Identification risk for microdata stemming from official statistics

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1. Introduction

If a number of legal restrictions are observed microdata generated by German official statistics can be released for purposes of social scientific research. The Federal Act on Statistics (§16 Abs. 6 BStatG 1987) stipulates factual anonymity rather than absolute anonymity of the respondents. In the case of factual anonymity the cost in terms of manpower, time, and money of identifying an individual in a released microdata file (MDF) exceeds the returns.

In order to clarify the conditions under which factual anonymity of released microdata can be guaranteed, the University of Mannheim (Prof. Walter Müller), the German Federal Office of Statistics (StBA, Wiesbaden) and ZUMA carried out a research project. The identification risk for individuals in a released microdata file was tested under realistic conditions by using empirical data.

Since the Federal Act on Statistics is based on the notion of identity disclosure (cf. Duncan, Lambert 1989, p. 208), this concept was used for the "Research Project on Data Anonymity". Identity disclosure or "Identification of an individual takes place when a one-to-one relationship between a record in released statistical information and a specific individual can be established" (Bethlehem, Keller, Pannekoek 1990, p. 38). For the identification of an individual whose data are in a file of microdata stemming from official statistics, a potential intruder needs so-called "prior knowledge" (or "identifying information") about persons which has some variables in common with the microdata file. The prior knowledge is organized in an identification file (IF). This has to include formal identifiers such as names and adresses of the individuals to which the data apply. The identification of an individual can only be achieved by creating a one-to-one association between unique records of the microdata file and the identification file.

2. Using a social science scenario in testing factual anonymity

Under the regulations of the German Federal Act on Statistitics factual anonymous microdata may only be released for scientific purposes. Thus the aim of the Research Project on Data Anonymity was to determine the dislosure risk and the cost of identity disclosure in the framework of a scientific scenario. One main contribution of the project was the analysis of potential motives and benefits of identity disclosure and the information content of prior knowledge from sources the scientists have access to.

On the basis of these results several subscenarios were developed which were intended to cover a wide range of possible situations where there might be a danger for data anonymity in the scientific scenario. For two of these subscenarios identification experiments with empirical data were carried out. The research project has not been finished yet. So in this paper only a description of the results of one specific subscenario is given.

In this subscenario, it was assumed that the intention of the intruder was a mass identification. It was assumed that the intruder carried out a "fishing operation", i. e. tried to identify as much individuals as possible in a released microdata file irrespective of the persons identified. An additional assumption was that the intruder did not know whose data are in the MDF.

3. The data

As a microdata file (MDF) in the experiments the 1987 microcensus of the German state North Rhine-Westfalia could be used. The microcensus is a survey of 1 % of the total population (approximately 17 million persons). The file given to the project group contained 169 368 records with a selection of variables needed for the experiments. Only the formal identifiers (names and addresses) had been removed from the MDF. There had been no other measures to secure the anonymity of the respondents.

To find or to construct a corresponding IF a comprehensive list of sources of prior knowledge an intruder could use was compiled. It was ascertained that handbooks about professional groups like architects, jurists, scientists etc. might be a relatively

comfortable source of prior knowledge. These handbooks often comprise the whole subpopulation. They provide detailed information on attributes like region, profession, age, sex etc. As these variables are also included in the microcensus, they are common variables and can be regarded as key variables (cf. Dalenius 1986) in the MDF. For the experiments "Kürschners Deutscher Gelehrtenkalender", a handbook about German scientists and scholars, was selected. Nearly the total subpopulation of German university professors and parts of the subpopulation of other scientists were included.

The information included in this handbook comprised 10 attributes which were also in the microcensus. This was the highest number of common variables of all the relevant handbooks. The common variables were:

- region ("Bundesraumordnungsregion")
- size of place of residence
- sex
- year of birth
- half-year of birth
- industry
- occupation
- occupational status
- specification of the professional activity
- subject of the university degree

The information of the "Gelehrtenkalender" handbook was not formalized but in the form of uncoded text. The German Federal Office of Statistics did the coding for the identification experiments according to microcensus categories. Thus, a high comparability between the codes of the MDF and the IF was guaranteed.

A major problem arising during the coding work were the ambiguities of many statements. Not in all cases was it possible to define exactly the category of an indivual. For example, there were heads of university hospitals who were university professors as well as physicians. It was unknown which these respondents would had regarded as their primary occupation if they had been interviewed in microcensus. In all these cases a second variable was coded. With four key variables ambiguities were important. Where there was no ambiguity the alternativ variables was set to

the "missing" value.

The IF contained 7 983 records from the German Land North Rhine-Westfalia.

Taking empirical data for the experiments did not involve making real identifications. To control the identification results a costly method ("double blind procedure") was developed. The project group in Mannheim (ZUMA/ University) received the data files without formal identifiers for the experiments. Each record had a definite number. After the construction of an association between single records in the IF and the MDF by means of an identification method these numbers were sent to a neutral person called "data trustee". He had a file with the numbers and the addresses of the respondents but no further information. This enabled him to control how many people had given data for both files and to control whether the "identifications" were correct.

4. The simple-matching method

The simple-matching method is based on a comparison of the values of the key variables in the MDF and the IF. If an intruder succeeds in finding a unique value set in a MDF which is completely identical to a value set in his IF this record is regarded as identified.[1]

The simplicity of the method is an advantage from the standpoint of the intruder with regard to the necessary efforts, but it is also its weak point. From the analysis of Paass (Paass 1988, Paass, Wauschkuhn 1985) it is known, that there are two problems an hypothetical intruder has to deal with:

- There is a broad variety of incompatibilities between the data of the two used files. These deviations may be the result of "noise" in the data, of coding errors, reliability problems, different definitions of categories, and different points of time the data refer to.
- In most cases the intruder only has data based on samples. Thus he does not know whether there are cases in the unknown rest of

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[1] A general description of the realization of the matching process is given by Dalenius (1986).

the population which have the same attributes as those he wants to identify.[2]

If the data files are not completely comparable and/or the files are only samples, a simple-matching method may fail. No statistical estimation is provided, which can deal with data errors or the possibility of "statistical twins" in the population when different people have the same values in the relevant variables. This method leaves an intruder uncertain about the reliability of his identification efforts.

5. Results (I)

For testing the simple-matching method the matching procedure of SPSS^X was used. The IF contained 10 key variables and 4 alternative key variables. Since the SPSS^X matching does not allow to take these alternative variables into account, 2^4 variations of the "Gelehrtenkalender" were created. Thus there were 16 different part-identification files. Each part-IF included only one of the alternatives in the relevant four variables respectively.

The data base revealed a high identification risk. Between 45 and 65 % of the records of the part-IFs were unique. The microdata file had 36 % unique records. If only the relevant subpopulation was regarded, the rate of unique cases was higher. To do this, only cases of the MDF were included which had values in the variables which were also in the IF (because in simple matching only these values are important). The reduced MDF had 3 099 records. The rate of uniqueness in this file was 79 % (see Table 1). Since the "Gelehrtenkalender" contained the total subpopulation of the German university professors, a high identification risk was to be expected provided that the information in the data files was completely comparable.

In matching all 16 part-IFs with the microdata file only 14 records corresponding without ambiguity on a one-to-one level were found (Table 1). The checking of the record numbers by the data trustee showed that only 4 of the 14 matches were correct. The simple method failed with a probability of 0.71.

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[2] But there are statistical methods to estimate the rate of unique cases in the population (Bethlehem et al. 1990 and Mokken et al. 1990).

Table 1: Results of experiments realized with a simple-matching procedure using data of "Kürschners Deutschem Gelehrtenkalender" ("IF") and Microcensus of Nordrhein-Westfalen (MDF).

Rate of unique records in the part-IFs (a) and quantity of one-to-one associations (b)

	MDF		No. of the part-IFs														
	total	red.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
N	169368	3099	7983	7983	7983	7983	7983	7983	7983	7983	7983	7983	7983	7983	7983	7983	7983	7983
a)	% 38.7	% 79.3	% 62.7	% 45.1	% 45.2	% 51.5	% 64.5	% 51.5	% 64.5	% 62.8	% 51.4	% 64.4	% 64.4	% 51.4	% 50.8	% 50.8	% 64.1	% 64.1
b)	14		1	-	3	-	-	-	-	7	-	3	-	-	-	-	-	-

4 of the total of 14 one-to-one associations were correct (28.6%)

The data trustee ascertained that the data of 53 individuals were present in both files. Only 4 of these could be related on a one-to-one level in the experiments.

In addition to these one-to-one associations there were ambiguous associations. 13 cases of the MDF were related to more than one case of the "Gelehrtenkalender". 2 were related to one case in the IF. Six of these additional associations were correct. But under the assumptions made there were no further identity disclosures. Because of the ambiguity of the associations the identity of the respondents was not uncovered. 81% of the persons whose data were in both files had incompatible values in the key variables. Thus these 43 records could not have been identified with a simple matching method. Even if there had been additional information (i. e. more variables) an identification with a simple-matching methode would have been impossible.

The cost of the experiments carried out were high. The preparation of the identification file by the Federal Federal Office of Statistics costed about 44 000 DM. The costs of developing the identification concept and of computing amounted to 17 000 DM. Hence it costed about 61 000 DM to determine 14 one-to-

one relations between records in the MDF and the IF.

6. Paass' method based on discriminant analysis

To overcome the weaknesses of simple-matching methods and to carry out realistic tests of data anonymity a procedure based on discriminant analysis (PDA) was developed by the "German National Research Center for Computer Science" ("Gesellschaft für Mathematik und Datenverarbeitung" - GMD) in St. Augustin. The method was conceived to solve the mentioned problems of a hypothetical data agressor.

To overcome the difficulties with "statistical twins" and data incompatibilities identification is regarded as a statistical decision problem. Thus, the method of Paass has the important advantage of explicit computing the probability of correctly relating two records, which makes it a very powerful tool. Only a short description of the method was published in English (Paass 1988). The report of the whole research project is only available in German language (Paass, Wauschkuhn 1985). The long version shows the enormous complexity of the method. Only a short overview is possible in this context.

i Every case in the MDF is treated as a class of its own in discriminant analysis.

ii To do this, probability distributions within classes are estimated. These distributions depend on assumptions about data incompatibilities. Information describing these deviations has to be used as input for the estimation.

iii The method provides an estimation of unconditional probabilities to overcome the problem of "statistical twins".

iv To compute the probability that one record from the MDF and one record from the IF stem from the same person, the results of steps ii and iii have to be related to each other. This is done in a Bayes approach typical for linear discriminant analysis.

v The intruder has to compare this probability with an a priori chosen certainty level (e. g. 99 %). If the computed probability is higher he will accept the relation between the two cases as an identification.

The statistical idea of the procedure is shown by the chosen

Bayes approach. From the theory of discriminant analysis it is known that the probability of a case z_j belonging to a class y_a can be given by the following expression:

$$p(y_a|z_j) = \frac{p(z_j|y_a)\ p(y_a)}{\Sigma_i\ p(z_j|y_i)\ p(y_i)}$$

A z_j is a case from the IF and a y_a one from the MDF. The $p(z_j|y_i)$ (the class probability) gives the prior probability of a case z_j stemming from the same person as y_i. This conditional probability is computed on the basis of the distributions[3] of data errors and data incompatibilies the intruder has to specify (step ii). Expression (1) is equivalent to (2), as can be shown using computing rules for conditional probabilities.

$$p(y_a|z_j) = \frac{p(z_j|y_a)\ p(y_a)}{p(z_j)} \qquad (2)$$

The intruder has to compute $p(z_j)$, which is the unconditional probability to find a record z_j.

If the intruder has only samples serving as IF and as MDF he has to use an estimator for $p(z_j)$. It is shown at length in Paass, Wauschkuhn (1985, pp. 112ff.) that instead of (2) expression (3) can be used (if $p(y_a)$ is equal for all cases a).

$$p(y_a|z_j) = \frac{p(z_j|y_a)}{p(z_j|y_a) + (N-1)p_w(z_j)} \qquad (3)$$

To compute the conditional probabilities $p(z_j|y_a)$ and especially the estimator p_w is a very tedious task. The GMD developed a computer program accomplishing it. The program combines many different statistical and numerical procedures to estimate the different probability densities.

The PDA was applied by Paass and Wauschkuhn in their disclosure-risk experiments. As an MDF they used the German Earnings and

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[3] The word "distribution" is used to describe the case of discrete and continuous variables by only one term.

Consumption Sample (Einkommens- und Verbrauchsstichprobe - EVS). As an IF they used a sample synthetically generated out of these data by a modification with stochastic errors. For the distributions and the magnitudes of these errors they made assumptions based on estimations by experts from the Federal Office of Statistics and other institutions (Paaß, Wauschkuhn 1985, p. 177).

In the experiments done by the GMD the PDA was very effective. The simulations were based on different types of scenarios. In these, different assumptions concerning the motive of the intruder, the amount of common variables and the probability and the structure of data errors were tested. If there were about 40 common variables nearly every second of persons whose data were in both files could be identified. Even if there were only 15 variables the data were not safe.

In the international discussion on data confidentiality the results have been noticed. It has been taken for granted that an identification under a broad range of conditions is possible using methods like the PDA.

7. Results (II)

In the project on data anonymity the PDA was applied using two different files with empirical data as an MDF and as an IF. To keep the results comparable to those obtained by simple-matching procedures the same files were used: the Microcensus of Nordrhein-Westfalen of 1987 and "Kürschners deutscher Gelehrtenkalender".

To implement the PDA program on the available computer and to do adaptations for the structure of the used data we needed about a year because of the complexity of the method. The whole cost of computation during the time of implementation and application of the method, without the cost of working time and of the preparation of the data were about 140 000 DM. Thus the PDA includes no real danger for the factual anonymity of official data in the context of a social science scenario.

One problem arising in the application of the method was that double-valued variables could not be dealt with properly. It was impossible to check all possible combinations as we did in the case of the simple matching procedures. A run of the PDA program needs

too much computing time. So it was tried to find the most plausible combination of the alternative variables. Finally the combination No. 8 was chosen, which had had the most one-to-one relations in the experiments with the simple matching procedure. Thus the research design had two steps: it was assumed that a supposed intruder at first tries simple matching procedures and then the PDA.

To realize an experiment with the PDA we had to specify the properties of data errors. To find an empirical basis for this task, the data of a study on reliability (ALLBUS 1984) were analysed (cf. Porst, Zeifang 1987).[4] But besides reliability problems there are other sources of data incompatibilities. So assumptions had to be made. To control for the effects of these assumptions we worked with two levels of errors. Experiment No. 1 was done with error specifications related only to reliability problems. A higher level of errors based on plausible assumptions was the starting point of experiment No. 2.

Table 2
Results of experiments realized with Paass' method based on discriminant analysis (PDA) using data of "Kürschners Deutschem Gelehrtenkalender" ("IF") and of the Microcensus of North Rhine-Westfalia (MDF).
Chosen certainty level of a correct "identification": 99%

No. of Experiment	1	2
level of errors with respect to incompatibilities	reliability problems only	different sources of data
number of "identifications"	9	11
correct "identifications"	2	2
percentage of correct "ident."	22	18

[4] Special research on errors in the microcensus (cf. Deininger 1960, Herberger 1985, StBA 1978) was used additionally.

Table 2 shows the results obtained in the experiments. When it was worked with the simple matching method using file No. 8 as "IF" 7 one-to-one relationships between records of the "IF" and the MDF were found, three of these were correct. The "rate of success" was 42.9 %. Compared with this the PDA was less "successful".

In the experiments of the GMD the method was very reliable. There were only a few cases which were wrongly associated. Tests realized in Mannheim with the same data constellation, i. e. using a synthetic IF, yielded similar results. But the outcome of the experiments with two different files were completely different. What are the causes of these differences? A definite answer cannot be given, because there are four possibilities.

- The PDA was not designed to deal with ambiguous information resulting in the construction of double-valued variables. Taking a specific combination of alternatives for granted leads to an overestimation of the probability of a correct relation.
- The method was originally tested with variables most of which were quantitative. Most of the microcensus variables were, however, quantitative. Under the used common variables there was only one with a metric level of scale.[5]
- The level of errors is higher as was expected in the experiments of the GMD. This can be shown from studies on reliability.
- The structure of the incompatibilities is completely different from those assumed. The mentioned studies on reliability indicate that the distributions of data errors are often not of a simple type (for example normal distribution). But there is a lack of information about the parameters of complex multivariate distributions.

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[5] In the report of Paass and Wauschkuhn it was argued, refering to experiments of Titterington et al. (1981), that the linear discriminant analysis shows good results in the case of nominal variables too. This was confirmed by the tests with a synthetic IF in Mannheim.

8. Conclusions

What kind of conclusions can be drawn from the results obtained in the experiments in Mannheim?

The experiments show the unexpected finding that identity disclosure is not as easy to do as it is often assumed (cf. for instance Steinmüller 1984). Most of the one-to-one associations of records established in the simulations of "fishing operations" were simply wrong.

Thus it can be concluded that an identification is possible under special circumstances. But following the definition of factual anonymity there was no single case of identity disclosure. The one-to-one relationships of records gotten from the simulations cannot be regarded as identifications by a rational intruder in a social science context. He cannot distinguish these from the overwhelming majority of wrong associations.

The costs of the used methods and experiments were considerable. In the assumed scenario it would be cheaper to try an alternative way to get the wanted information. Thus a rational person would pay a detective for the job or try another method (for instance organize a survey if he really wants the data of a lot of persons).

The calculation of an intruder was analysed in the project on data anonymity. It cannot outlined in this paper. But the mentioned costs make it plausible that the factual anonymity of microdata is secured under a range of conditions.

The results of the experiments show that assessments of the risk of data confidentiality based on the counting of unique cases in the sample or on an estimation of the rate of unique cases in the population should be supplemented by an estimation of the frequency of errors in the data and of other incompatibilities. The empirical experiments indicate that these deviations are a "natural barrier" against intruders. They have the same effects as deliberately chosen measures to secure the anonymity of the data.

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