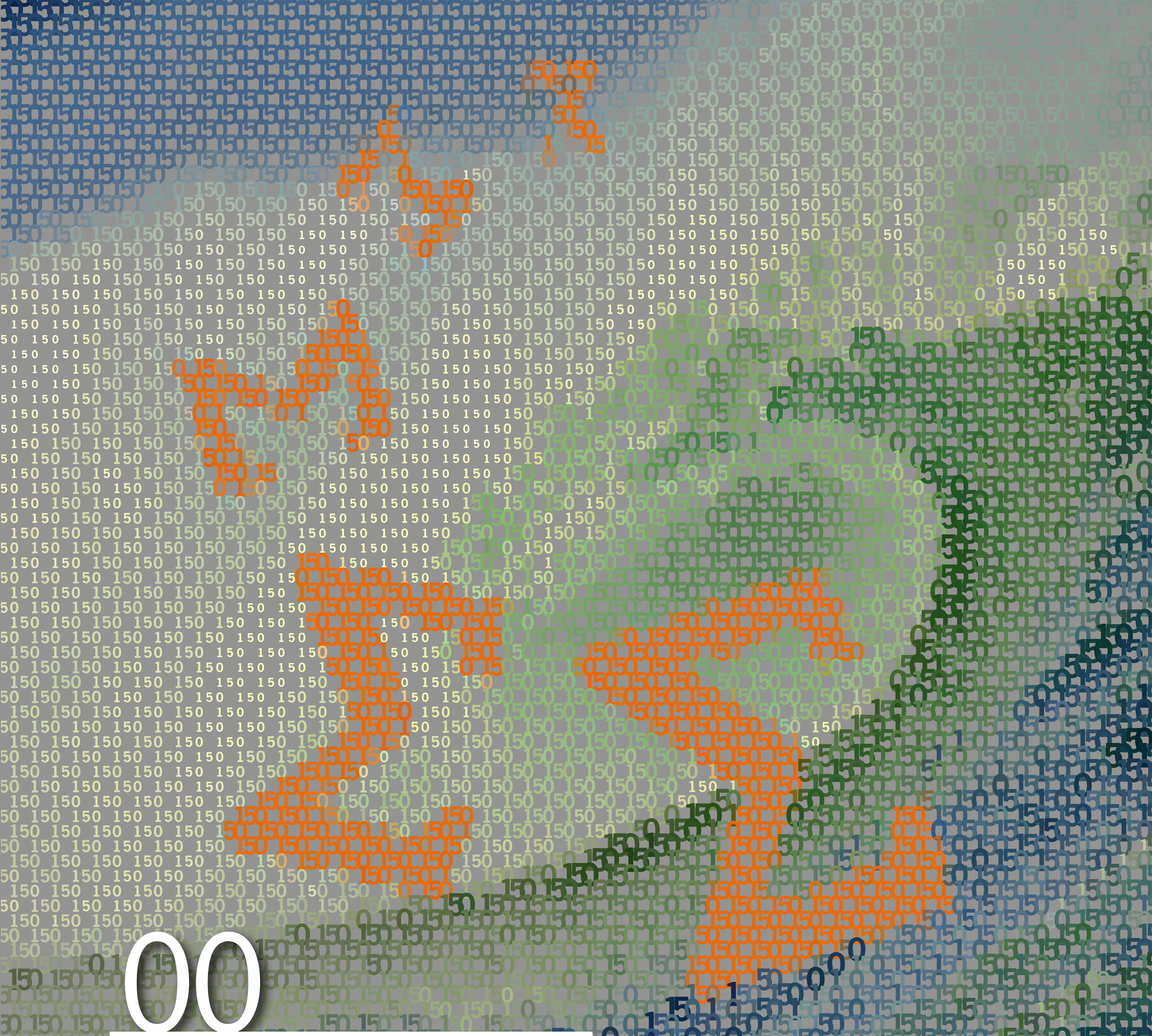

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Methodology report

Describing the Anticipated Accuracy of the Swiss Population Survey

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Neuchâtel, 2010

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Statistik der Schweiz

Methodenbericht

Swiss Statistics

Methodology report

Describing the Anticipated Accuracy of the Swiss Population Survey

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Preface

To assist the discussion on the accuracy of the foreseen Swiss Population Survey, in 2006 the Division for Population Studies and Household Surveys of the Swiss Federal Statistical Office (FSO) gave a mandate to the Statistical Methods Unit of the FSO. The mandate was to investigate the achievable and necessary accuracy of a large scale survey and prepare the background material for the discussion. The project grew over some time due to the complexity of the issue. In fact, the discussion of such a very vast number of possible analyses on the level of cantons, districts and municipalities is an ambitious undertaking.

After changing to the University of Applied Sciences Northwestern Switzerland (FHNW) Beat Hulliger continued to work on the project under a research contract with FSO.

The authors are grateful for the good collaboration and continuous support from Ernst Matti, Markus Schwyn and Jean-Paul Kauthen from the Division for Population Studies and Household Surveys.

Summary

From 2010 onwards the Swiss Population Survey together with the data from the administrative registers on persons, dwellings and buildings of Switzerland will provide yearly structural statistics on Switzerland. The discussion of the accuracy of the Swiss Population Survey is difficult due to its multi-purpose, multi-user nature. In particular there is a concern about the accuracy of the Swiss Population Survey for small municipalities. The resolution and the change-resolution are introduced as new indicators of accuracy which combine relevance and accuracy and serve a wide range of problems. With the help of the new accuracy indicators the potential and limitations of the planned sample of the Swiss Population Survey of a size of 200 000 persons is discussed.

Key words

Methodology report; sampling; sample size; census; variance; accuracy requirement; relevance; domain.

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Contents

1 Introduction

The Swiss Population Census has been carried out by the Swiss Federal Statistical Office every 10 years since 1850. From 2010 onwards it shall be replaced by a system combining a yearly register-based census, a yearly large-scale sample survey, the Swiss Population Survey, and smaller sample surveys with changing topics (Bundesversammlung der Schweizerischen Eidgenossenschaft, 2007). Instead of a large direct census every 10 years, register based census figures on demographic variables will be produced yearly on the basis of the inhabitant registers, which are harmonised by a Swiss Federal Law passed in 2006 (Bundesversammlung der Schweizerischen Eidgenossenschaft, 2006).

In addition to the register census, the Swiss Population Survey will provide yearly structural information on biography, employment, education, commuting, household, religion, language, etc. The Swiss Federal Statistical Office plans to base the Swiss Population Survey on a stratified random sample of $200\,000$ persons aged 15 and over. This sample size is a compromise between costs and feasibility on one hand and accuracy on the other hand. The concept of the Swiss Population Survey is discussed in committees and expert groups with the stakeholders. The accuracy of the Swiss Population Survey is a returning and difficult subject in these discussions.

A broad definition of accuracy is the “closeness of computations or estimates to the exact or true values that the statistics were intended to measure” (OECD, 2008). The accuracy of an estimator based on a random sample is measured by the mean squared error and thus involves variance and bias. In the context of this article we assume unbiased estimation and therefore we use accuracy and precision, the level of variance, interchangeably. The problem with accuracy is that it refers to one single statistic while there will be a vast multitude of statistics (many different objectives of many different users) derived from the Swiss Population Survey.

The aim of this article is to give meaning to the notion of accuracy for the Swiss Population Survey with its multi-user, multi-purpose nature. In particular the accuracy of statistical results for small sub-populations is discussed. This is a major concern of many users from local administrations which up to now have based their decisions on the figures of the population census. The question of accuracy for a Population Census concerns only non-sampling errors, i.e. errors due to measurement, non-response, over-coverage, missing values and processing (Kilchmann et al., 2005a,b; Renaud, 2004). The accuracy of the Population Census has not received much attention by the users up to now and, in particular, accuracy in terms of sampling error is a new concern for them.

The requirement on the accuracy, in principle, must be derived from the need of a user to detect those facts which are relevant to him or her. The specification of an accuracy requirement is based on the theory of statistical hypothesis tests (see, e.g. Bickel and Doksum (1977)). In short, the difference between a hypothesis and an alternative is relevant for a particular user if his or her decision would be different under the hypothesis than under the alternative. A statistic should be sufficiently accurate to detect a relevant difference. This is equivalent to saying that the power of a test should be sufficiently large at a relevant alternative.

Based on the requirement of accuracy and for a particular sample design, the necessary sample size may be derived. Sample size determination is part of the classical literature on survey sampling. For example Cochran dedicates a chapter to the issue (Cochran, 1977, Chapter 4) but gives little guidance on how to elicit the desired variance from the user. The development in the survey sampling literature is mainly based on confidence intervals, a notoriously difficult concept. A similar problem to eliciting an accuracy requirement is eliciting the effect size of a treatment in an experiment. This latter is necessary for the calculation of a sample size to obtain a specified power for a statistical hypothesis test. For example Lenth (2001) discusses the elicitation of effect size in the context of medical studies.

The primary objective of this article is to develop instruments to discuss the accuracy of a multi-purpose, multi-user survey with a particular focus on sub-populations of very different size. The instruments should be as simple as possible, i.e. should not go deep into the theory of hypothesis testing or confidence intervals as the approaches known from the literature do. These instruments should help the many users to judge the accuracy of the intended sample size. The estimation of the size or proportion of a group and the comparison of the sizes or the proportions of two groups are the two basic problems we discuss primarily. A secondary objective is to discuss with the help of these instruments the accuracy of the planned sample of the Swiss Population Survey of a size of $200\,000$ persons.

This article is entirely based on finite population sampling theory without assistance from statistical models using information from outside the sample. We do not use calibration (Deville and Särndal, 1992) or Small Area Estimation (see, e.g., (Pfeffermann, 2002) or (Heady and Ralphs, 2004)).

This study was conducted before it was decided to limit, for practical and organisational reasons, the Swiss Population Survey to the population aged 15 and over. The article does not take into account this restriction of the survey population. All the presented calculations and examples are based on the whole population without any age limitation. We assume that the foreseen limitation of the survey population will only have a marginal impact on the presented results and conclusions.

The data used for illustration and the planned sample design of the Swiss Population Survey is presented in Section 2. The estimation of the size of a small group of a municipality or a domain of the population is treated in Section 3. First, the probability of not observing any member of a group is discussed and then an approach is studied where a relevance criterion and a condition for the detection of a group is used. Section 3.4 introduces the resolution, an indicator which combines relevance and detectability. The comparison of proportions and a change-resolution as well as the power of χ^2-tests is discussed in Section 4. Section 5 draws some conclusions.

2 Data, design and estimation problems

The data of the Swiss Population Censuses of 1990 and 2000 serve as examples and basis for this article. The questionnaires from these censuses contained most of the variables that will be implemented either in the inhabitant registers or in the Swiss Population Survey. We concentrate our analysis on three variables of the Swiss Population Survey: Labour market status, place of work and main language. These three variables are important for the Swiss Population Survey and they should reveal the problems likely to be encountered with other categoric variables of the Swiss Population Survey. Labour market status has the following categories: Employed (including self-employed persons), unemployed, not active, underage.

Place of work can be any of the 2896 municipalities of Switzerland in 2000 or the surrounding countries. Language is recoded here into 6 languages and a category for other languages.

Swiss cantons and municipalities differ very much in size. According to the Swiss Population Census 2000 the largest canton, Zürich, had $1\,247\,906$ inhabitants while the smallest canton, Appenzell Innerrhoden, had only $14\,618$ inhabitants. The largest city, again Zürich, had $363\,273$ inhabitants, the smallest municipality had only 22 inhabitants. The distribution of the sizes of municipalities is heavily skewed. Table 1 shows that there are 155 municipalities with less than 100 inhabitants and 54% of municipalities have less than 1000 inhabitants. There are 62 municipalities with more than $15\,000$ inhabitants. These municipalities with more than $15\,000$ inhabitants make up for 32% of the population and 72% of the population live in municipalities of size 3000 or more.

Municipalities and cantons are the most important sub-populations for which useful results are expected from the Swiss Population Survey. There are also demographic sub-populations which may be of interest. For example, 20 year old unemployed persons, or persons working more than 50 km from their home. Many results which are valid for municipalities of a certain size are also valid for other sub-populations of that size. However, only municipalities would be used for stratification and would have their sample size fixed.

In spite of its mandatory character, there will be some non-response for the Swiss Population Survey, though hopefully less than in more complicated surveys. The non-response rate can be estimated more safely after the first pilot surveys. The sample sizes used in this article are always respondent, i.e. net, sample sizes.

We make abstraction of the changes of municipalities between any time points we are looking at. In fact, the data of the Census 1990 and 2000 were harmonised such that their structure corresponds to the nomenclature of municipalities for the Census 2000. There has been some preparation for the data within municipalities. In particular for each municipality the categories of a variable with less than 10 persons were grouped together.

The sample design assumed is a stratified random sample of $n_U = 200\,000$ persons. The strata are the municipalities. We can safely assume that we know the exact size of the population of the municipalities from the registers of inhabitants. The sample is allocated to the municipalities proportionally to their size. Here we implemented a small deviation from the proportional allocation to avoid problems with variance calculation: Every municipality obtains at least a sample of two persons. The final sample design of the Swiss Population Survey may deviate from these assumptions since they reflect the state of the preparations as of mid 2007.

The size of the Swiss population in 2000 was $N_U = 7\,288\,010$. We therefore have a net sampling rate of $f = n_U/N_U = 2.74\%$ for a sample of size $n_U = 200\,000$. It is planned to coordinate the yearly samples negatively, i.e. to ensure that a person will not be included in the sample more than once in five years, say. We may pool together the yearly samples of the Swiss Population Survey. When pooling the samples over 5 years we obtain a pooled sample of $n_U = 1\,000\,000$ persons. The negative coordination of the samples will make the estimation of changes more complex because the yearly samples are not independent. However, the dependence will not be severe and we ignore it for the exposition in this article. In other words we assume that the yearly samples are independent and that a a pooled sample over 5 years has a size of $n_U = 1\,000\,000$. Thus we assume that the accuracy of a pooled 5-year sample can be investigated as if a sample of size $n_u = 1\,000\,000$ had been drawn in one year. Note that parameters that can be estimated from the pooled sample refer to characteristics of the population during the years that are pooled together. Therefore some care is needed when interpreting results from pooled samples.

The size of the sample in the cantons ranges from 401 to $34\,245$ for a total sample size of $n_U = 200\,000$. Table 1 shows size classes of municipalities and the maximum sample size for a municipality in the size class when $n_U = 200\,000$. The limits of the size classes correspond roughly to quantiles of the distribution of municipality sizes and to particular cases of sizes like 3000 (a large village), $10\,000$ (above which a municipality counts as a city) and the smallest canton (Appenzell Innerrhoden with approximately 15 000 inhabitants) and Zürich, the largest city of Switzerland with 363 273 inhabitants. The city of Zürich will obtain a sample of roughly $n_D = 10\,000$.

Table 1 Size classes of municipalities and sample sizes for $n_u = 200\,000$

N_D	M	total N	$\max n_D$
22 - 99	155	9896	3
100 - 499	856	243818	14
500 - 999	563	407909	27
1000 - 2999	781	1383358	82
3000 - 9999	422	2181073	274
10000 - 14999	57	693610	412
15000 - 99999	57	1407003	2744
100000 - 363273	5	961343	9967

M indicates the number of municipalities in the corresponding size class. The third column, total N, indicates the number of inhabitants of all municipalities of the size class. The fourth column max n_D indicates the sample size at the upper limit of a size class and at the same time the minimal sample size of the next larger class. Source: Federal Statistical Office.

In order to answer the seemingly simple question about the accuracy of the Swiss Population Survey, the size of the sample in the 26 cantons of Switzerland and in the 2986 municipalities must be taken into account.

The first problem we consider is the estimation of the size N_A of a group A in a small domain D of size N_D. For example, in 2000, $N_A = 158$ was the number of Italian speaking persons in the municipality Veyrier with $N_D = 8\,892$ inhabitants. Are we able to estimate this number N_A with sufficient accuracy by a sample survey? What does sufficiently accurate mean? A variant of the size-estimation problem is the estimation of the proportion $p_A = N_A/N_D$ of a group. The proportion of Italian speaking persons in Veyrier was 1.8% in 2000. How accurately must we estimate such a proportion?

The estimation of N_A and p_A are equivalent if N_D is known. Even if mathematically N_A and p_A are equivalent indicators, the discussion about whether the size of N_A or p_A is relevant differs considerably between large and small municipalities, i.e. between large and small N_D. For the city of Zürich, a proportion $p_A = 5\%$ corresponds to $N_A = 18\,164$ persons, a group larger than the smallest canton, which certainly would be considered relevant. On the other hand for the smallest municipality of Switzerland with $N_D = 22$ a 5% group corresponds to just 1 person!

The second problem we consider is the estimation of the net change of the size of a group between time $t = 1$ and $t = 2$. In other words we are not interested in N_{A1} or N_{A2} alone, the sizes of the groups at these time-points, but in the difference $\Delta_A = N_{A2} - N_{A1}$. For example we may want to know how much the number of Italian speaking persons in Veyrier has changed from 1990 to 2000. In fact, $N_{A1} = 172$ and $N_{A2} = 158$ and we have a difference of $\Delta_A = -14$. Would we detect this net change if we took samples only instead of censuses in 1990 and in 2000? How accurately do we have to estimate such a change? And, is a difference of that size relevant at all?

Instead of the difference of the sizes, we may be interested in the percentage change $\delta_A = p_{A2} - p_{A1} = N_{A2}/N_{D2} - N_{A1}/N_{D1}$. Note that the population of the domain may change its size too, i.e. usually $N_{D2} \neq N_{D1}$. Therefore we cannot infer the absolute difference Δ_A from the difference in proportions δ_A even if we know N_{D2} and N_{D1}. How accurate must an estimate of this change of proportion be?

The estimation problem is the same if instead of a change between two time-points, we consider the difference between two distinct municipalities or sub-populations at the same time. This is true because we assume independent samples either between two time points or between two distinct municipalities (or sub-populations) at the same time. For example we may want to compare the number of unemployed persons in two municipalities or among immigrants of two different nationalities. Often the two municipalities or sub-populations differ in size and therefore usually the focus is on the proportions of the groups and not on the size. Thus we may interprete $\delta_A = p_{A2} - p_{A1}$ as the difference in the proportion of a group within two sub-populations or municipalities at the same time.

The estimation of a proportion is discussed in the next Section, while the estimation of change is covered in Section 4. More general comparisons between two domains, involving several categories, are natural extensions of the change-estimation problem. For example we may want to compare the distribution of the language groups within two municipalities, or instead of only looking at the group of unemployed we want to compare the five categories of labour market status. We shall look into these problems shortly in Sub-Section 4.2.

3 Estimation of a proportion

3.1 Unobserved groups

It may happen that a group of the population is not represented at all in a sample, i.e. there is no person of the group in the sample. In that case we can say that the group has not been detected by the sample. We now look at the probability of such an event. More specifically we assume that a group A belongs to a municipality D. The sample size $n_D = fN_D$ in D is given by the sample design and the sampling rate f (see Table 1). For each possible sample a different number n_A of members of the group A may be observed. Due to the simple random sampling without replacement in D, the number n_A has a hypergeometric distribution. The probability that A is not detected is the probability of $n_A = 0$. This probability should be reasonably low, say 5%, if the size N_A of the group is considered relevant. The probabilities in Table 2 show that for sample size $n_U = 200\,000$ the group must be roughly of size $N_A = 200$ to be sure that at least one member of it is included in any municipality. For a group of size $N_A = 40$ on average every fifth sample for small municipalities or every third sample for large municipalities will not contain any person of A. And even for $N_A = 80$ every tenth sample will not contain a member of A in larger municipalities. We may conclude that it is not reasonable to estimate groups of size less than $N_A = 100$ or even 140 for a total sample size of $n_U = 200\,000$ (We will see in Section 3.4 that $N_A = 140$ plays an important role in our discussion). In other words, for a sample of $n_U = 200\,000$ in Switzerland, groups of size $N_A < 100$ must be considered too small to estimate their size from the sample because the probability of not observing at least one member of group A is larger than 5%. For total sample size $n_U = 1\,000\,000$ we may consider estimating groups with size $N_A > 20$.

Table 2 Probability in percentage of not observing any person of a group A

	$n_U = 200\,000$									$n_U = 1\,000\,000$			
	$P[n_A = 0]$ at $N_A =$									$P[n_A = 0]$ at $N_A =$			
N_D	5	10	20	40	60	80	100	140	200	5	10	20	40
100	86	73	51	21	6	1	0	0	0	46	20	3	0
500	87	75	56	31	16	8	4	1	0	47	22	5	0
1000	87	76	57	33	18	10	6	2	0	48	23	5	0
3000	87	76	57	33	19	11	6	2	0	48	23	5	0
10000	87	76	57	33	19	11	6	2	0	48	23	5	0
15000	87	76	57	33	19	11	6	2	0	48	23	5	0
100000	87	76	57	33	19	11	6	2	0	48	23	5	0
363273	87	76	57	33	19	11	6	2	0	48	23	5	0

Thus the probability that a small group is not observed in the sample sets a lower limit to what should be considered a relevant group size. However, it is not yet sufficient to describe in a general way above what size a group size is relevant.

3.2 Accuracy of the estimation

The estimation of the proportion $p_A = N_A/N_D$ of a group $A \subset D$ based on a simple random sample of size n_D is a standard problem in survey sampling (Cochran, 1977, p.50). The number n_A of persons from sup-population A in the sample can be written as a sum over an indicator variable $1\{i \in A\}$ which is 1 for persons from A and 0 otherwise, i.e. $n_A = \sum_{i=1}^{n_D} 1\{i \in A\}$. The classical estimator is the sample proportion $\hat{p}_A = n_A/n_D$, which is the sample mean of the indicator variable and thus the Horvitz-Thompson estimator. Under simple random sampling $\hat{p}_A$ is an unbiased estimator of p_A.

The variance of $\hat{p}_A$ under simple random sampling is

$$V(\hat{p}_A) = (1-f)\,\frac{p_A(1-p_A)}{n_D}\,\frac{N_D}{N_D-1} \approx (1-f)\frac{p_A(1-p_A)}{n_D} = \sigma^2(\hat{p}_A). \tag{1}$$

We keep the factor $1-f$, the finite population correction, to cover the 5-year sample with $f = 13.7\%$. The variance of the sample proportion is the same whether one estimates p or $(1-p)$ and we may switch to $(1-p)$ when $p > 0.5$. Therefore we do not treat explicitly proportions larger then 0.5, i.e. larger than 50%. The size of the group A is estimated by $\hat{N}_A = N_D\hat{p}_A$ and the variance of $\hat{N}_A$ is $N_D^2\sigma^2(\hat{p}_A)$.

An unbiased estimate of the variance $V(\hat{p}_A)$ is

$$\hat{\sigma}^2(\hat{p}_A) = (1-f)\frac{\hat{p}_A(1-\hat{p}_A)}{n_D - 1}. \tag{2}$$

We may try to elicit requirements on the accuracy of $\hat{p}_A$ from a user by directly asking him or her how small the variance $\sigma^2(\hat{p}_A)$ or the standard deviation $\sigma(\hat{p}_A)$ should be. The user's answer would depend on the problem he or she has in mind, in particular on the group A of interest and the domain or municipality D and their respective sizes. A user may have many situations in mind and give many different answers. There is no simple answer to the requirement of a single user and less so for the many different users of the Swiss Population Survey. Often the question on the needed accuracy of a sample is posed in the form of a confidence interval. Then the user must decide what is a relevant width for a confidence interval (see, e.g. (Cochran, 1977, p. 75)). Here we are planning the survey and we may use a tolerance interval instead of the confidence interval to simplify the treatment. A tolerance interval is a central region of the distribution of $\hat{p}_A$, for example covering 95% of the possible values. Being an interval it contains all values between a lower and an upper limit. Values which are not included in the tolerance interval are very rarely observed. A user may state at which distance from the true value he would need the values to have only a small probability of being observed. We then may say that an estimator is sufficiently accurate when the sample yields a tolerance interval which respects this relevant distance. We come back to this point in Section 3.3.

An approximate tolerance interval for $\hat{p}_A$ based on the assumption of a normal distribution is

$$[p_A - z\,\sigma(\hat{p}_A), p_A + z\,\sigma(\hat{p}_A)], \tag{3}$$

where the constant z is a quantile of the standard normal distribution. The width of the tolerance interval depends on the sample size through $\sigma(\hat{p}_A)$. For a 95% tolerance interval we may chose $z = 1.96$. In other words the numbers between $p_A - 1.96\ \sigma(\hat{p}_A)$ and $p_A + 1.96\ \sigma(\hat{p}_A)$ make up a 95% tolerance interval. Of course we could use another constant than $z = 1.96$ to obtain a different tolerance level. The true distribution of $\hat{p}_A$ is hypergeometric and the normal distribution is an approximation only. The quality of the approximation of the hypergeometric distribution of n_A by the normal distribution depends on the population and sample sizes and on the proportion p_A to be estimated. For small sample sizes n_D and small p_A the hypergeometric distribution is strongly asymmetric, giving a high probability to a value of 0. For confidence intervals many proposals exist to deal with the asymmetry when the number of observed members of a group is small (see, e.g. Korn and Graubard (1998)). Fortunately the coverage properties for tolerance intervals are better than for confidence intervals because they do not need an estimate of the variance. The coverage of the normal tolerance interval (3) is close to 95%, for N_D even as low as 500, i.e. for a yearly sample of $n_D = 14$ only and for a wide range of proportions. More elaborate tolerance intervals with continuity corrections and with asymmetry exist but the above tolerance interval is sufficient for the purpose of this article. Nevertheless we set the lower limit to 0 at the least and the upper limit to 1 at the most.

The tolerance interval (3) depends only on p_A, n_D and f. Now, in our design of a proportionally stratified random sample we have set $n_D = fN_D$, where f is the overall sampling rate. Therefore we can derive for each municipality of a given population size N_D its sample size n_D and the tolerance interval for any p_A.

Table 3 shows some tolerance intervals. A lower limit of 0 indicates that the crude formula (3) would give a negative lower limit, which is set to 0 explicitly. For example, with a municipality of size $N_D = 500$ and a proportion of $p_A = 0.2$, which corresponds to a group of size $N_A = 100$, we would still obtain a lower limit of the tolerance interval of 0. In other words we cannot exclude with 95% of confidence that nobody from group A would be in the sample. This reflects the probability of 4% for this event under the hypergeometric distribution, see Table 2.

Table 3 95% tolerance intervals for $\hat{p}_A$ with $n_U = 200\,000$.

N_D	$p_A = 0.005$		$p_A = 0.01$		$p_A = 0.05$		$p_A = 0.20$		$p_A = 0.50$	
500	0	21	0	31	0	81	0	203	121	379
1000	0	31	0	47	0	131	51	349	314	686
3000	0	60	0	94	10	290	344	856	1180	1820
10000	0	132	0	216	245	755	1533	2467	4416	5584
15000	0	176	8	292	439	1061	2429	3571	6786	8214
100000	240	760	633	1367	4196	5804	18524	21476	48155	51845
363273	1320	2312	2933	4333	16631	19697	69841	75468	178120	185153

3.3 Detection of a relevant difference of proportions

The specification of a requirement of accuracy needs a comparison scale: a relevant difference. The basic idea to arrive at a definition for a relevant difference is simple: If we assume that a proportion in a domain of size N_D is p_0 but in fact it is p_A,what difference $p_A - p_0$ would we consider relevant? Obviously what is relevant depends on the particular use. When discussing relevance we must draw on the discussions in the expert groups and on the experience about uses of the past censuses. In the following we present an attempt to formalise the definition of a relevant difference.

For small p_A and p_0 the estimators $\hat{p}_A$ and $\hat{p}_0$ may be assumed to follow two independent Poisson-distributed random variables. Then $K_1^2 = N_D(\hat{p}_A - \hat{p}_0)^2/(p_A + p_0)$ approximately follows a χ_1^2 distribution if we further assume $p_A = p_0$. Thus we may use a quantile of the χ_1^2 distribution to determine a relevant difference. In other words, a relevant difference of two proportions fulfils $K_1 > \chi^2_{1;1-\beta} = \epsilon_1$ for a constant ϵ_1 or β chosen by the user. For large municipalities, too small differences become relevant with this criterion alone and, to avoid this, a second criterion is added: $K_2 = N_D|p_A - p_0| > \epsilon_2$ for a second constant ϵ_2 to be chosen by the user. As default values we use $\epsilon_1 = \sqrt{\chi^2_{1;0.98}} = 2.33$ and $\epsilon_2 = 100$ in this article. In other words, here we consider a difference of proportions as relevant if $K_1 > 2.33$ and $K_2 > 100$ simultaneously. Of course there is arbitrariness in these constants because $\epsilon_1 = \sqrt{\chi^2_{1;0.99}}$ or $\epsilon_2 = 50$ might be also appropriate. The reader should take the choice $\epsilon = 2.33, \epsilon_2 = 100$ as illustrative.

An alternative definition of relevance involving a further criterion on the raw difference of proportions was abandoned because it was deemed too complex and because no natural parameters could be agreed on.

Once we have decided that a proportion p_A is at a relevant distance from a hypothesised value p_0 we may use the tolerance interval around p_0 to decide whether we would detect that difference. We define that a difference $p_A - p_0$ is detected if p_A is not in the tolerance interval around p_0:

$$p_A \notin [p_0 - z\,\sigma(\hat{p}_0),\; p_0 + z\,\sigma(\hat{p}_0)]\,, \tag{4}$$

In other words, we call a difference $p_A - p_0$ detectable if (4) holds. We may also rephrase this definition to relate to p_0 only by saying that a proportion p_0 is "estimated accurately" if a proportion p_A which is at a relevant distance from p_0 would not be contained in a tolerance interval around p_0.

If we use the normal quantile z for a 95% tolerance interval, i.e. $z = 1.96$, and if we assume that $p_A = p_0 - 1.96\sigma(\hat{p}_0)$, i.e. p_A is just at the lower limit of the tolerance interval, then $P[\hat{p}_A \notin [p_0 - z\,\sigma(\hat{p}_0),\ p_0 + z\,\sigma(\hat{p}_0)]$ would be approximately 50%. This is the power of a Z-test for a normal mean with known variance at the lower end of a tolerance interval with the level 5%. In order to increase that power we would need a larger distance from p_0. For a power of 80% we would have to set $z = \Phi^{-1}(0.8) + 1.96 = 2.80$.

We now apply our definitions of a relevant difference and of a detectable difference to the differences between the Swiss Population Censuses of 1990 and 2000. The value of the proportion in 1990 plays the role of p_A and the one of 2000 the role of p_0. The development of the municipalities is taken into account by standardizing to the size N_D of 2000. For our study the categories of the variables that establish the groups within municipalities, e.g. language, are called classes. To avoid a large number of tiny classes the categories with less than 10 persons within a municipality were aggregated into one class.

Every class is judged according to two dimensions: whether the difference between 1990 and 2000 is relevant and whether the difference is detectable. The four possible cases as to how a difference is judged relevant and detectable are shown in Table 4. Among the classes with a relevant difference there should be few classes which are not detected (case B). If not, the sample is too small. The differences which are not relevant are less important. However, the user of the Swiss Population Survey must be aware that a detectable difference may not be relevant (case C).

Table 4 Cases of differences

	detectable	not detectable
relevant	A	**B**
not relevant	C	D

The classes of case B, with relevant differences that are not detectable, may be called missed classes. We may count these cases and describe them. The number of classes in B is difficult to judge. The number of persons which are in these missed classes, the **missed persons**, is more tangible. The number of missed persons is calculated as $|N_{A2} - N_{A1}N_{D2}/N_{D1}|$, i.e. corresponds to criterion K2. Both indicators, missed classes and missed persons within classes, will be analysed in the following.

As an example we analyse the situation in the municipality of Veyrier in the canton Geneva. There are 7 language classes in the municipality after aggregation of small classes. The municipality grew from $N_{D1} = 7\,039$ to $N_{D2} = 8\,892$. The sample size in 2000 would be $n_{D2} = 244$ for the yearly and $n_{D2} = 1220$ for the five-yearly sample. Table 5 shows the classes in 1990 and 2000 as well as the relevance and detectability of the differences under the yearly (det. 200k) and five-yearly (det. 1000k) sample. There are 2 relevant differences. None of them is detectable with the yearly sample and only one of them is detectable with the five-yearly sample. This leads to 2 missed classes or 1 missed class respectively. To find the number of missed persons we have to sum criterion K2 over the missed classes. There are 704 missed persons for the yearly sample and 309 missed persons for the five-yearly sample. The user, e.g. the mayor of Veyrier, must decide whether this is a relevant number. He may, of course, also disagree with the definition of relevance. From a statistical point of view it seems inappropriate to consider the yearly sample in Veyrier large enough to yield satisfactory results, while the five-yearly sample may be useful.

Table 5 Language classes of Veyrier (GE)

Language	N_{A1}	N_{A2}	K2	K1	rel.	det. 200k	det. 1000k
French	5443	7271	395	3.32	yes	no	yes
German	504	517	120	3.52	yes	no	no
English	386	404	84	2.80	no	no	no
Italian	172	158	59	3.06	no	no	no
Portuguese	150	143	46	2.55	no	no	no
Spanish	119	132	18	1.09	no	no	no
Others	265	267	68	2.76	no	no	no

Criterion K2 with $\epsilon_2 = 100$, criterion K1 with $\epsilon_1 = 2.33$. Note that K2 is a difference which is adjusted for the growth of Veyrier. Source: Federal Statistical Office

Table 6 shows results aggregated over Switzerland for the variable Labour Market Status and for size-classes of municipalities. There is only one relevant class in a municipality below $N_D = 1000$. The percentage of missed persons in the last column is rather high for municipalities between 3000 and $100\,000$ inhabitants. Table 7 shows the proportion of the population missed in larger municipalities. For $n_U = 200\,000$ and municipalities larger than $15\,000$ the missed persons for Labour Market Status account for 4.2% of the population in these municipalities. Many users may find this proportion too large. However, aggregation of missing persons over a set of municipalities is equivalent to summing absolute errors. The error for estimating the number of persons in a Labour Market Status would have a much smaller error because then errors would, at least partially, cancel out. Thus the sum of absolute errors of 4.2% may be not be compared to the error of an estimate for that aggregate of municipalities. However it is difficult to judge whether this sum of absolute errors is acceptable.

For Place of Work and Language the percentages of missed persons are somewhat lower but not negligible. The five-yearly sample of size $n = 1\,000\,000$ improves these percentages clearly even with the lower limit for a large municipality set at 3000. These results based on criterion K1 and K2 suggest that the sample of the Swiss Population Survey, as it is foreseen presently, may not yield sufficiently accurate results for municipalities or sub-populations with less than $15\,000$ inhabitants yearly and less than 3000 inhabitants five-yearly.

The definition of a relevant difference and its detection gives some insight into what accuracy of the Swiss Population Survey means. However the criterion for a relevant difference depends on a theoretical value p_0, on the size of the domain N_D and on the parameters, ϵ_1 and ϵ_2, while detectability depends on the z-value of the tolerance interval. The results on missed persons depend on the choice of these parameters, a choice which is not clear-cut. Therefore, in the next section a simpler measure for accuracy which connects relevance and detectability directly is developed.

Table 6 Results for Labour Market Status and municipalities with $n_U = 200\,000$.

N_D	total N	M	n.class	n.rel	m.class	m.pers	p.m.pers
22-99	9896	155	586	0	0	0	0.0
100-499	243818	856	4534	0	0	0	0.0
500-999	407909	563	3349	1	1	118	0.0
1000-2999	1383358	781	4686	187	187	23419	1.7
3000-9999	2181073	422	2532	736	736	142428	6.5
10000-14999	693610	57	342	187	187	58005	8.4
15000-99999	1407003	57	342	234	201	88878	6.3
100000-363273	961343	5	30	28	9	9743	1.0
Total	7288010	2896	16401	1373	1321	322591	

Relevance according to the definition with $\epsilon_2 = 100$ and $\epsilon_1 = 2.33$. Detectability with approximate power 80%, i.e. with $z = 2.80$. M is the number of municipalities, n.class is the number of classes, n.rel is the number of relevant classes, m.class the number of missed (relevant) classes, m.pers the number of missed persons and p.m.pers the proportion of missed persons.

Table 7 Proportion of persons missed in larger municipalities

Variable	n_U	lowest size	m.pers	p.m.pers
Labour Market Status	200000	15000	98621	4.2
Labour Market Status	1000000	3000	97846	1.9
Place of Work	200000	15000	95861	4.0
Place of Work	1000000	3000	89825	1.7
Language	200000	15000	74709	3.2
Language	1000000	3000	10542	0.2

p.m.pers is the proportion of missed persons in the municipalities larger than lowest size, i.e. $2\,368\,346$ is the denominator for lowest size $15\,000$ and $5\,243\,029$ for lowest size 3000.

3.4 Resolution

The existence of a natural inferior bound for the detection of a group (see Subsection 3.1) stimulates the search for an accuracy description which is directly linked to the estimation of the size of a small group. We try to determine a size or a proportion of a group which must be considered too small to be estimated with sufficient accuracy from the sample. We call this smallest estimable size the **resolution** of the sample in analogy to the capability of optical devices to distinguish two objects which are close together.

We have seen in Table 3 that the lower limit of the tolerance interval for small proportions can become 0. We would like to exclude $\hat{p}_A = 0$ from occuring. Thus we ask how large must a sample be to ensure that a $p_A \pm z\sigma(\hat{p}_A)$ tolerance interval does not include 0. The constant z can be chosen similar to a confidence interval: The probability of an estimate $\hat{p}_A = 0$ should be sufficiently low, e.g. below 2.5%. This choice leads to $z = 1.96$ as for (3). By giving a low probability for the observed proportion $\hat{p}_A$ to be 0 we ensure a low probability that $\hat{p}_A$ is larger than a reasonable upper bound, namely roughly twice the theoretical proportion. For example if $p_A = 2\%$ we will have a low probability of obtaining $\hat{p}_A = 0$ or $\hat{p}_A > 4\%$. We think that this is a reasonable band for probabilities up to about 10% or even up to 25%.

To obtain the size of the group for which this band is respected we may assume that $p_A < 0.5$ and therefore only the lower limit of the tolerance interval must be considered. The inequality that n_D must fulfill is

$$p_A - z\sigma(\hat{p}_A) = p_A - z\sqrt{(1-f)\frac{p_A(1-p_A)}{n_D}} > 0. \tag{5}$$

We substitute p_A by N_A/N_D in (5) and solve the inequality for N_A. We obtain

$$N_A > \frac{N_D z^2(1-f)}{n_D + z^2(1-f)}. \tag{6}$$

If we choose N_A such that

$$N_A > \frac{N_D z^2}{n_D} = \frac{z^2}{f} \tag{7}$$

we are sure that N_A fulfills (5). Since $z^2(1-f)$ usually is small compared to n_D, e.g. $z^2(1-f) = 3.75$ for $z = 1.96$ and $f = 0.0274$, the relaxation of inequality (6) by (7) is often small. In inequality (7) neither the proportion p_A nor the size of the domain N_D is directly involved. Knowing the sampling fraction f and fixing $z = 1.96$ we can calculate the minimal N_A which can be detected reliably. For example for $f = 0.0274$, the sampling fraction for the sample size $n_U = 200\,000$, we obtain $N_A \approx 140$.

Now we define the resolution:

Definition: *The $100 \cdot (1-\beta)$%-resolution $R(\beta, f)$ of a simple random sample is z^2/f, where $z = \Phi^{-1}(1-\beta/2)$ is a standard normal quantile and f is the sampling rate.*

The resolution is the smallest size R of a group which can be detected reliably with a simple random sample. Here reliable detection means that the probability of a sample estimate of the size being larger than 0 and less than the double of R is approximately $1-\beta$. The 95%-resolution for the Swiss Population Survey with $n_U = 200\,000$ is $R \approx 140$ and with $n_U = 1\,000\,000$ it is $R \approx 28$.

As an example we see from Table 5 that in Veyrier the language classes French, German, English, Italian and Portuguese would be above the resolution $R = 140$ for a yearly sample in 1990 (N_{A1}) and in 2000 (N_A2), while Spanish and all smaller language groups, which we subsumed in the others category, are below resolution. For the five-yearly sample besides Spanish Arabic ($N_{A2} = 57$), Dutch ($N_{A2} = 50$) and Swedish ($N_{A2} = 33$) would also be above the resolution of $R = 28$ and thus their existence would be detected.

For a sub-population or domain which is not a stratum with a fixed sample size, i.e. which is not a municipality, some additional variability is induced by the hypergeometric distribution of the size of the part of the sample falling into the sub-population. For a domain of size $N_D \geq 15\,000$ the expected size of the yearly sample in the domain is $n_D = 412$ with standard deviation 20. Thus for domains of this size or above the resolution is approximately valid even if the sample size for the domain is not fixed as for municipalities.

Given a desired resolution R we can easily calculate the size of the Swiss Population Survey that is necessary to achieve it: $n_U = z^2 N_U/R$. In other words we may choose a limit above which a group is considered to have a relevant size. Setting the resolution to this relevant size directly leads to the necessary sample size to ensure its detection.

Table 8 shows the sample sizes necessary to obtain a predetermined resolution for a population of size $N_U = 7\,288\,010$. Obviously some arbitrariness of the resolutions $R = 28$ and $R = 140$ exists because these numbers are induced by the round sample sizes they correspond to. However, these numbers lie in a reasonable order of magnitude. They explain that with the yearly sample a group of a size just fitting into a tram may remain, so to speak, invisible, but not a group just fitting in a suburban train, while in the 5-year sample only a small school class might pass unnoticed. Every group above these thresholds would have a very low chance of passing unnoticed. This holds for any size of municipality and, approximately, for any sub-population to be analysed.

Table 8 Sample size to obtain a given resolution R

R	n_U	Remark
10	2 799 762	
20	1 399 881	
28	999 915	5-year pooled sample
50	559 952	
70	399 966	2- year pooled sample
100	279 976	
140	199 983	yearly sample
200	139 988	
500	55 995	

4 Estimation of a change of proportions

We now turn to the estimation of the change of a proportion over time and the comparison of two (or more) proportions. In this Section we assume that we have two independent random samples either at the same time in two distinct sub-populations or at two different times for the same sub-population. This is different from what we assumed in former sections where only one random sample was considered and a deviation from a hypothetical parameter was the focus. Now the variability of both samples must be considered. We develop the problem for a change between two time points for the same sub-population but the problem is equivalent if we compare two different sub-populations at the same time point.

The ingredients of the problem are the sizes of the population at times $t = 1$ and $t = 2$, i.e. N_{D1} and N_{D2}, and the sizes of the group N_{A1} and N_{A2}. The difference of proportions $\delta_A = p_{A2} - p_{A1}$ may be estimated by the difference of estimates of proportions $\hat{\delta}_A = \hat{p}_{A2} - \hat{p}_{A1}$. Since the two samples are assumed independent the variance of $\hat{\delta}_A$ is the sum of the variances of the estimates of proportion, i.e. $\sigma^2(\hat{\delta}_A) = \sigma^2(\hat{p}_{A2}) + \sigma^2(\hat{p}_{A1})$. An approximate tolerance interval based on the assumption of normal distribution of the two estimates of proportion is

$$[\delta_A \pm z\, \sigma(\hat{\delta}_A)]. \tag{8}$$

For a 95% tolerance $z = 1.96$.

Here we assume that $p_{A1} < p_{A2}$, i.e. δ_A is assumed positive. In analogy to equation (5) for the resolution when estimating a single proportion we demand that

$$\delta_A - z\sigma(\hat{\delta}_A) > 0. \tag{9}$$

We would like to obtain a simple expression for δ_A from inequality (9). However, there is no simple closed form solution. To simplify we assume $N_{D1} = N_{D2} = N_D$, i.e. we assume that the two sub-populations under consideration have the same size. Note that in that case $\Delta_A = N_{A2} - N_{A1} = N_D \delta_A$.

With these assumptions and after some algebra[1] (9) is equivalent to

$$\delta_A > \left((0.5 - p_{A1})^2(\gamma^2 - 2\gamma) + \gamma/2\right)^{1/2} + \gamma(0.5 - p_{A1}) = r_c(p_{A1}, N_D, \beta, f), \tag{10}$$

where

$$\gamma = \frac{z^2(1-f)}{n_D + z^2(1-f)} \tag{11}$$

with $n_D = f \cdot N_D$ and $z = \Phi^{-1}(1 - \beta/2)$. Obviously we must let the bound depend on one of the involved probabilities and here we chose the smaller probability p_{A1}. The expression for the change-resolution is not as simple as for the resolution. Nevertheless all the parameters of the right hand side of (10) are known and the change-resolution may be readily calculated.

The corresponding bound for Δ_A is $N_D r_c(p_{A1}, N_D, \beta, f)$.

Definition: *The $100 \cdot (1 - \beta)$% change-resolution $R_c(p_{A1}, N_D, \beta, f)$ at probability p_{A1} of a simple random sample in a domain of size N_D is*

$$R_c(p_{A1}, N_D, \beta, f) = N_D r_c(p_{A1}, N_D, \beta, f),$$

where $z = \Phi^{-1}(1 - \beta/2)$ is a standard normal quantile and f is the sampling rate.

The change-resolution has a positive value at $p_{A1} = 0$, increases until a maximum somewhat smaller than 0.5 and then decreases again to reach 0 at $p_{A1} = 1$. Thus, as expected, the most difficult changes are the ones with proportions around 0.5

The change-resolution gives us a simple number for each concrete problem we have at hand. But it depends on the proportion p_{A1} and on the size of the municipality N_D. Note that due to the sample size n_D in γ the dependence of the change resolution on N_D is not linear. Furthermore the change-resolution is strictly valid only under the assumption that $N_{D1} = N_{D2}$. This latter assumption may be approximately true for a change of proportion within the same domain or municipality. For comparing the proportions of two disjoint domains we may use the larger of the two involved domain sizes for determining the resolution. This will yield a conservative bound. For a sharper bound the full equation (9) may be solved numerically.

Table 9 shows the change-resolution at different proportions p_{A1} and for some domain sizes N_D. For example, when $N_D = 15\,000$ we may be interested in the increase of a group which accounted for 20% of the population, i.e. contained $N_{A1} = 3000$ persons. Assuming that the population of the municipality stays the same, the size of the considered group would have to be $N_{A2} = 3000 + 847 = 3847 = 0.256 \cdot N_D$ if the change should have a high probability of being detected ($\delta_A = 0.056$ in that case).

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[1] Substituting $p_{A2} = p_{A1} + \delta$ in (9) and squaring (9) yields $\delta^2 - 2\delta(0.5 - p_{A1})\gamma > 2p_{A1}(1 - p_{A1})\gamma = (0.5 - 2(0.5 - p_{A1})^2)\gamma$ with γ as in (11)

Note that the change-resolution for $p_{A1} = 0$ is only slightly lower than the corresponding resolution, which is $R = 140$ and $R = 28$. Thus the situation is similar whether we want to detect a group of size R or we want to detect a change of size R_c from an inexistent group. In both situations only the variability of one sample counts. As soon as we assume that a group existed at both time points the situation changes because the variability of two samples has to be accounted for. Accordingly the change-resolution may become much larger than the resolution. For each p_{A1} the change-resolution roughly increases like the square root of the domain size N_D, i.e. $R_c/\sqrt{N_D}$ is approximately constant.

Table 9 95% change-resolution R_c

		$p_{A1} =$					
n_U	N_D	0	0.01	0.05	0.2	0.5	0.8
200 000	3000	130	173	260	395	442	317
200 000	15000	135	277	504	847	1007	766
200 000	100000	136	590	1200	2129	2609	2047
1 000 000	3000	24	51	94	159	190	145
1 000 000	15000	24	97	197	348	426	333
1 000 000	100000	24	231	490	887	1100	873

4.1 χ^2-test for equality of two proportions

The change-resolution is more complex than the resolution since it depends on more parameters. It is still simpler than a hypothesis test, though at the cost of approximations. In the next two subsections we explore the relationship of the change-resolution with the χ^2-test.

The classical testing problem is the test for equality of the two proportions. The hypothesis $H_0 : p_{A1} = p_{A2}$ or $\delta_A = 0$ is tested against the alternative $H_1 : p_{A1} \neq p_{A2}$ or $\delta_A \neq 0$. The classical test for equality of two proportions is based on the χ^2-statistic. The χ^2-statistic in our situation is

$$\chi^2 = \frac{(n_{D1} + n_{D2})(n_{A1}n_{B2} - n_{B1}n_{A2})^2}{n_{D1}n_{D2}(n_{A1} + n_{A2})(n_{B1} + n_{B2})}, \tag{12}$$

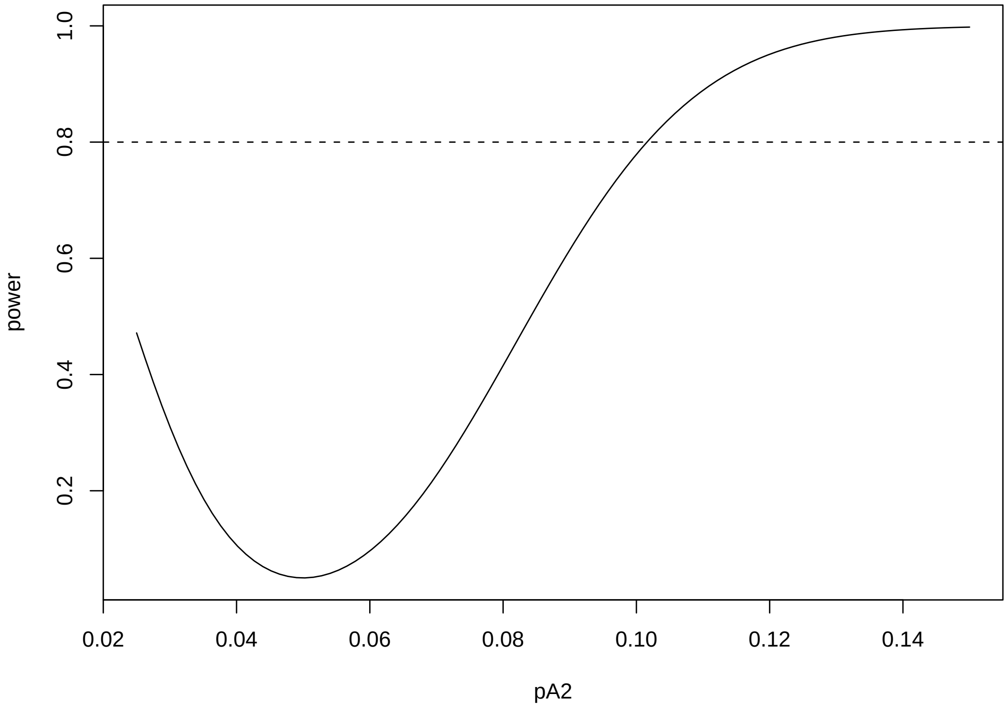
where $n_{B1} = n_{D1} - n_{A1}$ and $n_{B2} = n_{D2} - n_{A2}$ (cf. (Agresti, 1996, p. 52)). If χ^2 is larger than a critical value from the χ^2-distribution with 1 degree of freedom, say c, the hypothesis of equality of proportions is rejected.

The probability of the test rejecting the hypothesis of equality of proportions, the level of the test or type I error, is $\alpha = P_0[\chi^2 > c]$, the subscript 0 indicating a probability under the Null-hypothesis. The level is usually set to $\alpha = 5\%$. In other words we accept a 5% risk of deciding for a true difference when there is none in reality. For the discussion about the accuracy of a sample the important error is the type II error, the probability β of accepting the hypothesis of equality of proportions if in fact the alternative holds. The probability of rejecting the hypothesis at a certain alternative, i.e. $1 - \beta = P_1[\chi^2 > c]$ for $\delta_A \neq 0$ is the power of the test at δ_A.

The power of the χ^2-test versus p_{A2} when $N_{D1} = N_{D2} = 15\,000$ and $p_{A1} = 0.05$ is plotted in Figure 1. We see that the power is about 80% when $p_{A2} = 0.10$, i.e. with $\delta_A = 0.05$. It is, again, a matter of judgment whether this power is large enough. Though a power of 80% is less established than the level 5%, it is a figure that is chosen in many practical applications (see e.g. Parker and Berman (2003)). A chance of 20% of not detecting a real difference of that size in a population of $15\,000$ may mean neglecting the needs of 750 persons. However, the chance of neglecting a change of this size during two or more years is very small with the Swiss Population Survey. For the comparison of two proportions among two sub-populations of the same population, and all things remaining equal, the type II errors multiply each year because the yearly samples can be considered independent. Then $P_1[\chi^2(t) \leq c \cap \chi^2(t+1) \leq c] = \beta^2$. Thus, in our example it would drop to $\beta^2 = 4\%$ in the second year and $\beta^3 = 0.8\%$ in the third year, corresponding to a power of 96% and 99.2% respectively.

For the comparison of changes over more than two years we would have to specify more precisely what we would like to detect. It could be a change at a certain point in time or a trend over time. We could then use a model to describe the change and estimate the model using all available data. The power of corresponding tests should then be evaluated for the problem at hand. For example Salamin (1997) shows how longitudinal analysis can enhance the precision of estimates of a trend.

Figure 1 Power of χ^2-test for $p_{A2} = p_{A1}$ at $p_{A1} = 0.05$ and $n_{D1} = n_{D2} = 412 = f \cdot 15'000$.



The 95% change-resolution $R_c = 504$ at $p_{A1} = 0.05$ implies an alternative at $p_{A2} = 0.05 + 504/15000 = 0.0836$ (cf. Table 9), which corresponds to a power of the χ^2-test of 49%. In general, the level 95% of the resolution or the change-resolution will yield a power of approximately 50% under a hypothesis test at the level 5%. If a higher power should be ensured we must increase the level of the resolution. If the power should be about 80%, the necessary level is approximately 99.5%, which corresponds to $z = 2.8$. The 99.5%-change-resolution at $N_D = 15\ 000$ and $p_{A1} = 0.05$ is $R_c = 759$. Thus, only for a change from $N_{A1} = 750$ to at least $N_{A2} = 1509$ we can affirm that for 4 out of 5 samples we would declare it significant.

That these orders of magnitude make sense may be illustrated when one translates them into expected numbers in the sample. The sample for $N_D = 15000$ will be $n_D = 412$ and thus the expected number of members of group A in the samples are $n_{A1} = p_{A1}n_D = 20.6$ and $n_{A2} = p_{A2}n_D = 34.4$. Thus for $p_{A2} = 0.0836$ an expected difference of 13.8 results. The standard deviation of the difference is 7.2. Thus the construction of the change-resolution implies rightly, that a 95% tolerance interval for the difference of the number of members from group A in the sample would approximately touch 0 with one of its ends. A difference of 759 corresponding to $z = 2.8$ would be clearly outside the tolerance interval.

4.2 χ^2-test for several proportions

We now shortly examine the problem of the comparison of several proportions by the χ^2-test. We compare sub-populations within municipalities at the same time point. For example we may consider the contingency table of Labour Market Status (employed, unemployed, inactive, underage) versus gender (men, women). Such a table can be drawn up in every municipality. We may then test the independence of Labour Market Status and gender with a χ^2-test. With the data of the census 2000 of the 2896 tables 2332 yield a significant test, 2270 of the significant tables having less than $15\,000$ inhabitants. The test takes into account the size of the municipality. Therefore it is no surprise that all tables are significant for the 62 municipalities with more than $15\,000$ inhabitants. This accounts for the number of persons concerned by the particular association. The test with the data of the census, in fact, relates to an underlying hypothetical population of infinite size, of which the census is a realisation.

For each municipality the power of the same χ^2-test, when only a sample instead of the census is observed, can be calculated from the non-central χ^2-distribution with non-centrality parameter according to the actually observed census table. This is the probability of obtaining a significant test result with the sample, given the actually observed alternative holds.

An objective comparison of census and sample may be based on the average power over the tables of the municipalities, $\sum P_1[\chi^2_U > c]/M$ and $\sum P_1[\chi^2_S > c]/M$, where χ^2_U refers to the χ^2-statistic for a sample of the size of the population, χ^2_S to the χ^2-statistic of the sample, M is the number of municipalities over which the sum extends and P_1 denotes probabilities under the alternative. Table 10 shows this average power for 3 size classes and for the two sample sizes considered. With sample size $n_U = 200\,000$ the average power is high if $N_D > 15\,000$ and for $n_U = 1\,000\,000$ for $N_D > 3000$ though, of course, lower than for the census. Looking at the percentage of tables where the power is larger than 0.8 (Table 11) a similar picture arises. For the yearly sample 95.2% of the tables in municipalities with more than $15\,000$ inhabitants have a power larger than 80%. Thus from this analysis we may conclude that the Swiss Popoulation Survey yields sufficient power to distinguish distributions as markedly different as labour market status of men and women. Of course, the dependence of labour market status on gender is strong in most municipalities and the alternatives are relatively far away and thus the power is high in many municipalities. For other tables the power may be lower and more varied across the municipalities.

Table 10 Average power of χ^2-test on Independence of labour market status and gender

n_D	$N_D < 3000$	$3000 \leq N_D < 15\,000$	$N_D \geq 15\,000$
200 000	0.128	0.518	0.938
1 000 000	0.430	0.982	1.000
Census	0.891	1.000	1.000
M	2355	479	62

Table 11 Percentage of χ^2-tests on independence of labour market status and gender with power above 0.8

n_D	$N_D < 3000$	$3000 \leq N_D < 15\,000$	$N_D \geq 15\,000$
200 000	0.0	9.8	95.2
1 000 000	14.8	99.4	100.0
Census	80.9	100.0	100.0
M	2355	479	62

5 Conclusions

The Swiss Population Survey is a multi-purpose, multi-user survey where particular attention is given to the accuracy of results for municipalities. Given the many purposes and many users of the Swiss Population Survey and their varying degrees of statistical knowledge, the discussion with the users about accuracy requirements is difficult. The article gives two new indicators for the accuracy, the resolution and the change-resolution. These indicators give a more widely applicable description of the accuracy of a survey than the classical measures derived from hypothesis tests or confidence intervals and they carry an intuitive meaning for non-expert users. Thus the resolution of a survey and the change-resolution are introduced as measures to help the communication with the users of the Swiss Population Survey.

The resolution is the smallest group than can be detected safely with a simple random sample of a given size. The resolution of the yearly sample of the Swiss Population Survey is 140. This resolution may be too large for the needs of small and medium sized municipalities, while for cities above 15 000 inhabitants and for the cantons it should be sufficient for many purposes. Medium municipalities with at least 3000 inhabitants would have to wait up to five years until a pooled sample could give them sufficiently accurate results.

The change-resolution is more complex and generally larger then the resolution. For a municipality of size 15 000 and the most difficult proportion 0.5 the change-resolution is 1 007. The change-resolution as well as the consideration of the power of the χ^2-test show that relatively large changes may remain undetected by the Swiss Population Survey during a few years.

On the other hand the χ^2-test for independence for contingency tables may have sufficient power with the sample only compared with the power of the corresponding test with the census when the municipality is larger than 15 000 for the yearly and larger than 3 000 for the five-yearly sample.

Considering the resolution we think that the yearly sample of size $n_U = 200\,000$ covers the requirements for the estimation of a proportion for larger municipalities of size at least 15 000 but that the needs of smaller municipalities will only be fulfilled when pooling over several years. Considering the change-resolution, the situation is more complex since it depends not only on the change but also on the probabilities involved. Nevertheless we think that the needs for comparisons of proportions often must be based on pooled samples of several years even for larger municipalities and therefore, a larger sample would be desirable for that purpose.

The decision on the size of a sample in practice is a compromise between cost and accuracy. From the point of view of accuracy a larger sample would be desirable but, of course, more costly. On the other hand the size of the Swiss Population Survey, as it is planned, is useful for many purposes in spite of its limitations.

The quality of a Swiss Population Survey does not depend on the size alone. It will only become a reference survey for all other surveys of Switzerland if its response rate is very high. The response to the Swiss Population Survey will be declared mandatory for those persons selected to participate. This should help to achieve a response rate of over 90% and, therefore, a gross sample of $222\,000$ should be enough to obtain a net sample of size $200\,000$.

The accuracy-requirements which were treated in this article refer to proportions. The situation is different when quantitative variables are involved like housing rent or travel time to the place of work. The variability of such variables is not directly related to their mean as for proportions. Furthermore it may be even more difficult to elicit relevant differences from the users. It is also usually more difficult to obtain information on monetary values from the survey respondents and more missing values have to be expected. Therefore, no conclusion on the usefulness of a sample of size $200\,000$ for the analysis of quantitative variables in small groups can be drawn from this article.

The accuracy of results involving quantitative variables is a domain of further research. Small area estimation is applied in other countries but has not yet been used in Switzerland. Application studies with Small Area Estimation methods for Switzerland should therefore be undertaken. Also the analysis of longitudinal and pooled data should be investigated further in the light of the requirements of the users of the Swiss Population Survey.

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From 2010 onwards the Swiss Population Survey together with the data from the administrative registers on persons, dwellings and buildings of Switzerland will provide yearly structural statistics on Switzerland. The discussion of the accuracy of the Swiss Population Survey is difficult due to its multi-purpose, multi-user nature. In particular there is a concern about the accuracy of the Swiss Population Survey for small municipalities. The resolution and the change-resolution are introduced as new indicators of accuracy which combine relevance and accuracy and serve a wide range of problems. With the help of the new accuracy indicators the potential and limitations of the planned sample of the Swiss Population Survey of a size of 200'000 persons is discussed.

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