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Forschungsinstitut Freie Berufe (FFB)

July 1994

FFB Forschungsinstitut Freie Berufe

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July 1994

ISSN 0942-2595

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Research for this paper is based back on my work and experience from the Sonderforschungsbereich 3 (Sfb 3) 'Microanalytic Foundations of Social Policy' at the Universities of Frankfurt and Mannheim, Germany, first as a senior research associate in the Sfb 3-project 'Microsimulation' (headed by H.P. Galler), and then in my own Sfb 3-project 'Market and Non-market Activities of Private Households'. Financial funding by the German National Science Foundation (DFG) is gratefully acknowledged.

This study is a revised version of my former Sfb 3-Working Paper No. 315 and is supported by the German National Science Foundation (DFG) within my recent DFG-project on 'Time Use in Employment and Household Production - Dynamic Microanalyses with Paneldata'; it concerns our work and research with microdata and microanalyses at my chair at the University of Lüneburg.

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Summary

Microdata have become increasingly important for economic and social analyses. One striking problem with almost any practical analysis of microdata, microdata as a singular cross or longitudinal sample or within (static) microsimulation, is to achieve representative results.

In this study a consistent solution of the microdata adjustment problem - that is to achieve representative results by re-weighting microdata to fit aggregate control data - is presented based on the Minimum Information Loss (MIL) principle. Based on information theory this principle satisfies the desired positivity constraint on the weighting factors to be computed. For the consistent solution which simultaneously adjusts hierarchical microdata (e.g. household and personal information), a fast numerical solution by a specific modified Newton-Raphson (MN) procedure with a global exponential approximation is proposed.

Practical experiences for large microdata sets in a pension reform analysis with e.g. more than 60.000 households and 240 restrictions simultaneously to be achieved within the Sfb 3 microsimulation model show that this MN procedure was able to rather largely reduce the computional expenses by 75%. The available efficient PC-computer program ADJUST is also succesfully applied in a described microsimulation analyses of the recent 1990 German tax reform investigating the impacts on market and non-market labour supply within the formal and informal economy, and in a recent firm microsimulation analysion explaining factors of successful firms in the German engineering industry.

JEL: C80, C81

Keywords: *Microdata Adjustment, Microanalyses, Microsimulation, Minimum Information Loss, Modified Newton-Raphson Algorithm, PC program package ADJUST*

Zusammenfassung

Mikrodaten sind von zunehmender Bedeutung für wirtschafts- und sozialpolitische Analysen. Ein besonderes Problem für fast alle praktischen Analysen mit Mikrodaten überhaupt, seien es zu analysierende Mikrodaten als singuläre Querschnitts- oder Längsschnitt-Stichproben oder im Bereich der statischen Mikrosimulation zur Aktualisierung und Fortschreibung der Situation sozioökonomischer Gruppen, ist es, repräsentative Ergebnisse zu erhalten.

In dieser Studie wird eine konsistente Lösung der Hochrechnung von Mikrodaten - repräsentative Mikrodaten durch eine entsprechende (Um-)Gewichtung der Mikrodaten zu gewinnen - basierend auf dem Prinzip des minimalen Informationsverlustes (MIL) vorgestellt. Auf informationstheoretischer Basis sichert das MIL-Prinzip vor allem die gewünschte Positivitätsbedingung der zu berechnenden Gewichtungsfaktoren. Für die konsistente Lösung des Hochrechnungsproblems, die simultan hierarchische Mikrodaten (bspw. Haushalt- und Personeninformationen im Haushalts- / Familienrahmen) anpaßt, wird eine relativ schnelle numerische Lösung mit einer spezifischen Newton-Raphson (MN) Prozedur bei globaler exponentieller Approximation vorgeschlagen.

Praktische Erfahrungen mit großen Mikrodatenfiles mit mehr als 60.000 Haushalten und 240 simultan zu erreichende Restriktionen innerhalb des Sfb 3 Mikrosimulationsmodells zeigen, daß diese MN-Prozedur den Rechenaufwand um 75% reduzieren konnte. Das verfügbare effiziente PC-Computerprogramm ADJUST wurde erfolgreich auch in einer Mikrosimulationsanalyse von Wirkungen der deutschen Steuerreform 1990 auf markt- und nichtmarktmäßige Arbeitsangebot in der formellen und informellem Ökonomie sowie in einer neueren Mikrosimulationsanalyse zu Determinanten erfolgreicher Firmen in der deutschen Maschinenbauindustrie angewendet.

JEL: C80, C81

Schlagwörter: *Hochrechnung von Mikrodaten, Mikroanalysen, Statische Mikrosimulation, Minimaler Informationsverlust, Modifizierter Newton-Raphson Algorithmus, PC-Programmpaket ADJUST*

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1 Introduction

Microdata have become increasingly important in recent years for economic and social analyses, e.g. for microanalyses on a personal, family, household, firm or other association's level. Microdata form the basis for descriptive analyses, statistical testing of social and economic hypotheses on an individual level and are fundamental for microsimulation models in analyzing distributional and financial impacts of economic and social policies.

Microdata are - as a rule - not available as a total survey of an entire population but rather as samples, as partial surveys. The general problem and task of an adjustment (grossing-up, re-weighting) of microdata to achieve representative results is to express the sample values in terms of the entire population. Microdata adjustment not only is essential to (re-)weight a cross or longitudinal sample but also of particular importance within static microsimulation when updating and extrapolating (static aging) the situation of any socioeconomic group, e.g. characterized by occupational status like professions, self employed, employees or any other grouping of interest.

If, in idealiter, we really would have a random sample under investigation, the question of achieving representative results could easily be answered: as a microunit characteristics' representative weight take the reciproce value of the sampling ratio. However, there are a number of reasons, like problems in the sampling procedure, non-response, over- and underrepresentation of certain groups in voluntary surveys, selectivity problems in editing and/or analyzing procedures etc., so that the strict randomness of the sample almost as a rule is not satisfied. One striking problem for (almost) any practical microdata analysis in achieving representative results, therefore, is to find an aqequate representative weighting scheme.

In this study a consistent solution of the microdata adjustment problem - a properly (re-) weighting of microdata to fit aggregate control data - is presented based on the Minimum Information Loss (MIL) principle. Based on information theory the MIL principle in particular satisfies the desired positivity constrained of the weighting factors to be computed. In addition, the consistent solution simultaneously adjusts hierarchical microdata, e.g. household and personal information within a household/family setting. Since microdata files contain a large number of observations and characteristics, a fast numerical method to solve the adjustment procedure is necessary. Such a fast numerical solution is proposed by a modified Newton-Raphson procedure where within a set of given steplengths a 'global exponential' modification with a variable steplength yields impressive results.

The remainder of this paper is divided as follows: After defining the general adjustment problem more precisely and discussing available solutions, including a survey of used adjustment procedures in major microsimulation models, its solution by the Minimum Information Loss (MIL) principle is presented. A modified Newton-Raphson (MN) procedure with a specific global exponential appproximation then is proposed as a fast numerical solution. Microdata adjustment then is briefly described as an important contribution within the microsimulation approach. Practical experiences for a pension reform microsimulation analysis with large microdata sets of more than 65.000 households and more than 230 restrictions simultaneously to be achieved within the Sfb 3-microsimulation model show that this MN procedure was able to rather largely reduce the computional expenses by 75%. The available efficient PC-computer program ADJUST, stand alone and as a part of MICSIM, a PC microsimulation model, is also succesfully applied in a described microsimulation analyses of the recent German tax reform investigating the impacts on multiple labour supply in market and non-market labour supply within the formal and informal economy. To pinpoint possibilities of microdata adjustment in sensitivity and scenario microsimulation analyses with the adjustment as the central tool of investigation, a recent firm microsimulation analysis on what determines successful firms in the German engineering industry is briefly discussed. Some further aspects of microdata adjustment conclude the paper.

2 The adjustment problem and its characteristics

To adjust microdata is to fit microdata to prescribed and known aggregate totals (control data, restrictions, margins, population totals). For each microunit of a microdata file (sample) a suitable weight is searched so that the weighted sum of all microunit characteristics will achieve their externally given aggregates.

In general, two types of adjustment procedures may be distinguished: a free and a tied adjustment (see Statistisches Bundesamt 1960). Within a free adjustment there are no microunit dependent weights, all sample values are multiplied by the reciprocal value of the sampling ratio. In this case, besides the overall sampling ratio, no additional information of any type is included in the adjustment process. Additional information, concerning various characteristics of a population known from other statistics or models, however, is used with a tied adjustment yielding microunit dependent weights. In the tied case, preferably one particular adjustment factor for each microunit and a set of characteristics (for example for each household with its diverse household and personal attributes) has to be calculated. In order not to loose given information from other statistics (like an already available weighting scheme from a statistical office) these new factors should be close to available weights.

2.1 Adjustment components: microdata sample information file and aggregate control data

Before discussing in the following the adjustment problem in a convenient formal way, some remarks are given concerning its components, the microdata and sample information file and the aggregate restrictions to be reached.

Microdata and sample information file

A microdata file consists of microunits such as persons, families, households or firms. They are described by various characteristics. If for example these microunits are persons, they would be described by age, sex, employment or other characteristics of particular interest for the current topic under investigation.

For many economic and social policy problems, it is not sufficient to investigate and adjust only person-related microdata. For example, the calculation of social security claims or tax payments calls for the consideration of individual persons within their family and their household association. In such cases, it is necessary to account for personal characteristics as well as family and/or household information. If the microunits are classified in a hierarchical manner, an adjustment should then simultaneously satisfy the desired characteristics of the individual hierarchical classification. For a ***consistent adjustment*** of this type, adjustment factors are then computed for the 'highest' hierarchical level (e.g. the household level) with the guarantee to keep the restrictions for the other levels (e.g. families and persons). An example of an adjustment with families and persons as hierarchical levels is the National Health Insurance Model (NHI) (see Devine and Wertheimer 1981, p. 41). Households and persons are the hierarchies in static microsimulation models like the TRIM (Webb, Michel and Bergsman 1990) and the MATH model (see Beebout 1986). Persons in a family and household association are adjusted for example in the ex ante simulation data base of the Sfb 3 Microsimulation Model discussed in the applications section of this study.

For a precise description the microdata to be adjusted are arranged in a ***sample information matrix*** **S**. Every column vector s^j which characterizes a microunit j is comprised of m characteristics of the different hierarchical levels, for example household and personal characteristics. Thus, the first part of a column vector $\mathbf{s}^j$ of each household j (j=l,...,n) includes the individual household characteristics, the second part includes personal characteristics etc. The applicable characteristic (e.g. household type: three-person household with a self-employed household head aged 30 - 35) for a household j is then designated by a '1' in the appropriate row. Correspondingly, the other possible household types - since they are mutually exclusive - are designated by a '0' (zero):

$$\mathbf{S}_{m,n} = \overset{\text{microunits j (e.g. households)}}{\left(\begin{array}{ccccc} s_{11} & \cdots & s_{1j} & \cdots & s_{1n} \\ & & \vdots & & \\ s_{i1} & & s_{ij} & & s_{in} \\ \hline s_{i+1,1} & & s_{i+1,j} & & s_{i+1,n} \\ & & \vdots & & \\ s_{k1} & & s_{kj} & & s_{kn} \\ \hline s_{k+1,1} & & s_{k+1,j} & & s_{k+1,n} \\ & & \vdots & & \\ s_{m1} & & s_{mj} & & s_{mn} \end{array}\right)} \begin{array}{l} \text{hierarchical step 1} \\ \text{(e.g. household - characteristica)} \\ \\ \text{hierarchical step 2} \\ \text{(e.g. family - characteristica)} \\ \\ \text{hierarchical step 3} \\ \text{(e.g. personal - characteristica)} \end{array}$$

In an analogous manner additional household characteristics are imputed, e.g. for household income or expenditures in a certain income or expenditure class. In the second part of the column vector $\mathbf{s}^j$, the number of persons for whom a personal characteristic is applicable (e.g. to be a recipient of old-age pension) is then entered in the appropriate row. Note that the information matrix **S** consists in the first dimension only of the subset of information (m) important for the adjustment interest. In its second dimension, **S** still includes all the sample units (n). Further information of the applicable sample is not included.

The arrangement of the sample matrix **S** as described above focuses on demographic (qualitative) characteristics. This might include, for example, the number of households in particular income or expenditure classes. The sample can, however, also contain exact quantitative characteristics such as the exact amount of household income. An alternative simple algorithm for this **economic aging** problem (see Merz 1986) is given by microunit *in*dependent factors to be interpreted as in-/deflators (sample sum / given aggregate value).

Aggregate control data

The aggregate control data restrict the microdata to their desired total values. Aggregate statistics will deliver single restrictions or a set of constraints which could be given as a multidimensional cross tabulation. In general, the restrictions may be given by (official) aggregate statistics, by other samples or by other models. Aggregate sample information, for example, may be given by a population census or a more frequent microcensus with demographic variables, labour force participation information etc. A third source of aggregate data restrictions are data from exogeneous micro- or macromodels. As given by a simultaneous equations macro model or in the case of a single variable (equation) model, these regression cross and/or time series type models may deliver future restrictions as forecasted values. If future restrictions are to be obtained, the problem of static and dynamic aging arises and is discussed in the microsimulation section. The following adjustment methodology and procedure remains the same regardless whether the aggregate totals are from the sample period or of any forecasted period.

The restrictions will be stored in a column vector **r** with m single restrictions. The single restrictions r_i (i=l,...,m) may only have mutually exclusive dimensions (e.g. the total number of certain household types, persons in age classes, working persons, retired persons etc.)[1] and are not (strictly) combined with other characteristics. On the other hand, the restrictions r_i may be cells in an external cross tabulation where the characteristics are mutually combined. Naturally, the single restrictions must be appropriate to the respective row of the sample

1) For the respective interpretation of the restrictions in the relative or absolute adjustment problem see the remarks in Secion 3

information matrix **S,** which - on the substantial level - might causes problems with respect to different variable definitions out of different data sources.

2.2 The adjustment problem

In general, the adjustment problem is to find a n-vector **p** of adjustment factors optimizing an objective function Z(**p,q**) - a function evaluating the distance between the new adjustment factors **p** to be computed and the available factors **q** - satisfying the m restrictions **Sp**=**r**:

(1) $Z(\mathbf{p},\mathbf{q}) = \min!$

(2) s.t. $\mathbf{S}_{(m,n)}\ \mathbf{p}_{(n)} = \mathbf{r}_{(m)}$.

This adjustment problem is a simultaneous one, where for even a quite large number of characteristics just one single weighting factor has to be computed for each microunit, which after summing up fulfills consistently all hierarchical microdata restrictions simultaneously.

The objective function minimizes the distance between new adjustment factors **p** and the given factors **q** in order to capture eventually already available information and corrections due to non-response, sampling errors etc. If such corrections are not given in advance (or as a simple microunit independent sampling ratio), q_j would be equal for each microunit j (j=1,...,n). In the case of mainly demographic features in the sample information matrix **S** (and the restrictions) a single (absolute) adjustment factor for a sample micro unit j represents p_j total population microunits.

2.3 Available adjustment procedures

There are various procedures and functional forms in quantitative economics where an objective function Z(**p**,**q**) weight the distance of two (adjustment) factors. In general, procedures with quadratic (unweighted or weighted) and other objective functions (linear or nonlinear) are conceivable. A solution based on a quadratic and unweighted objective function is used, for example, by Galler 1977 to determine a consistent adjustment procedure for the Integrated Microdata File (IMDAF-69) of the SPES project and its successor, the Sonderforschungsbereich 3 (Sfb 3) 'Microanalytic Foundations of Social Policy' at the Universities of Frankfurt and Mannheim, Germany. Hollenbeck 1976 proposed a quadratic weighted objective function for the adjustment of the micromodels of Mathematica Policy Research, Inc. (MPR) and The Policy Research Group, Inc. A constrained quadratic loss function is also used for instance by Stone 1976 and extended by Byron 1978 in an input/output context to estimate large social account matrices. Different algorithms may solve the quadratic programming approach (e.g. by Frank and Wolfe 1956, Hildreth 1957 or Houthakker 1960). These operations research procedures, however, become relatively inconvenient for large adjustment problems, particularly those with many microunits and many characteristics.

Oh and Scheuren 1980 took a multivariate raking ratio estimation in their 1973 exact match study to fit several types of sample units (design, analysis and estimation units) (see their bibliography on raking). The raking ratio estimation, reaching back to Deming and Stephan 1940, uses proportional factors in each iteration to fit the marginals of a multi-way table (see also 'iterative proportional fitting' in Bishop and Fienberg 1975 and the log linear approach within contingency tables in Mosteller 1968). For a further treatment of different approaches, like algorithms connected with input/output tables, and procedures see Wauschkuhn 1982 and Merz 1986, Chapt. 7.

3 The adjustment of microdata by the minimum information loss (MIL) principle

The above briefly discussed solution procedures may produce negative adjustment factors, or zero factors when restricted. But non-positive adjustment factors cannot be interpreted meaningfully in applied work because an (demographic) adjustment factor has to represent a certain number of households or persons. Therefore, strictly positive weights are required to keep all sample microunits for further analyses.

Minimum information loss (MIL) principle

A solution procedure is now proposed which ensures the positivity constraint by an objective function theoretically based on the information theory which optimizes a logarithmic function according to the Minimum Information Loss Principle is now proposed. In recent years, information theory - well known in engineering sciences - has found some applications in economics. Theil's 1967 'information inaccuracy' is used for instance within criteria to judge the forecasting accuracy of econometric models (see e.g. Merz 1980). Measuring income inequality by an approach based on information theory is another example (Theil 1972, Foster 1983). More recently, minimum information was used to estimate allocation models (Theil, Finke and Flood 1984, Finke and Theil 1984).

Based on the probability distribution p_j with $\mathbf{p}=(p_1,...,p_n)'$, $(p_j>0)$, $\sum_j p_j=1$, $(j=1,...,n)$, the *entropy* or *information* content of **p** is defined as

(3a) $H(\mathbf{p}) = H(p_1,...,p_n) = \Sigma_j p_j \log(1/p_j).$

An extension of the entropy concept is the *information loss* (or gain) when a multinomial distribution $\mathbf{q}=(q_1,...,q_n)'$ is substituted by a similiar distribution $\mathbf{p}=(p_1,...,p_n)'$

(3b) $I(\mathbf{p}:\mathbf{q}) = \Sigma_j p_j \log(1/q_j) - \Sigma_j p_j \log(1/p_j) = \Sigma_j p_j \log(p_j/q_j),$

with $(p_j,q_j>0)$, $\Sigma_j p_j=\Sigma_j q_j=1$, $(j=1,...,n)$.

Within this concept the information loss is evaluated as the expected information before (weighted by p_j) minus the expected information after substitution. For an axiomatic derivation of the connected maximum entropy principle or principle of minimum cross-entropy see Shore and Johnson 1980, and Jaynes 1957 who first proposed entropy maximization within engineering purposes.

The information theory based approach as well as the approach with a quadratic distance function are specific cases of the *generalized entropy class* [2]

(3c) $I_\alpha(\mathbf{p},q) = [N\Sigma_j(p_j^\alpha q^{1-\alpha}-q)] / [\alpha(\alpha-1)],$

with uniform distributed adjustment factors $q_j=q=1/n$ and N is the number of all microunits in the population. The quadratic objective function is given for $\alpha=2$ with $I_2(\mathbf{p},q)=1/2\ \Sigma_j(p_j - q)^2$ divided by q. The information theory based approach is given for $\alpha=1$. Since the derivative of (3c) with respect to p_j is $Np_j^{\alpha-1}/(\alpha-1)$ the information based approach can be interpreted as that measure with the largest value of α where the first derivative approximates minus infinity and the weight approximates to zero (satisfying the positivity constraint).

2) As to Atkinson, Gomulka and Sutherland 1988 p. 230 who refer to the following MIL adjustment procedure by Merz 1983a.

Adjustment by the MIL principle

With reference to the above information theory concept the *adjustment problem under the minimum information loss (MIL) principle* is to minimize the objective function

(4a) $$Z(\mathbf{p},\mathbf{q}) = \min_{\mathbf{p}} \{\Sigma_j p_j \log(p_j/q_j)\}$$

(4b) $$\text{s.t. } \mathbf{Sp} = \mathbf{r}.$$

where p_j=new adjustment factor for a microunit (e.g. household) j (j=1,...,n), q_j= available (known) adjustment factor for each micro unit j, n=number of micro units, with $\mathbf{S}_{(m,n)}=[s_{ij}]$ sample information matrix (i=1,...,m; j=1,...,n), $\mathbf{r}_{(m)}=[r_i]$ vector of restrictions, m=number of restrictions.

As a solution condition it is necessary that a) the number of micro units in a random sample is higher than the number of characteristics ($n \geq m$), and b) the matrix **S** is row regular, meaning that the distribution of the individual characteristics in a random sample is linear independent (rank **S**=m). Generally, the usual condition a) will be fulfilled; condition b) can be guaranteed by omitting one respective characteristic from an exhaustive polytomuous distribution.

The Lagrangean is

(5) $$L(\mathbf{p},\lambda) = \Sigma_j p_j(\log p_j - \log q_j) - \lambda'(\mathbf{Sp} - \mathbf{r}),$$

which yields a *nonlinear equation system*

(6) $$\Sigma_j s_{ij} q_j \exp(\lambda'\mathbf{s}^j - 1) = r_i \qquad (i=1,...,m),$$

that has to be solved for the Lagrange multipliers λ_k (k=1,...,m) iteratively.

The *new adjustment factors* with the solution λ are

(7) $$p_j = q_j \exp(\lambda'\mathbf{s}^j - 1),$$

where $\mathbf{s}^j$ are the respective characteristics of the microunit j.

Thus, the new adjustment factors can be calculated relatively simply: the single given adjustment factor q_j is multiplied by a term which is determined by a linear combination of the respective microunit (e.g. household and personal) characteristics ($\mathbf{s}^j$) and the Lagrange multipliers. Thus, it is possible to determine the new adjustment factors after calculation λ independent of all other microunits and thus also independent from the sample size. This is important for practical work with mass (micro) data.

Absolute and relative adjustment factors

Usually the adjustment factors p_j and q_j are not formulated as probabilities respectively relative frequencies with $0<p_j,q_j<1$, $\sum_j p_j=\sum_j q_j=1$, but rather in absolute terms. The absolute adjustment problem

$$(8) \qquad Z(\mathbf{p},\mathbf{q}) = \min_{\mathbf{p}} \{\sum_j p_j \log(p_j/q_j), \text{ s.t. } \mathbf{Sp} = \mathbf{r}\}.$$

with respective cursive typed variables as *variables in absolute terms* yields the same solution (8) as in the relative case and is only different according to the interpretation with $p_j=p_jN$, $q_j=q_jN$ and $r_i=r_iN$ (N=number of all microunits in the total population).

In the absolute case a sample weight p_j (j=1,...,n) then represents the actual number of microunits (say households if the weights correspond to this type of microunit) in the total population. The restriction r_i (i=1,...,m) then is the absolute number of microunits with characteristic i (e.g. households with three persons and a self-employed household head) in the total population. The sample information matrix **S** remains the same in both cases and describes the microunits' characteristics in the sample.

If there are no specific weighting factors given in advance (free adjustment) and/or the sample under consideration would be a (pure) random one with an overall sampling ratio w = [sample size(n)/population size(N)] (like w=1/100 in a 1% microcensus case) then the old weights would be equal for each microunit j: In the relative case $q_j=q=1/n$ and in the absolute case $q_j=q_jN=(1/n)N=N/n=1/w$ as the inverse of the sampling ratio (w=n/N) (for example $q_j=q=100$ in a 1% microcensus case) for all microunits j (j=1,...,n).

Newton-Raphson solution

The main problem in solving the adjustment task according to the MIL principle for applied work is the efficient solution of the nonlinear equation system (6) for the practical case of many variables and microunits. Since nonlinear systems are not analytically completely solvable, iterative solution procedures have to be used (see e.g. Ortega and Rheinboldt 1980 and Rabinowitz 1970). Iterative procedures, as known, use respective function values and/or gradient values. The consideration of derivatives of second and higher order in general is too expensive, since in every iteration the calculation of the k-th derivative for an m equation system generally needs m^{k+1} function calculations. Procedures which need more than one derivation thus are unattractive for our numerical calculation. With regard to the numerical solution of the equation system (4) - independent of the optimization procedure to be chosen - the whole sample must be considered for each iteration. Where there is a relative large number of microunits, a procedure must be chosen which needs only few calculations per microunit (household) and only few iterations overall. A procedure which satisfies these conditions is the following Newton-Raphson procedure.

Starting with a nonlinear equation system with m unknowns, the Newton-Raphson procedure (first order) uses a Taylor development linearizing the m equation on a certain point. The roots determine the solution of the problem iteratively. The nonlinear system from (6)

(10) $$f_i(\lambda) = z_i(\lambda) - r_i = 0 \qquad (i=1,\ldots,m)$$
$$= \sum_{j=1}^{n} s_{ij} q_j \exp\left(\sum_{k=1}^{m} \lambda_k s_{kj} - 1\right) - r_i = 0$$

is solved, if for a m vector λ the calculated restrictions $z_i(\lambda)$ equals the given restrictions r_i $(i=1,\ldots,m)$.

If one describes the system with $f(\lambda)=[f_1(\lambda), f_2(\lambda), \ldots, f_m(\lambda)]'=\mathbf{0}$ then the linearized nonlinear system

(11) $$0 \approx f(\lambda^t) + \left[\partial f(\lambda^t)/\partial \lambda^t\right]^{-1}(\lambda^{t+1} - \lambda^t)$$

yields the well-known Newton-Raphson procedure with the iteration provision

(12) $$\lambda^{t+1} = \lambda^t - \left[\partial f(\lambda^t)/\partial \lambda^t\right]^{-1} f(\lambda^t)$$

(t marks the t-iteration), under the assumption that the (m,m) first derivative matrix

$$g_{il}(\lambda^t) = \partial f(\lambda^t)/\partial \lambda^t = \sum_{j=1}^{n} s_{ij} q_j s_{lj} \exp\left(\sum_{k=1}^{m} \lambda_k^t s_{kj} - 1\right) \qquad (i,l=1,\ldots,m)$$

is nonsingular. For the iterative solution of the adjustment problem according to the MIL principle, a new solution vector of an iteration is then calculated using $f(\lambda) = \mathbf{r} - \mathbf{z}(\lambda)$ and the inverse from the matrix $G=\left[g_{il}(\lambda^t)\right]$. Convergence is reached when the calculated restrictions **z** are close to the given ones **r**, hence when $|\mathbf{r} - \mathbf{z}(\lambda)| \leq \varepsilon$ $(0 \leq \varepsilon \leq 1)$.

4 A fast numerical solution by a modified Newton-Raphson procedure with an global exponential approach

In search for a faster procedure when compared to the original Newton-Raphson it is obvious to modify the steplength in (12) from in a way that fewer steps (iterations) become necessary. If the Newton procedure is extended by an iteration dependent factor which modifies the distance between λ^t and λ^{t+1} the result is

(13) $$\lambda^{t+1} = \lambda^t + \alpha_t \mathbf{d}^t$$

with $\mathbf{d}^t = \left[\partial f(\lambda^t)/\partial \lambda^t\right]^{-1} f(\lambda^t)$ as direction and $\alpha_t \mathbf{d}^t$ as the steplength of an iteration. Equation (13) is a 'smoothed' Newton procedure. There are now various procedures with an m solution vector but a single valued objective function such as the Davidon-Fletcher-Powell procedure. This procedure modifies α_t in a way that at the end of an iteration α_t converges to the Newton solution (α_t=1). Also as 'steplength' algorithms the Curry and Altman or the Goldstein principle are mentioned. All these procedures, however, are too expensive for large samples with calculations on the basis of all microunits. Hence, a procedure must be searched which in an efficient manner modifies the well-suited Newton procedure with its quadratic convergence.

A global exponential approach for variable steplengths

In principle, it is desirable that the iteration dependent scalar is determined in a way that with the next iteration the solution is found and the nonlinear system (6) solved. This can be reached by means of minimizing an objective function, with $z_i(\lambda^t - \alpha_t d^t)$ as calculated restrictions and r_i as given restrictions, for example

(14) $$h\left(\alpha_t \middle| \lambda^t, d^t\right) = \sum_{i=1}^{m} f_i^2(\lambda^t + \alpha_t d^t) = \sum_{i=1}^{m} \left(z_i(\lambda^t + \alpha_t d^t) - r_i\right)^2 = \min!$$

The function $h(\lambda^t)$ is a well-suited one, since according to the Newton approach and the quadratic distance function $h(\lambda^{t+1}) < h(\lambda^t)$, respectively $h'(\lambda^t)\, d^t > 0$ is fulfilled.

The problem now is to find the optimal α_t which minimizes (14). A minimization using the first derivatives of α_t with

(15) $$h'\left(\alpha_t \middle| \lambda^t, d^t\right) = \sum_{i=1}^{m} 2 \cdot \left[z_i \cdot (\lambda^t + \alpha_t \cdot d^t) - r_i\right] \cdot \partial z_i / \partial \alpha_t = 0$$

with

$$\partial z_i(\alpha_t)/\partial \alpha_t = \sum_{j=1}^{n} s_{ij}\, q_j \left(\sum_{k=1}^{m} d_k^t\, s_{kj}\right) \exp\left\{\left(\sum_{i=1}^{m} (\lambda_k^t + \alpha_t\, d_k^t)\, s_{kj}\right) - 1\right\}$$

however, does not yield to a simplified procedure, since α_t out of $h'(\alpha_t)=0$ cannot be determinated analytically due to the high nonlinearity of (15). Naturally one could use a one - dimensional algorithm with the result that for one step (e.g. via Newton) the whole example has to be carried out again for the calculation of $h'(\alpha_t)$. However, for reasons of efficiency this is not desirable in particular for large samples.

An approximation of the objective function (15) by a 'global' exponential approach

(16) $$g(\alpha_t)=a+b\exp(\alpha_t)$$

with root at $g(\alpha_t)=0$ with

(17) $$\alpha_t=\ln(-a/b)$$

simplifies the problem (see details in Merz 1983a, 1985). The coefficients a and b can be found for example by two points

$g(0)=h'(\lambda^t,\alpha_t=0)$, $g(1)=h'(\lambda^{t+1},\alpha_{t+1}=0)=h'(\lambda^t,\alpha_t=1)$ with

b= [g(1) - g(0)]/(e-1) and a = g(0) - b

where e is Euler's constant. Hence, such an approximation demands a calculation of $h'(\alpha_t)$ in each iteration. Even if this may be done independently from the sample size, additional computation and storage space is necessary. These costs may be avoided when the objective function $h(\alpha_t)$ from (14) itself is considered and its root (minimum) is determined analogous to the approximation above by using

$g(0)=h(\lambda^t,\alpha_t=0)$ and $g(1)=h(\lambda^{t+1},\alpha_t=1)$.

The necessary values $h(\alpha_t)$ and $h(\lambda^{t+1})$ from (14) have to be calculated successively during the iteration. They are necessary for other purposes and are at disposition without any further computational expense (see next paragraph).

The idea of the global exponential approximation thus is to find a best steplength in each iteration by balancing the effects of individual exponential influences. Nevertheless, each microunit's information is respected when new parameters of the global exponential function are computed for each new iteration.

The above approximation is considered in the following proposed procedure where several steplengths (including the global exponential approximization and the normal Newton approach) will lead to a 'best' next step and an overall fast solution.

A modified Newton-Raphson procedure with different steplengths

The proposed heuristic solution (Modified Newton-Raphson (MN) procedure) with fixed and variable steplengths is:

Within each iteration L different steplengths $\alpha_l \; (l = 1, \ldots, L)$ *are given. Whereas L-1 steplengths are fixed in the iteration process, one of the steplengths,* a_L *say, should be the variable steplength of the above global exponential approximation. If it occurs that one step* $z\left(l_l^{t+1}, \alpha_l^* \neq 1\right)$ *with* α_l* *is better than the Newton step with* $z\left(l_N^{t+1}, \alpha_{l=N} = 1\right)$ *then this step with* $z\left(l^t + \alpha_l \, d^t = l_l^{t+1}\right)$ *is used in the next iteration.*

One of the adequately chosen α_l is thus the Newton step with $\alpha_{l=N} = 1$ in order to guarantee convergence. As it is well-known, the Newton procedure cannot converge with an unfavorable starting position, hence no convergence can be guaranteed. However, one can evaluate the specific logarithmic function from the minimum loss principle and the functional form of the global exponential approximation as 'well-behaved'. Though a proper convergence proof set up on steplength algorithms[3] is desired[4], practical experiences with several large microdata bases (two of them are described in the next chapter) have always shown convergence supporting the chosen approach.

For the MN procedure with given α_l one would have to calculate different gradient matrices due to different α_l with every iteration, its inverses and the corresponding $\mathbf{d}^t$ out of them. Even using the symmetry condition this way would be too storage-exhaustive. Therefore it is advisable to calculate in an iteration t only one gradient matrix for the Newton step with different solutions according to different α_l. Only if a distance function (e.g. a quadratic one) shows that a solution will be superior to the Newton solution, it is advisable quasi to recalculate the respective gradient matrix in the next iteration in order to receive the next better solution from

$$\text{(18)} \qquad \lambda_l^{t+2} = \lambda_{l*}^{t+1} + \alpha_l \cdot d_{l*}^{t+1} \qquad (l = 1, \ldots, L)$$

During such a recomputation new $z\left(\lambda_l^{t+2}\right) = z\left(\lambda^{t+1} + \alpha_l \, d^{t+1}\right)$ for l=1,...,L can be computed, too, in the same run. The necessary iterations for each calculation of the modified Newton procedure with given α_l (1=1,...,L) are summarized in Appendix 1. In each iteration one matrix of derivatives and L different calculated aggregate restrictions $z(\alpha_l)$ have to be calculated.

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3 see Ortega and Rheinboldt 1970, chapt. 1.4.2

4 Convergence proofs for other iterative procedures like the iterative raking algorithm only exist with strong assumptions about cell counts (see Bishop and Fienberg 1969, Ireland and Kullback 1968) in general, there is no easily verifiable set of necessary and sufficient conditions which allow to determine when convergence will in fact occur (see Oh and Scheuren, p. 122).

5 Microsimulation and the adjustment of microdata

As mentioned, the adjustment of mcirodata plays an essential role within the microsimulation approach. Simulation models and microanalytic simulation models in particular are increasingly used for quantitative policy analysis of economic and social problems. For planning purposes as well as for the analysis of budget and distributional policy effects aimed at individuals, microsimulation models offer an powerful instrument that enables differentiated analyses on a disaggregated level. The focus of microsimulation models is on microdata with microunits (like persons, families etc.) described by certain characteristics (such as age of a person, the number of children of a households, taxes and transfers and so far). A microsimulation model then changes these characteristics depending on behavioural and institutional relationships.

The microsimulation approach - since it's seminal work by Orcutt 1957 - is surveyed and described e.g. by Bergmann, Eliassson, and Orcutt 1980, Haveman and Hollenbeck 1980a,b, Orcutt, Merz and Quinke 1986 and Hancock and Sutherland 1992. Microsimulation as an instrument to evaluate economic and social programmes is discussed in Merz 1993a. Merz 1991a, 1994b provide recent general surveys of microsimulation principles, developments and applications.

Microdata are essential for microsimulation models in several dimensions: microdata are the basis for estimating structural behavioural hypotheses formulating institutional patterns. In addition, microdata preferably as a (representative) sample serve as the initial data base to be updated or extrapolated by a microsimulation model. The results of any static or dynamic microsimulation computation obviously are microdata again. To achieve representative results in all static cases and in many dynamic cases the microdata have to be adjusted. It is naturally that the adjustment choose other restrictions than those under investigation .

The main need for an adjustment of microdata, however, is within static microsimulation. There, the aging of a sample, i.e. the extrapolating and actualizing of the microdata under cionsideration, is done by re-weighting the microunits ('static aging') in achieving actual or future aggregate control variables. In addition, by systematic chosing alternative margins, effective sensitivity evaluations are possible with regard to additional scenarios.

Different adjustment procedures used in major mircrosimulation models are provided in Table 1.

Tab. 1

6 Some practical experiences with the adjustment by the MIL principle

The following practical experiences with the adjustment of microdata by the MIL principle with the described modified Newton-Raphson procedure including a global exponential approximation and the developed computer program ADJUST will illustrate the particular suitability of this approach for various tasks: a consistent adjustment with up to three hierarchical levels for large microdata files within the framework of a microsimulation analysis of financial and distributional impacts of the German Pension Reform; a consistent adjustment for smaller surveys like in another microsimulation analysis of time allocation impacts of the recent German tax reform. In addition, a further example is given using the adjustment as the central tool in a recent investigation of how successful firms do act in the engineering industry.

6.1 Microdata adjustment and microsimulation of the German Pension Reform

In Germany the system of retirement pensions including dependents and disability allowances had to be reformed in 1984 in response to a Constitutional Court's decision on sex discrimination. Political parties therefore sought to restructure the system not only to make it conform to the constitution, but also to improve the social security of married women, in particular by recognizing child rearing and family support as a genuine contribution to a society's welfare. In addition, the reform was to achieve greater equality between social groups with regard to the relation between the contributions paid to and the benefits received from the pension system.

To analyze the financial and distributional impacts of the pension reform alternatives the former Sonderforschungsbereich 3 (Sfb 3, Special Collaborative Program 3) 'Microanalytic Foundations of Social Policy' at the Universities of Frankfurt and Mannheim, financed by the German National Science Foundation (DFG), investigated a set of altogether 14 proposed pension reform alternatives by dynamic cross-section, dynamic life-cycle microsimulation with features of static microsimulation and additional group simulation (Krupp, Galler, Hauser, Grohmann and Wagner 1981).

Since statistical information for this investigation were present until 1978, the ex ante microsimulation starts at that time. However, the most comprehensive microdata base available and suitable for a starting point of the pension reform microsimulation analysis was from 1969 (Dworschak and Merz 1982). The Sfb 3 microsimulation model therefore uses a data base which has been produced by extrapolation from the starting data base of the year 1969 by means of the micosimulation model and additional information up to the year 1978.

Two adjustments were carried out within the pension reform microsimulation: the first adjusted the initial data base 1969. The second used the newest available information 1978 to be as near as possible to the actual situation. In the following some results of the adjustment of the ex ante simulation data base 1978 and of one resulting file, a simulation file 1980 are discussed.

Adjustment of the ex ante simulation data basis 1978

The family structure is of special importance for example in comparing alternative statutory old age insurances and thus of specific importance for achieving representative results on a family and person related base. To summarize, the adjustment for the ex ante simulation data base 1978 uses the following adjustment information as restrictions:

- family structure; divided into couples, single men and single women with unmarried children in 10 age groups of the head of household (90 groups)
- age structure of persons; divided into age groups (groups of 5 years) and sex (38 groups)
- employment of persons; divided into occupational status and sex (10 groups)
- school population; divided into school categories (8 groups)
- old-age pension insurance information; divided into sex and status in old age insurance 18 groups).

In addition to family restrictions, every household of the sample was consistently adjusted by the MIL principle with one single factor for each microunit encompassing household, family and personal characteristics in three hierarchies.

This microfile consists of $n = 47{,}805$ microunits, where $m = 154$ restrictions have to be accounted for. While the normal Newton procedure needs 33 iterations, the MN procedure with two given steplengths 1.0 (Newton) and the current approximation by the global exponential function needs only 8 iterations for the final solution, hence a rather large reduction of the computational efforts by 76% (see Table 2).

A judgement of the procedures taking only the necessary iterations into account is not sufficient since the computation time naturally increases with additional steplengths. For the sample under investigation one additional steplength needs approximately 28 seconds CPU time. Nearly all of this time is spent on calculating the restrictions $z(\lambda)$ while running the sample and therefore depends most of all on the number of microunits of a sample. Considering the CPU time necessary until reaching the solution of the adjustment problem, the MN procedure with more than two steplengths leads to a reduction even by 72% of CPU total time.

Tab. 2

If more step modifications are used, for instance 4 or 6 steplengths (e.g. L=6, with α = 0.01, 0.l, 0.5, 1.0, 2.0) including the global exponential approximation, the reduction from 11 to 9 iterations is still considerable. However, better results will be reached only with one additional step modification - that is the proposed specific approximation with a global exponential function.

Adjustment of a microsimulation resulting file

The next example is a typical adjustment procedure of a microsimulation resulting file when additional external information is available. The (free) adjustment of the 1980 simulation file of the pension reform microsimulation analysis beside personal information focus on household information:

- household structure; divided into 6 age and occupation groups of the head of the household and 6 groups of household type information (18 groups)
- age structure of persons; divided into single age years (91) and sex (182 groups)
- school population; divided into school categories (8) and sex (16 groups)
- school grades of German population; divide into grade categories (4) and sex (8 groups)
- employment of persons; divided into professional (5) and sex (10 groups).

The adjustment of the 1980 simulation file includes n = 65,175 microunits and m = 234 simultaneous restrictions. Though the normal Newton procedure with 9 iterations converges relatively soon, the MN procedure with another two steplengths (Newton and global exponential) and 6 iterations is again more efficient with only 74% of iterations when compared to the original Newton procedure (see Table 2).

To summarize: The proposed approximation within the MN procedure has proved to be an efficient and practicable solution of an adjustment task according to the Minimum Information Loss (MIL) principle for quite large microdata sets in a complex microsimulation approach.

6.2 Combined static and dynamic microsimulation of the 1990 German Tax Reform on market and non-market activities of private households

In the economic and social-political discussion on incentives and disincentives of taxes and transfer payments, aspects of the formal as well as the informal economy are causing increasing interest. The shadow economy resulting thereof is considered an alternative economy to increase disposable income and the family resources. Within the frame of my Sfb-3 project 'Market and Non-Market Activities of Private Households', a combined static and dynamic microsimulation approach with behavioural response was chosen to analyze 1990 German tax reform impacts on time allocation in multiple market (paid) and non-market (unpaid) labour supply in the formal and informal economy (Merz 1989, 1990, 1993c, and Merz 1991b with focus on illicit work and Merz and Wolff 1993a,b with an overview of our project work in general).

The combined static and dynamic microsimulation used the simulated demographic structure from the above mentioned Sfb 3 Dynamic Cross-section Microsimulation Model to adjust the original Secondary Occupation Survey of 1984 to the 1990 and 2000 demographic situation. Static microsimulation by MICSIM, a PC microsimulation model based on a relational data base system (Merz and Buxmann 1990, Merz 1993b, 1994a), then compared the respective baseline supplied hours of work with the hours supplied according to the new individual tax situation in the respective family and household association via the behavioural equations.

Adjustments of the Sfb 3 - Secondary Occupation Survey 1984 for the years 1990 and 2000

The tied microdata adjustment by the MIL principle in this microsimulation study was used to actualize and to forecast a personal survey by static aging with focus on the following adjustment information:

- marital status; divided into up to 11 age classes for umarried, married, widowed and divorced and sex in the respective category (58 groups)
- school grades; divided into 3 categories and sex (6 groups).

The tied adjustments for 1990 and 2000 includes n=1,820 persons with household information (4th subsample of the Sfb3 Secondary Occupation Survey) as microunits and m=64 simultaneous restrictions. The adjustments with two steplengths (Newton and global exponential approximation) were done by my new PC version of ADJUST and required 7 (1990) respective 8 (2000) iterations till convergence was reached (altogether around 2 min computing time on a Compaq 386/25).

6.3 Microsimulation on the success of firms in the German engineering industry

In a recent microsimulation approach using data from the NIFA firm panel Widmaier, Niggemann and Merz 1994 follow the question 'what makes the difference between un-successful and successful firms in the German mechanical engineering industry'. This project is embedded in the Sonderforschungsbereich 187 (Sfb 187) 'New Information Technology and Flexible Working Systems: Development and Evaluation of CIM-Systems on the Basis of Partial Independent Flexible Production Structures' at the University of Bochum and an offspring of our interest to widen the microsimulation approach to firm behaviour at my chair and our Research Institute on Professions (FFB) at the University of Lüneburg.

On the background of rising costs and increasing competition it becomes more and more difficult for small and middle sized firms to be economically successful. In this study the hypothesis is analyzed, that product and market strategies as well as the internal mode of operation and organization differs significantly between firms doing economically well and less well.

Microdata adjustment is the central microsimulation instrument in our investigation to analyze different levels of success in capacity utilization according to those factors. The concrete objective of the adjustment by ADJUST of n=1,440 firms is to answer the question, how often a firm should exist under the restrictions of a different strategies of product innovation, degree of vertical integration of production, technology employed, flexibility, and object principle in production. Weighting with the respective scheme and the linkage to the sample's structure then allows to evaluate strategies with higher success. Some results: there are different strategies in determining the success of a firm in the sense of higher capacity utilization. First, the central categories to characterize modern production processes 'application of computer techniques' and 'object oriented production' are jointly one of the most successful strategies to utilize a firm's capacity. Second, complex bundle of strategies as combined ones are more successful than single strategies.

This example was chosen to pinpoint the power of application possibilities of the adjustment of microdata in various kinds of sensitivity and scenario microsimulation analyses.

Further applications of the adjustment of microdata using the MIL principle by the computer package ADJUST are given in different academic institutions and statistical offices, like within the adjustment of data of the German Socio-Economic Panel (GSOEP) or in the German Statistical Office when weighting microdata of the new German time use survey.

7 Concluding remarks

In this study a solution to the microdata adjustment problem is suggested by applying the Minimum Information Loss (MIL) principle with the special feature of accounting for the so-called positivity constraint. A modified Newton-Raphson (MN) procedure is proposed for a relatively fast numerical solution. The efficient computer programm ADJUST (Merz 1993b) as a PC stand alone version or in the context of MICSIM, a PC microsimulation model further developed at my chair at our Research Institute on Professions (FFB) at the University of Lüneburg, is available on request.

As pointed out, microdata adjustment is essential for representative results of sample microdata and an important feature within the microsimulation framework of any approach. In a dynamic microsimulation approach each microunit's characteristics are altered (aged) by behavioural and institutional relations through extrapolating the simulation basis (dynamic aging). Here the main task of an adjustment is to yield a representative initial data base, although resulting simulation files may also be adjusted by weighting the sample with appropriate consistent adjustment factors. Examples are several Sfb 3 microsimulation data bases analyzed in this paper.

One of the main tasks of a static microsimulation approach is in general to adjust a sample to a later period of investigation than the microdata at hand (static aging). Then future aggregate data are the restrictions to be reached. Because a static microsimulation approach is less expensive than a dynamic one (the sample is only aged by time-different restrictions), this method is widely used for analyzing public policy.

In contrast to the one-time adjustment discussed above, a dynamic adjustment in the sense of a sequential multiperiod task may need other techniques, e.g. dyamic techniques based on the Kalman filter technique within an optimal control approach as proposed in Merz 1983b.

Another adjustment application are sensivity investigations with different sets of restrictions and consequently different sets of weighting factors as in the mentioned firm analysis. With a certain distribution of the restrictions, a Bayesian analysis using this a priori information might be an approach for further research.

A last remark: In general, it would be desirable not to carry out any re-weighting to achieve representative results, but to have appropriate representative (sample) data. However, real-world complications certainly will further need adjustments. The proposed approach with its fast numerical procedure can solve this problem in an efficient way. Nevertheless, a demanding task remains in applied empirical work: that is to find substantially adequate and congruent data in both important sources, the microdata themselves and the aggregate totals.

Appendix

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