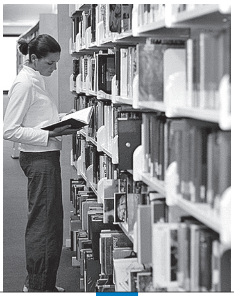

3

Sample Weights

INTRODUCTION

National and international surveys usually collect data from a sample. Dealing with a sample rather than the whole population is preferable for several reasons.

First, for a census, all members of the population need to be identified. This identification process presents no major difficulty for human populations in some countries, where national databases with the name and address of all, or nearly all, citizens may be available. However, in other countries, it is not possible for the researcher to identify all members or sampling units of the target population, mainly because it would be too time-consuming or because of the nature of the target population.

Second, even if all members of a population are easily identifiable, researchers may still draw from a sample, because dealing with the whole population:

- might require unreasonable budgets;
- is time-consuming and thus incompatible with publication deadlines;
- does not necessarily help with obtaining additional and/or required information.

Drawing a sample can be done in several ways depending on the population characteristics and the survey research questions. All sample designs aim to avoid bias in the selection procedure and achieve the maximum precision in view of the available resources. Nevertheless, biases in the selection can arise:

- If the sampling is done by a non-random method, which generally means that the selection is consciously or unconsciously influenced by human choices. The importance of randomness in the selection procedure should not be underestimated;
- If the sampling frame (list, index, or other population record) that serves as the basis for selection does not cover the population adequately, completely or accurately.

Biases can also arise if some sections of the population are impossible to find or refuse to co-operate. In educational surveys, schools might refuse to participate and within participating schools, some students might refuse to participate or simply be absent on the day of the assessment. The size of the bias introduced by the school or student non-response is proportional to the correlation between the school, or the student, propensity to participate and the variables measured with cognitive tests or contextual questionnaires. For instance, it may be that low achievers are more likely to be absent on the day of the assessment than high achievers. On the other hand, it would be less likely to observe a correlation between the height of a student and his/her propensity to participate. The non-response would therefore not introduce a bias in the height mean estimate.

To limit the size of the bias due to non-response, international education surveys require a minimal student participation rate. For PISA, this minimum is 80%.

Finally, if the sampling units do not have the same chances to be selected and if the population parameters are estimated without taking into account these varying probabilities, then results might also be biased. To compensate for these varying probabilities, data need to be weighted. Weighting consists of acknowledging that some units in the sample are more important than others and have to contribute more than others for any population estimates. A sampling unit with a very small probability of selection will be considered as more important than a sampling unit with a high probability of selection. Weights are therefore inversely proportional to the probability of selection.

Nevertheless, a sample is only useful to the extent that it can estimate some characteristics of the whole population. This means that statistical estimates computed on the sample, including a mean, a standard

deviation, a correlation, a regression coefficient, and so on, can be generalised to the population. This generalisation is more reliable if the sampling requirements have been met.

Depending on the sampling design, selection probabilities and procedures to compute the weights will vary. These variations are discussed in the following sections.

WEIGHTS FOR SIMPLE RANDOM SAMPLES

Selecting members of a population by simple random sampling is the most straightforward procedure. There are several ways to draw such a sample, *e.g.*:

- The N members[1] of a population are numbered and n of them are selected by random numbers without replacement;
- N numbered discs are placed in a container, mixed well, and n of them are selected at random;
- The N population members are arranged in a random order, and every $\frac{N}{n}$th member is then selected; or
- The N population members are each assigned a random number. The random numbers are sorted from lowest to highest or highest to lowest. The first n members make up one random sample.

The simple random sample gives an equal probability of selection to each member of the population. If n members are selected from a population of N members according to a simple random procedure, then the probability of each member i to be part of the sample is equal to:

$$p_i = \frac{n}{N}$$

For example, if 40 students are randomly selected from a population of 400 students, the probability of each student i to be part of the sample is equal to:

$$p_i = \frac{n}{N} = \frac{40}{400} = 0.1$$

In other words, each student has one chance out of ten of being selected.

As mentioned previously, weights are usually defined as the inverse of the probability of selection. In the case of a simple random sample, the weight will be equal to:

$$w_i = \frac{1}{p_i} = \frac{N}{n}$$

The weight of each of the 40 students selected from a population of 400 students will therefore be equal to:

$$w_i = \frac{1}{p_i} = \frac{N}{n} = \frac{400}{40} = 10$$

This means that each student in the sample represents himself or herself, as well as nine other students. Since each unit has the same selection probability in a simple random sample, the weight attached to each selected unit will also be identical. Therefore, the sum of the weights of the selected units will be equal to the population size, *i.e.* N.

$$\sum_{i=1}^{n} w_i = \sum_{i=1}^{n} \frac{N}{n} = N$$

In the example,

$$\sum_{i=1}^{40} 10 = 400$$

Furthermore, since all sampled units have the same weight, the estimation of any population parameter should not be affected by the weights. For instance, consider the mean of some characteristic, *X*. The weighted mean is equivalent to the sum of the product of the weight and *X* divided by the sum of the weights.

$$\hat{\mu}_{(X)} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

Since w_i is a constant, the weighted mean and the unweighted mean will be equal.

$$\hat{\mu}_{(X)} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} = \frac{w_i \sum_{i=1}^{n} x_i}{w_i \sum_{i=1}^{n} 1} = \frac{\sum_{i=1}^{n} x_i}{n}$$

However, even with an equi-probabilistic sample, statistical software packages might return different results for weighted and unweighted data. Unlike SPSS®, SAS® proposes four options for dividing the weighted sum of square, *i.e.* *(i)* the number of valid observations; *(ii)* the number of valid observations minus 1; *(iii)* the sum of the weights for the valid observations; and *(iv)* the sum of the weights for the valid observations minus 1. By default, SAS® divides the weighted sum of square by (n–1) while SPSS® divides it by the sum of the weight minus 1.

Table 3.1
Height and weight of ten persons

Individual	Weight	Height
1	10	160
2	10	162
3	10	164
4	10	166
5	10	168
6	10	170
7	10	172
8	10	174
9	10	176
10	10	178

Table 3.2
Weighted and unweighted standard deviation estimate

	Standard deviation estimate
SAS® unweighted estimate	6.0553
SAS® weighted estimate default option	19.14854
SAS® weighted estimate option = N	18.1659
SAS® weighted estimate option = DF	19.14854
SAS® weighted estimate option = WGT	5.74456
SAS® weighted estimate option = WDF	5.7735
SPSS® unweighted estimate	6.0553
SPSS® weighted estimate	5.7735

Table 3.1 presents the height of ten individuals and Table 3.2, the different standard deviation estimates returned by SPSS® and SAS®.

Table 3.2 clearly indicates how a population estimate can be affected by the weighting process offered in the statistical software, even with an equi-probabilistic sample. Data analysts are strongly recommended to carefully read the software documentation related to the weights.

SAMPLING DESIGNS FOR EDUCATION SURVEYS

Simple random sampling is very rarely used in education surveys because:

- It is too expensive. Indeed, depending on the school population size, it is quite possible that selected students would attend many different schools. This would require the training of a large number of test administrators, the reimbursement of a large amount of travel expenses and so on;
- It is not practical. One would have to contact too many schools; and
- It would be impossible to link, from a statistical point of view, student variables to school, class, or teacher variables. Educational surveys usually try to understand the statistical variability of the student's outcome measure by school or class level variables. With just one or only a few students per school, this statistical relationship would have no stability.

Therefore, surveys in education usually draw up a student sample in two steps. First, a sample of schools is selected from a complete list of schools containing the student population of interest. Then, a simple random sample of students or classes is drawn from within the selected schools. In PISA, usually 35 students from the population of 15-year-olds are randomly selected within the selected schools. If less than 35 15-year-olds attend a selected school, then all of the students will be invited to participate.

This two-stage sampling procedure will have an impact on the calculation of the weights and, similarly, the school selection procedure will affect the characteristics and properties of the student sample.

Suppose that the population of 400 students is distributed in 10 schools, each school containing 40 students. Four schools are selected randomly and within schools, ten students are selected according to a similar procedure. Each school, denoted *i*, has a selection probability equal to:

$p_{1\_i} = \frac{n_{sc}}{N_{sc}} = \frac{4}{10} = 0.4$ with N_{sc} being the number of schools and n_{sc} the number of schools sampled.

Within the four selected schools, each student, denoted *j*, has a selection probability equal to:

$$p_{2\_ij} = \frac{n_i}{N_i} = \frac{10}{40} = 0.25$$

with N_i being the number of students in school *i* and n_i the number of students sampled in school *i*. This means that within each selected school, each student has a chance of one in four of being sampled.

The final selection probability for student *j* attending school *i* is equal to the product of the school selection probability by the student selection probability within the school, *i.e.:*

$$p_{ij} = p_{1\_i}\, p_{2\_ij} = \frac{n_{sc}\, n_i}{N_{sc}\, N_i}$$

In the example, the final student probability is equal to:

$$p_{ij} = p_{1\_i}\, p_{2\_ij} = \frac{n_{sc}\, n_i}{N_{sc}\, N_i} = \frac{4 * 10}{10 * 40} = 0.4 * 0.25 = 0.10$$

The school weight, denoted w_{1_i}, the within-school weight, denoted w_{2_ij}, and the final student weight, denoted w_{ij}, are respectively equal to:

$$w_{1\_i} = \frac{1}{p_{1\_i}} = \frac{1}{0.4} = 2.5$$

$$w_{2\_ij} = \frac{1}{p_{2\_ij}} = \frac{1}{0.25} = 4$$

$$w_{ij} = \frac{1}{p_{ij}} = \frac{1}{0.1} = 10$$

Table 3.3 presents the selection probability at the school level, at the within-school level, and the final probability of selection for the selected students, as well as the weight for these different levels where schools 2, 5, 7 and 10 have been selected.

Table 3.3

School, within-school, and final probability of selection and corresponding weights for a two-stage, simple random sample with the first-stage units being schools of equal size

School label	School size N_i	School probability p_{1_i}	School weight w_{1_i}	Within-school probability p_{2_ij}	Within-school weight w_{2_ij}	Final student probability p_{ij}	Final student weight w_{ij}	Sum of final weights $n_i w_{ij}$
1	40							
2	40	0.4	2.5	0.25	4	0.1	10	100
3	40							
4	40							
5	40	0.4	2.5	0.25	4	0.1	10	100
6	40							
7	40	0.4	2.5	0.25	4	0.1	10	100
8	40							
9	40							
10	40	0.4	2.5	0.25	4	0.1	10	100
Total			**10.0**					**400**

As shown in Table 3.3, the sum of the school weights corresponds to the number of schools in the population, *i.e.* 10, and the sum of the final student weights corresponds to the number of students in the population, *i.e.* 400.

In practice, schools differ in size. Often, school enrolment numbers tend to be larger in urban areas than rural areas. If schools are selected by simple, random sampling, the school selection probability will not change, but within the selected schools, the student selection probability will vary according to the school size. In a small school, the student selection probability will be large, while in a very large school, this probability will be small. Table 3.4 shows an example of the results obtained from schools of different enrolment sizes.

Table 3.4

School, within-school, and final probability of selection and corresponding weights for a two-stage, simple random sample with the first-stage units being schools of unequal size

School label	School size	School probability	School weight	Within-school probability	Within-school weight	Final student probability	Final student weight	Sum of final weights
1	10							
2	15	0.4	2.5	0.66	1.5	0.27	3.75	37.5
3	20							
4	25							
5	30	0.4	2.5	0.33	3.0	0.13	7.50	75.0
6	35							
7	40	0.4	2.5	0.25	4.0	0.10	10.00	100.0
8	45							
9	80							
10	100	0.4	2.5	0.10	10.0	0.04	25.00	250.0
Total	**400**		**10.0**					**462.5**

Table 3.5

School, within-school, and final probability of selection and corresponding weights for a simple and random sample of schools of unequal size (smaller schools)

School label	School size	School probability	School weight	Within-school probability	Within-school weight	Final student probability	Final student weight	Sum of final weight
1	10	0.4	2.5	1.00	1.0	0.40	4.00	40.0
2	15	0.4	2.5	0.66	1.5	0.27	3.75	37.5
3	20	0.4	2.5	0.50	2.0	0.20	5.00	50.0
4	25	0.4	2.5	0.40	2.5	0.16	6.25	62.5
Total			**10.0**					**190.0**

Table 3.6

School, within-school, and final probability of selection and corresponding weights for a simple and random sample of schools of unequal size (larger schools)

School label	School size	School probability	School weight	Within-school probability	Within-school weight	Final student probability	Final student weight	Sum of final weight
7	40	0.4	2.5	0.250	4.0	0.10	10.00	100.0
8	45	0.4	2.5	0.222	4.5	0.88	11.25	112.5
9	80	0.4	2.5	0.125	8.0	0.05	20.00	200.0
10	100	0.4	2.5	0.100	10.0	0.04	25.00	250.0
Total			**10.0**					**662.5**

With a simple, random sample of schools of unequal size, all schools have the same selection probability and the sum of school weights is equal to the number of schools in the population. However, the sum of the final student weights are not necessarily equal to the number of students in the population. Further, the final student weights differ among schools depending on the size of each school. This variability reduces the reliability of all population parameter estimates.

Table 3.5 and Table 3.6 present the different probabilities and weights if the four smallest schools or the four largest schools are selected. As shown in these two tables, the sums of final student weights vary substantially from the expected value of 400. The sum of school weights, however, is always equal to the number of schools in the population.

The focus of international education surveys such as PISA is more on the student sample than on the school sample. Many authors even consider that such studies do not draw a school sample *per se*. They just consider the school sample as an operational stage to draw the student sample. Therefore, a sampling design that consists of a simple random sample of schools is inappropriate as it would underestimate or overestimate the student population size. It would also result in an important variability of final student weights and consequently increase the sampling variance.

In order to avoid these disadvantages, schools are selected with probabilities proportional to their size (PPS). Larger schools will therefore have a higher probability of selection than smaller schools, but students in larger schools have a smaller within-school probability of being selected than students in small schools. With such procedures, the probability of a school to be selected is equal to the ratio of the school size multiplied by the number of schools to be sampled and divided by the total number of students in the population:

$$p_{1\_i} = \frac{N_i * n_{sc}}{N}$$

The formulae for computing the within-school probabilities and weights remain unchanged. The final probability and weight are still the product of the school and within-school probabilities or weights. For instance, the school probability for school 9 is equal to:

$$p_{1\_9} = \frac{N_9 * n_{sc}}{N} = \frac{80*4}{400} = \frac{4}{5} = 0.8$$

The student within-school probability for school 9 is equal to:

$$p_{2\_9j} = \frac{n_9}{N_9} = \frac{10}{80} = 0.125$$

The final probability is equal to:

$$p_{9j} = 0.8*0.125 = 0.1$$

As shown in Table 3.7, the school and within-school weights differ among schools, but final student weights do not vary. The weights therefore do not increase sampling variability. Further, the sum of final student weights corresponds to the total number of students in the population. However, the sum of school weight differs from the expected value of ten, but this does not present a major problem as such educational surveys are primarily and mainly interested in the student sample.

Table 3.7

School, within-school, and final probability of selection and corresponding weights for PPS sample of schools of unequal size

School label	School size	School probability	School weight	Within-school probability	Within-school weight	Final student probability	Final student weight	Sum of final weight
1	10							
2	15							
3	20	0.2	5.00	0.500	2.0	0.1	10	100
4	25							
5	30							
6	35							
7	40	0.4	2.50	0.250	4.0	0.1	10	100
8	45							
9	80	0.8	1.25	0.125	8.0	0.1	10	100
10	100	1.0	1.00	0.100	10.0	0.1	10	100
Total	**400**		**9.75**					**400**

With a PPS sample of schools, and an equal number of students selected in each selected school, the sum of the final student weights is always equal to the total number of students in the population (non-response being ignored at this stage). This will be the case even if the smallest or the largest schools get selected. The sum of the school weights, however, is not equal to the number of schools in the population. If the four smallest schools get selected, the sum of school weights is equal to 25.666. If the four largest schools get selected, the sum of school weights is equal to 6.97.

In order to keep the difference between the number of schools in the population and the sum of the school weights in the sample minimal, schools are selected according to a systematic procedure. The procedure consists of first sorting the schools according to their size. A sampling interval is computed as the ratio between the total number of students in the population and the number of schools in the sample, *i.e.:*

$$Int = \frac{N}{n_{sc}} = \frac{400}{4} = 100$$

A random number from a uniform distribution [0;1] is drawn. Let us say 0.752. This random number is then multiplied by the sampling interval, *i.e.* 0.752 by 100 = 75.2. The school which contains the student number 76 is selected. Then the sampling interval is added to the value 75.2. The school which contains the student having the student number 176 will be selected. This systematic procedure is applied until the number of schools needed in the sample has been reached. In the example, the four selection numbers will be the following: 75.2, 175.2, 275.2 and 375.2. See Table 3.8.

Table 3.8
Selection of schools according to a PPS and systematic procedure

School label	School size	From student number	To student number	Part of the sample
1	10	1	10	No
2	15	11	25	No
3	20	26	45	No
4	25	46	70	No
5	30	71	100	Yes
6	35	101	135	No
7	40	136	175	No
8	45	176	220	Yes
9	80	221	300	Yes
10	100	301	400	Yes

Sorting the school sampling frame by the measure of size and then using a systematic selection procedure prevents obtaining a sample of only small schools or (more likely) a sample with only large schools. This therefore reduces the sampling variance on the sum of the school weights, which is an estimate of the school population size.

WHY DO THE PISA WEIGHTS VARY?

As demonstrated in the previous section, a two-stage sample design with a PPS sample of schools should guarantee that all students have the same probability of selection and therefore the same weight. However, the PISA data still needs to be weighted.

Different factors contribute to the variability of weights:

- **Oversampling or undersampling of some strata of the population**. Usually, the school population is divided into different subgroups, called strata. For instance, a country might decide for convenience to separate the urban schools from the rural schools in the list of schools. In most cases, the number of students selected in the rural stratum and in the urban stratum will be proportional to what these two strata represent in the whole population. This stratification process guarantees for instance that a predefined number of schools within each stratum will be selected. Without the stratification, this number might vary. Nevertheless, for national reporting purposes, a country might decide to sample more students than what would have been sampled based on a proportional allocation in some part of the student population. Suppose that 90% of the student population in a country pursue academic tracks and 10% of the students pursue vocational tracks. If the national centre staff wants to compare the performance of the students by track, then it would be necessary to sample more vocational students than what would be sampled based on a proportional allocation. Further, since PISA 2003, the OECD offers countries the opportunity to adjudicate the data at a subnational level. This process however requires countries to sample at least 50 schools and 1 500 students per subnational entities. This requirement of course leads to some oversampling. Some subnational entities were separately adjudicated for Italy, Spain and the United-Kingdom in PISA 2003 and PISA 2006, and Belgium in PISA 2006.

- **Lack of accuracy or no updated size measure for schools on the school sampling frame**. When schools are selected with a probability proportional to their size, a measure of size needs to be included in the school list. In PISA, this measure of size is the number of 15-year-olds in each school in the population, but national statistics per school and per date of birth are not always available. Therefore, the measure of size can be the number of students in the modal grade for 15-year-olds, or the total number of students in the school divided by the number of grades. Further, even if national statistics per school and per date of birth are available, these data might be one or two years old. Therefore, inconsistencies between the number of 15-year-olds at the time of testing and the measure of size used in the school sample frame generate some variability in the final student weights. Let us suppose that school 9 in Table 3.7 has 100 15-year-old students at the time of testing. When schools were selected from the list of schools, the measure of size was set at 80. The school weight was set at 1.25. The within-school weight will be equal to 100 divided by 10, *i.e.* 10 rather than 8. Therefore, the final student weight will be equal to 12.5 instead of the expected 10.
- **School and within-school weight adjustment for school and student non-response**. Some schools, and within the selected and participating schools, some students might refuse to participate. To compensate for this non-response, a weight adjustment is applied at each level where non-response occurs. For instance, if only 25 students out of the 35 selected students from a participating school are present on the day of the assessment, then the weight of the participating students will be multiplied by a ratio of 35 by 25. The student participation rates vary from one school to another, and therefore the final student weights vary. A similar procedure is also applied to compensate for the school non-response. It should be noted that student non-response adjustment has been modified for counterbalancing different participation rates. More information about these adjustment factors is available in the PISA Technical Reports (Adams and Wu, 2000; OECD, 2005, forthcoming).

CONCLUSION

This chapter briefly described: *(i)* what a weight is and how to compute it; *(ii)* what the PISA sampling design is and why such a design is considered the most appropriate; *(iii)* why the PISA final student weights show some variability.

All statistical analyses or procedures concerning the PISA data should be weighted. Unweighted analyses will provide biased population parameter estimates.

Notes

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1. *N* usually represents the size of the population and *n* the size of the sample.

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User's Guide

Preparation of data files

All data files (in text format) and the SPSS® control files are available on the PISA website (*www.pisa.oecd.org*).

SPSS® users

By running the SPSS® control files, the PISA data files are created in the SPSS® format. Before starting analysis in the following chapters, save the PISA 2000 data files in the folder of "c:\pisa2000\data\", the PISA 2003 data files in "c:\pisa2003\data\", and the PISA 2006 data files in "c:\pisa2006\data\".

SPSS® syntax and macros

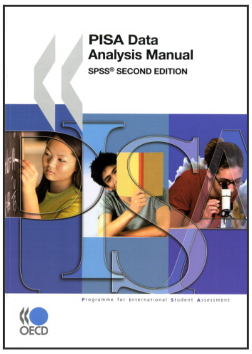
All syntaxes and macros in this manual can be copied from the PISA website (*www.pisa.oecd.org*). These macros were developed for SPSS 17.0. The 19 SPSS® macros presented in Chapter 17 need to be saved under "c:\pisa\macro\", before staring analysis. Each chapter of the manual contains a complete set of syntaxes, which must be done sequentially, for all of them to run correctly, within the chapter.

Rounding of figures

In the tables and formulas, figures were rounded to a convenient number of decimal places, although calculations were always made with the full number of decimal places.

Country abbreviations used in this manual

AUS	Australia	FRA	France	MEX	Mexico
AUT	Austria	GBR	United Kingdom	NLD	Netherlands
BEL	Belgium	GRC	Greece	NOR	Norway
CAN	Canada	HUN	Hungary	NZL	New Zealand
CHE	Switzerland	IRL	Ireland	POL	Poland
CZE	Czech Republic	ISL	Iceland	PRT	Portugal
DEU	Germany	ITA	Italy	SVK	Slovak Republic
DNK	Denmark	JPN	Japan	SWE	Sweden
ESP	Spain	KOR	Korea	TUR	Turkey
FIN	Finland	LUX	Luxembourg	USA	United States



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