.3	589.9	657.7	730.9
Indonesia	0.156	0.406	0.315	0.107	0.016	0.001	0.000	303.5	374.7	442.4	512.4	582.2	648.0	0.0
Ireland	0.030	0.125	0.262	0.313	0.199	0.063	0.008	302.4	379.9	450.0	520.5	591.1	660.9	732.9
Israel	0.116	0.200	0.242	0.234	0.149	0.052	0.007	291.8	375.0	447.3	520.3	591.1	661.9	733.0
Italy	0.060	0.173	0.269	0.287	0.169	0.039	0.002	302.0	377.1	448.2	520.3	589.9	657.8	730.3
Japan	0.019	0.078	0.180	0.283	0.286	0.130	0.024	304.4	379.3	450.9	523.4	593.9	662.9	736.3

Country	Frequencies						Means							
	$L_0$	$L_1$	$L_2$	$L_3$	$L_4$	$L_5$	$L_6$	$L_0$	$L_1$	$L_2$	$L_3$	$L_4$	$L_5$	$L_6$
Jordan	0.194	0.306	0.306	0.162	0.030	0.002	0.000	287.4	374.5	445.0	514.5	582.8	652.4	0.0
Korea	0.033	0.112	0.216	0.294	0.239	0.093	0.014	300.1	378.5	450.3	522.0	592.4	661.2	732.9
Kosovo	0.285	0.395	0.241	0.072	0.006	0.000	0.000	295.1	372.2	441.8	510.1	579.8	648.9	0.0
Lebanon	0.304	0.324	0.218	0.117	0.033	0.004	0.000	286.3	371.7	443.5	515.9	585.3	656.0	718.2
Latvia	0.027	0.147	0.296	0.319	0.173	0.035	0.003	309.2	379.3	449.6	519.9	588.9	657.7	727.1
Lithuania	0.059	0.190	0.294	0.264	0.150	0.040	0.003	303.7	377.2	447.8	519.4	590.9	658.7	729.7
Luxembourg	0.070	0.190	0.246	0.252	0.172	0.061	0.009	303.8	376.0	447.5	520.9	591.6	661.9	734.4
Macao	0.012	0.070	0.204	0.344	0.278	0.083	0.009	307.5	382.4	452.0	522.8	592.1	659.4	731.4
Malta	0.146	0.181	0.232	0.218	0.147	0.061	0.016	280.3	374.9	447.3	519.8	592.6	662.8	741.4
Mexico	0.128	0.353	0.343	0.152	0.023	0.001	0.000	302.1	375.9	444.2	512.9	581.3	649.9	0.0
Moldova	0.141	0.283	0.312	0.198	0.058	0.007	0.000	293.7	375.0	445.6	516.8	585.5	655.2	724.2
Montenegro	0.190	0.323	0.288	0.152	0.044	0.005	0.000	293.4	374.3	444.6	516.0	586.4	657.0	722.0
Netherlands	0.043	0.144	0.217	0.263	0.222	0.096	0.016	305.4	377.1	448.9	521.6	593.3	661.8	735.3
New Zealand	0.044	0.132	0.214	0.265	0.216	0.102	0.027	302.0	377.7	448.9	522.0	593.0	663.2	739.5
Norway	0.047	0.141	0.245	0.293	0.194	0.070	0.011	299.3	377.6	449.1	520.9	591.3	661.7	735.7
Peru	0.218	0.369	0.276	0.116	0.020	0.001	0.000	297.1	372.9	443.4	513.4	582.3	648.2	0.0
Poland	0.029	0.135	0.264	0.301	0.198	0.064	0.010	301.8	379.6	448.7	521.1	591.3	660.8	733.2
Portugal	0.034	0.141	0.252	0.289	0.209	0.068	0.007	306.1	378.5	449.0	521.3	591.6	659.9	728.3
Puerto Rico	0.230	0.326	0.264	0.135	0.041	0.004	0.000	293.8	373.0	443.7	515.8	586.9	653.2	0.0
Qatar	0.219	0.281	0.244	0.164	0.074	0.016	0.001	291.1	372.8	445.5	518.0	588.7	658.2	732.1
Romania	0.102	0.285	0.348	0.200	0.058	0.007	0.000	302.2	376.2	445.8	515.7	586.2	652.7	719.2
Russian Federation	0.030	0.153	0.310	0.310	0.159	0.035	0.002	308.9	379.6	449.0	519.7	589.9	658.5	729.6
Singapore	0.021	0.076	0.150	0.236	0.275	0.187	0.056	304.0	378.4	450.3	523.6	595.8	664.9	742.8
Slovak Republic	0.110	0.199	0.274	0.249	0.132	0.033	0.003	290.7	375.7	448.2	519.5	589.8	658.3	733.0
Vietnam	0.002	0.058	0.252	0.368	0.237	0.071	0.012	315.8	385.9	452.2	521.4	590.8	661.1	736.7
Slovenia	0.031	0.121	0.231	0.292	0.219	0.092	0.015	305.8	378.6	449.7	521.8	592.7	662.2	735.3
Spain	0.040	0.144	0.263	0.315	0.188	0.047	0.003	303.7	377.7	449.6	520.7	589.9	658.2	725.4
Sweden	0.066	0.151	0.238	0.270	0.189	0.072	0.013	295.9	376.9	448.4	520.8	592.2	662.0	736.0
Switzerland	0.045	0.141	0.227	0.264	0.225	0.087	0.011	300.2	378.0	448.4	521.7	593.2	661.1	734.1
Thailand	0.130	0.339	0.319	0.161	0.046	0.005	0.000	302.7	374.9	444.5	515.6	586.9	653.9	717.2
Trinidad and Tobago	0.179	0.281	0.269	0.184	0.073	0.013	0.001	293.5	373.6	445.4	517.2	588.2	657.2	726.9

Country	Frequencies						Means							
	$L_0$	$L_1$	$L_2$	$L_3$	$L_4$	$L_5$	$L_6$	$L_0$	$L_1$	$L_2$	$L_3$	$L_4$	$L_5$	$L_6$
United Arab Emirates	0.156	0.263	0.267	0.191	0.094	0.026	0.002	292.8	374.3	445.7	518.5	590.0	659.6	731.0
Tunisia	0.217	0.444	0.263	0.068	0.007	0.000	0.000	302.9	372.6	440.5	511.0	580.0	645.8	0.0
Turkey	0.129	0.317	0.310	0.192	0.048	0.003	0.000	302.7	375.1	445.3	516.2	583.4	651.1	719.3
FYROM	0.291	0.340	0.243	0.103	0.020	0.002	0.000	285.4	372.7	442.7	514.0	584.1	653.3	733.3
United Kingdom	0.038	0.137	0.224	0.277	0.215	0.091	0.018	301.4	377.5	448.8	521.7	592.6	663.0	736.8
United States	0.048	0.156	0.253	0.267	0.190	0.073	0.012	301.9	377.7	448.6	520.5	592.8	662.2	737.0
Uruguay	0.124	0.286	0.300	0.204	0.073	0.012	0.001	301.3	374.9	445.9	517.8	586.7	655.6	723.3

Table 6: Population shares and mean scores of each level.

Country	Code	Absolute values			% of the sample mean		
		Poverty	Excellence	O. Perf.	Poverty	Excellence	O. Perf.
Albania	AL	0.057	0.00011	0.89	119.7	3.4	83.1
Algeria	DZ	0.118	0.00001	0.69	245.6	0.2	64.2
Australia	AU	0.023	0.00772	1.28	48.8	231.9	119.3
Austria	AT	0.026	0.00449	1.20	54.4	134.7	112.3
Belgium	BE	0.026	0.00497	1.24	54.8	149.2	115.6
Brazil	BR	0.100	0.00029	0.79	208.4	8.6	74.2
Bulgaria	BG	0.064	0.00139	0.98	133.0	41.8	92.1
Canada	CA	0.012	0.00811	1.35	25.0	243.5	126.6
Chile	CL	0.047	0.00047	0.98	97.9	14.2	91.3
Chinese Taipei	TW	0.016	0.01044	1.38	32.4	313.2	129.4
Colombia	CO	0.072	0.00012	0.84	150.7	3.6	79.0
Costa Rica	CR	0.057	0.00004	0.85	118.6	1.3	79.8
Croatia	HR	0.029	0.00203	1.10	60.7	60.8	103.2
Czech Republic	CZ	0.025	0.00430	1.19	51.4	129.1	111.1
Denmark	DK	0.018	0.00413	1.23	38.3	124.0	114.7
Dominican Republic	DO	0.207	0.00000	0.54	431.5	0.1	50.5
Estonia	EE	0.008	0.00860	1.38	17.6	258.1	129.4
Finland	FI	0.014	0.00960	1.37	28.2	288.0	128.3
France	FR	0.031	0.00438	1.20	65.2	131.3	112.6
Georgia	GE	0.087	0.00041	0.83	181.3	12.3	78.0
Germany	DE	0.021	0.00706	1.27	44.4	211.9	118.7
Greece	GR	0.047	0.00092	1.01	97.8	27.8	94.9
Hong Kong	HK	0.010	0.00337	1.32	20.4	101.3	123.7
Hungary	HU	0.036	0.00228	1.11	75.3	68.4	104.3
Iceland	IS	0.033	0.00180	1.09	68.4	54.0	102.4
Indonesia	ID	0.076	0.00002	0.79	157.3	0.7	73.6
Ireland	IE	0.017	0.00400	1.23	35.3	120.1	114.9
Israel	IL	0.050	0.00351	1.08	104.9	105.2	100.9
Italy	IT	0.030	0.00189	1.13	62.0	56.7	105.5
Japan	JP	0.011	0.01007	1.41	22.3	302.3	131.7
Jordan	JO	0.084	0.00005	0.82	175.9	1.6	76.6
Korea	KR	0.017	0.00632	1.30	36.3	189.8	121.4
Kosovo	XK	0.116	0.00000	0.70	241.9	0.1	65.3
Lebanon	LB	0.122	0.00021	0.74	254.1	6.2	69.3
Latvia	LV	0.018	0.00185	1.16	36.8	55.7	109.0
Lithuania	LT	0.030	0.00201	1.10	63.4	60.2	103.3
Luxembourg	LU	0.034	0.00418	1.15	70.4	125.5	107.2
Macao	MO	0.008	0.00489	1.35	15.8	146.7	126.2
Malta	MT	0.062	0.00555	1.08	128.3	166.6	101.3
Mexico	MX	0.063	0.00003	0.84	131.4	1.0	78.4
Moldova	MD	0.064	0.00030	0.90	133.7	9.1	84.0
Montenegro	ME	0.082	0.00019	0.83	170.8	5.6	77.7
Netherlands	NL	0.022	0.00695	1.27	46.7	208.6	118.6
New Zealand	NZ	0.022	0.00947	1.29	45.8	284.3	121.0
Norway	NO	0.024	0.00489	1.21	49.6	146.7	113.7

Country	Code	Absolute values			% of the sample mean		
		Poverty	Excellence	O. Perf.	Poverty	Excellence	O. Perf.
Peru	PE	0.093	0.00003	0.77	194.6	0.9	71.9
Poland	PL	0.018	0.00442	1.22	37.0	132.6	114.5
Portugal	PT	0.019	0.00391	1.22	40.5	117.4	114.5
Puerto Rico	PR	0.095	0.00014	0.80	197.2	4.1	74.7
Qatar	QA	0.089	0.00084	0.87	185.2	25.1	81.1
Romania	RO	0.050	0.00022	0.92	104.8	6.6	86.1
Russian Federation	RU	0.019	0.00177	1.15	38.9	53.2	107.4
Singapore	SG	0.011	0.01915	1.51	23.5	574.8	140.9
Slovak Republic	SK	0.049	0.00182	1.05	101.3	54.6	97.9
Vietnam	VN	0.004	0.00511	1.33	8.2	153.5	124.0
Slovenia	SI	0.017	0.00665	1.28	35.4	199.7	120.0
Spain	ES	0.022	0.00233	1.18	45.2	69.8	110.5
Sweden	SE	0.031	0.00546	1.20	64.0	163.9	112.0
Switzerland	CH	0.023	0.00567	1.25	48.2	170.2	117.1
Thailand	TH	0.063	0.00016	0.87	131.6	4.9	80.9
Trinidad and Tobago	TT	0.076	0.00061	0.89	158.0	18.3	83.3
United Arab Emirates	AE	0.068	0.00146	0.94	140.8	44.0	88.4
Tunisia	TN	0.097	0.00001	0.72	202.4	0.2	67.6
Turkey	TR	0.061	0.00009	0.88	126.6	2.7	82.6
FYROM	MK	0.120	0.00007	0.73	248.9	2.2	67.9
United Kingdom	GB	0.021	0.00726	1.27	43.6	218.1	118.8
United States	US	0.025	0.00541	1.21	52.1	162.5	112.9
Uruguay	UY	0.057	0.00052	0.93	119.4	15.5	86.8

Table 7: Values of poverty, excellence and overall performance.

Country	Score and O. Perf.	Poverty	Excellence
Singapore	1	6	1
Japan	2	5	3
Estonia	3	3	6
Chinese Taipei	4	9	2
Finland	5	8	4
Macao	6	2	20
Canada	7	7	7
Vietnam	8	1	18
Hong Kong	9	4	31
Korea	10	12	13
New Zealand	11	21	5
Slovenia	12	11	12
Australia	13	24	8
United Kingdom	14	18	9
Germany	15	19	10
Netherlands	16	22	11
Switzerland	17	23	14
Ireland	18	10	28
Belgium	19	29	19
Denmark	20	15	27
Poland	21	14	23
Portugal	22	17	29
Norway	23	25	21
United States	24	27	17
Austria	25	28	22
France	26	34	24
Sweden	27	33	16
Czech Republic	28	26	25
Spain	29	20	32
Latvia	30	13	37
Russian Federation	31	16	40
Luxembourg	32	36	26
Italy	33	31	36
Hungary	34	37	33
Lithuania	35	32	35
Croatia	36	30	34
Iceland	37	35	39
Israel	38	42	30
Malta	39	47	15
Slovak Republic	40	40	38
Greece	41	38	43
Chile	42	39	47
Bulgaria	43	50	42
United Arab Emirates	44	52	41
Uruguay	45	44	46
Romania	46	41	51

Country	Score and O. Perf.	Poverty	Excellence
Moldova	47	51	49
Albania	48	45	57
Turkey	49	46	58
Trinidad and Tobago	50	55	45
Thailand	51	49	54
Costa Rica	52	43	61
Qatar	53	59	44
Colombia	54	53	56
Mexico	55	48	62
Montenegro	56	56	53
Georgia	57	58	48
Jordan	58	57	60
Indonesia	59	54	64
Puerto Rico	60	61	55
Brazil	61	63	50
Peru	62	60	63
Lebanon	63	67	52
Tunisia	64	62	65
FYROM	65	66	59
Kosovo	66	64	68
Algeria	67	65	66
Dominican Republic	68	68	67

Table 8: Positions in rankings according to poverty, excellence and overall performance.