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Measures of Mobility and Some Associated Inference Problems

SOCIAL or occupational mobility can be defined in terms of changes in occupation between generations or over time, among socio-economic categories, and likewise changes as a result of the distribution of the total population among the constituent classes from one generation to another or from one period of time to another. This distribution, however, will eventually reach a steady state.

Measures of social and occupational mobility based on stochastic models for representing such transitions during generations and over time have been suggested, among others, by Prais (1955), Matras (1960), Bartholomew (1967), and Mukherjee and Basu (1979). But in all the previous works there was no attempt to solve statistical inference problems like the problem of estimating any such measure from sample data or the problem of testing some hypothesised extent of mobility in a given society.

In the present paper some new measures of social mobility have been suggested. Further, inference problems involving some of the measures have been considered and a procedure for testing the hypothesis regarding the extent of mobility in a given society, by using minimum discrimination information statistic (m.d.i.s) has been discussed.

1. Transition Model

Let $P_{ij}^{(t)}$ denote the probability of transition from the ith class at time (in generation) t to the jth class at time (in generation) $t+1$. Obviously if there are k classes then

$$\sum_{j=1}^{k} P_{ij}^{(t)} = 1 \; (i = 1, \ldots, k)$$

Also let $\pi_i^{(t)}$ $(i = 1, \ldots, k)$ denote the proportion of the total population at time t belonging to class i. Then we can specify the nature of change as

$$\pi^{(t+1)} = [P^{(t)}]\, \pi^{(t)} \tag{1.1}$$

where $P^{(t)} = (p_{ij}^{(t)})k\ k$ is the transition probability matrix and $\pi^{(t)}$ is the vector giving the population distribution at time t. A repeated application of (1.1) gives, on the assumption that $P^{(t)} = P$ is independent of time

$$\pi^{(t)} = (P)^t\, \pi^{(0)} \tag{1.2}$$

If P is regular, P^{∞} will exist and the limiting distribution will be given by

$$\pi = P^{\infty}\, \pi^{(0)} \tag{1.3}$$

This has to satisfy the relation $\pi = (P')^{\infty}$ which is true if $p_{ij}^{(\infty)} = p_j$.

2. Measurement of Mobility

Measures of mobility can be grouped into the following categories:

(*a*) Measures based on transition probabilities only.

(*b*) Measures based on transition probabilities and limiting distribution.

(*c*) Measures based only on two successive distributions (obtaining in two consecutive generations or times).

(*d*) Measures based on transition probabilities and the initial distribution.

To facilitate the interpretation of an observed value of any measure of social or occupational mobility let us first extend the notations of a perfectly mobile society, a perfectly immobile society and a society showing extreme movement to the general case of k classes by means of the following transition probability matrices respectively

$$P_1 = \begin{pmatrix} r_1 & r_2 & \ldots & r_k \\ r_1 & r_2 & \ldots & r_k \\ \ldots & \ldots & \ldots & \ldots \\ r_1 & r_2 & \ldots & r_k \end{pmatrix} k \times k \tag{2.1}$$

$$P_2 = \begin{pmatrix} 1 & 0 & \ldots & 0 \\ 0 & 1 & \ldots & 0 \\ \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & \ldots & 1 \end{pmatrix} k \times k = I \tag{2.2}$$

$$P_3 = \begin{pmatrix} 0 & p_{12} & \ldots & p_{1k} \\ p_{21} & 0 & \ldots & p_{2k} \\ \ldots & \ldots & \ldots & \ldots \\ p_{k1} & p_{k2} & \ldots & 0 \end{pmatrix} k \times k \tag{2.3}$$

where $\sum_{i=1}^{k} r_i = \sum_{i=2}^{k} p_{1i} = \sum_{i \neq 2} p_{2i} = \ldots = \sum_{i \neq k} p_{ki} = 1.$

We may have, in particular

$$r_i = 1/k \ \forall \ i \text{ in } P_1 \tag{2.4}$$

and

$$\begin{aligned} p_{ij} &= 1/(k-1) \ \forall \ i, j \ (i \neq j) \\ p_{ii} &= 0 \ \forall \ i \\ &\text{in } P_2. \end{aligned} \tag{2.5}$$

3. Existing Measures of Mobility

A simple measure of mobility based on the transition probability matrix P is $|P|$.

Another measure of this type suggested in [4] is tr $P = T$ (say). A more direct and meaningful measure suggested in [1] is obtained by counting the class boundaries crossed in passing from one generation to the next, given by

$$D = \sum_i \sum_j \pi_i^{(t)} p_{ij} \, | i - j | \tag{3.1}$$

or the corresponding measure taking into account the limiting distribution, given by

$$D = \sum_i \sum_j \pi_i p_{ij} \, | i - j | \tag{3.2}$$

TABLE 1—ACTUAL AND PREDICTED EQUILIBRIUM DISTRIBUTIONS AMONG THE SOCIAL CLASSES

Class	*Fathers*	*Sons*	*Equilibrium*
1. Professional and Higher Administrative	0.037	0.029	0.023
2. Managerial and Executive	0.043	0.046	0.042
3. Higher grade supervisory and non-Manual	0.098	0.094	0.088
4. Lower grade supervisory and non-Manual	0.146	0.131	0.127
5. Skilled Manual and routine and non-Manual	0.432	0.409	0.409
6. Semi skilled Manual	0.131	0.170	0.182
7. Unskilled Manual	0.111	0.121	0.129

By regarding the distributions of the population at times t and $t+1$ as two multinomial populations, a measure of divergence between them, by using Bhattacharya's distance (1945-46), has been suggested in [4] as below

$$\cos \Delta = \sum_{i=1}^{k} \sqrt{\pi_i^{(t)} \ \pi_i^{(t+1)}} \tag{3.3}$$

$$\Delta = 0 \qquad \text{if } P = I = P_2 \quad \text{(ref. 2.2).}$$

$$\cos \Delta = \sum_{1}^{k} \sqrt{\pi_i^{(t)} \sum_{1}^{k} r_j \ \pi_j^{(t)}} \quad \text{if } P = P_1 \quad \text{(ref. 2.1).}$$

and $\cos = 1/\sqrt{(k-1)} \sum_{i=1}^{k} \sqrt{\pi_i^{(t)}(1 - \pi_i^{(t)})}$

in the special case of extreme movement (see 2.5).

Another measure, based on the variances of $\pi_i^{(t)}s$, is given by

$$R' = (\pi^{(t)'} \ P'P \ \pi^{(t)})/(\pi^{(t)'} \ \pi^{(t)}) \tag{3.4}$$

4. Suggested Measures of Mobility

(i) *Using Plackett's coefficient* (ψ) : Plackett (1965) defined a class of bivariate distributions as follows :

TABLE 2—ESTIMATES OF ψ (PLACKETT'S COEFFICIENT) FOR ALL PARTITION POINTS FOR THE EXAMPLE FROM GLASS AND HALL (1954)

21.533	9.872	10.050	7.233	5.785	8.683
25.175	15.798	12.356	8.138	6.428	8.807
28.432	18.270	11.889	7.429	5.973	5.518
53.161	20.846	11.482	7.642	5.827	5.512
—	27.777	12.344	7.254	5.448	4.556
—	30.000	10.835	5.985	4.095	4.804

Given marginal distributions $F(x)$ and $G(Y)$ the bivariate distribution $H(X, Y)$ is defined uniquely through a parameter ψ by way of

$$\psi = (H(1 - F - G + H))/(F - H)(G - H) \quad (0 < \psi < \infty).$$

The value of the coefficient ψ for a contingency table with ordered categories has been derived in [5].

In our case we can write the transition probabilities $p_{ij}^{(t)}s$ in a $k \times k$ contingency table as below : Assuming time homogeneity we shall write $p_{ij}s$ for $p_{ij}^{(t)}s$.

TABLE 4.1

i \ j	1	2	3	...	k	
1	p_{11}	p_{12}	p_{13}	...	p_{1k}	1
2	p_{21}	p_{22}	p_{23}	...	p_{2k}	1
3	p_{31}	p_{32}	p_{33}	...	p_{3k}	1
...	...	...	...	...	...	...
k	p_{k1}	p_{k2}	p_{k3}	...	p_{kk}	1
	p_{01}	p_{02}	p_{03}	...	p_{0k}	k

From Table 4.1 we calculate $t = (k-1)^2$, ψ coefficients as below :

$$\psi_{ij} = \left(\sum_{\alpha=1}^{i} \sum_{\beta=1}^{i} p_{\alpha\beta} \times \sum_{\alpha=i+1}^{k} \sum_{\beta=j+1}^{k} p_{\alpha\beta} \right) \Big/ \left(\sum_{\alpha=1}^{i} \sum_{\beta=j+1}^{k} p_{\alpha\beta} \times \sum_{\alpha=i+1}^{k} \sum_{\beta=1}^{i} p_{\alpha\beta} \right) \qquad (4.1)$$

Limiting values of ψ can be easily obtained as follows :

Perfect Mobility ($P = P_1$)

$$\psi_{ij} = \left(j \sum_{\alpha=1}^{i} r_\alpha \, (k-j) \sum_{\alpha=i+1}^{k} r_\alpha \right) \Big/ \left((k-j) \sum_{\alpha=1}^{i} r_\alpha \times j \sum_{\alpha=i+1}^{k} r_\alpha \right)$$
$$= 1 \;\forall\; i, j$$

In case of perfect immobility ($P = P_2 = I^{k\times k}$), *each one of* ψ_{ii}, ψ_{ij} ($i < j$) *and* ψ_{ij} ($i > j$) *becomes infinite.*

Extreme Movement ($P = P_3$)

In this case we do not get any unique value of ψ_{ij}. In the special case (2.5) we have

$$\psi_{ij} = ((ij - i)\, 1/(k-1)\, [(k-i)(k-j) - (k-j)]\, 1/(k-1))/(i \leqslant j)$$
$$(i(k-j)\, 1/(k-1)\, [j(k-i) - (j-i)]\, 1/(k-1))$$
$$= [(ij-i)(k-j)(k-i-1)]/[i(k-j)(kj-ij-j+i)]$$

Similarly we get ψ_{ij} for $(i > j)$ by interchanging i and j. We have $\psi_{ii} = [(i-1)(k-i-1)]/[i(k-i)]$

(ii) Using measures of association between two attributes. We may consider a measure of association as an inverse measure of mobility since in the case of perfect mobility there will be no association between two successive generations.

Suppose we have two attributes A and B with k and l classes respectively and of the n individuals under study f_{ij} belong to the category A_i of A together with the category B_j of B.

Let $f_{i0} = \sum_{j=1}^{l} f_{ij}$ and $f_{0j} = \sum_{i=1}^{k} f_{ij}$

Obviously $n = \sum_i f_{i0} = \sum_j f_{0j} = \sum_i \sum_j f_{ij}$

Measures of association between A and B are defined as below :

(*a*) Karl Pearson's coefficient of contingency :

$$C_{AB} = [(\chi^2_{AB})/(n + \chi^2_{AB})]^{1/2}$$

where

$$\chi^2_{AB} = n \sum_i \sum_j [(f_{ij}^2)/(f_{i0} f_{0j})] - n.$$

In our case using Table (4.1)

$$\chi^2_{AB} = k\left[\sum_i \sum_j \left(p_{ij}^2 / p_{0j} \right)\right] - k$$

and

$$C_{AB} = \left[\left(\Sigma\, \Sigma \left(p_{ij}^2 / p_{0j} \right) - 1 \right)\Big/\left(\sum_i \sum_j \left(p_{ij}^2 / p_{0j} \right)\right)\right]^{1/2} \qquad (4.2)$$

(*b*) Tschuprow's coefficient

$$T_{AB} = \left[\chi^2_{AB} \Big/ (n \sqrt{(k-1)(l-1)}) \right]^{1/2}$$

In our case using Table (4.1)

$$T_{AB} = \left[\left(\sum_i \sum_j \left(p_{ij}^2 / p_{0j} \right) - 1 \right)\Big/(k-1) \right]^{1/2} \qquad (4.3)$$

We find that for $P = P_1$

$$C_{AB} = \left[\left(k \sum_i \left(r_i^2 / k\, r_i \right) - 1 \right) \Big/ \left(k \sum_i \left(r_i^2 / k\, r_i \right)\right)\right]^{1/2}$$

$$= [(\Sigma\, r_i - 1)/\Sigma\, r_i]^{1/2} = 0 \qquad [\Sigma\, r_i = 1]$$

and

$$T_{AB} = \left[\left(k \sum_i \left(r_i^2 / k\, r_i \right) - 1 \right) \Big/ (k - 1) \right]^{1/2} = 0$$

For $P = P_2 = I$, we have

$$C_{AB} = [(k - 1)/k]^{1/2}$$

and

$$T_{AB} = [(k - 1)/(k - 1)]^{1/2} = 1.$$

While for the special case of extreme movement defined in (2.5)

$$C_{AB} = [((k^2 - k)\, 1/((k - 1)^2) - 1)/((k^2 - k)\, 1/(k - 1)^2)]^{1/2} = 1/\sqrt{k}$$

and

$$T_{AB} = [((k^2 - k)\, 1/((k - 1)^2) - 1)/(k - 1)]^{1/2} = 1/(k - 1)$$

(iii) Using minimum discrimination information statistic. By assuming the distribution of the population at times t and $t + 1$ as two multinomial populations a measure of divergence between them can be defined as follows :

Probability vectors defining the two populations are

$$\pi^{(t)} = (\pi_1^{(t)}\, \pi_2^{(t)} \ldots \pi_k^{(t)})'$$

$$\pi^{(t+1)} = (\pi_1^{(t+1)}, \pi_2^{(t+1)} \ldots \pi_k^{(t+1)})'$$

Then the measure of divergence is given by,

$$J(1, 2) = \sum_{j=1}^{k} \left(\pi_j^{(t)} - \pi_j^{(t+1)} \right) \log_e \left(\pi_j^{(t)} / \pi_j^{(t+1)} \right) \qquad (4.4)$$

Values of the above measure in the three cases of interest work out as follows:

Perfect Mobility ($P = P_1$)

Here $\pi_j^{(t+1)} = \sum_j r_j\, \pi_j^{(t)}$ (using 1.1)

So $J(1, 2) = \sum_{j=1}^{k} \left(\pi_j^{(t)} - \sum_j r_j\, \pi_j^{(t)} \right) \log_e \left(\pi_j^{(t)} \Big/ \sum_j r_j\, \pi_j^{(t)} \right)$

In the special case of perfect mobility defined by (2.4) we have

$$J(1, 2) = \sum_{j=1}^{k} \left(\pi_j^{(t)} - 1/k\right) \log_e k\, \pi_j^{(t)} \qquad \text{as } \sum_j \pi_j^{(t)} = 1$$

$$= \sum_{j=1}^{k} \pi_j^{(t)} \log_e \pi_j^{(t)} - 1/k \sum_j \log_e \pi_j^{(t)}$$

Perfect Immobility ($P = P_2 = I$)

Here $\pi_j^{(t+1)} = \pi_j^{(t)} \; \forall \; j$ (using 1.1)

So $J(1, 2) = 0$

In case of extreme movement defined by (2.5)

$$\pi_j^{(t+1)} = (1 - \pi_j^{(t)})/(k - 1).$$

$$\text{So } J(1, 2) = \sum_{j=1}^{k} \left[\pi_j^{(t)} - \left(1 - \pi_j^{(t)}\right)/(k - 1)\right] \log_e \left[(k - 1)\, \pi_j^{(t)}/\left(1 - \pi_j^{(t)}\right)\right]$$

$$= k/(k - 1) \left[\sum \pi_j^{(t)} \log_e (k - 1) + \sum_j \pi_j^{(t)} \log_e \pi_j^{(t)}\right.$$

$$\left. - \sum \pi_j^{(t)} \log_e \left(1 - \pi_j^{(t)}\right)\right] - 1/(k - 1) \left[k \log_e (k - 1)\right.$$

$$\left. + \sum \log_e \pi_j^{(t)} - \sum \log_e \left(1 - \pi_j^{(t)}\right)\right]$$

5. Large Sample Distributions of Estimates

For problems of inference, we are required to derive the distribution of some estimates of a measure of mobility based on a sample of size N. First take the case of $\cos \Delta$ (given by 3.3). It is difficult to obtain the distribution of its estimate (for any form of mobility) generally since two multinomial distributions are involved. In particular, let us consider the special case of extreme movement where

$$\cos \Delta = 1/\sqrt{(k - 1)} \sum_i \sqrt{\pi_i^{(t)} (1 - \pi_i^{(t)})}$$

Let $n_i^{(t)}$ = size of the ith class at time t. Then $n_i^{(t)}$ $(i = 1 \ldots k)$ define a multinomial distribution with parameters N and $\pi_i^{(t)}$, where N = sample size. The *M L E* of $\pi_i^{(t)}$ is given by $n_i^{(t)}/N$. Let us take as an estimator of $\cos \Delta$

$$W = \widehat{\cos \Delta} = 1/\sqrt{(k - 1)} \sum_i \sqrt{n_i^{(t)}/N\left[\left(N - n_i^{(t)}\right)/N\right]}$$

Now $E\left[n_i^{(t)}\left(N - n_i^{(t)}\right)\right] = N(N-1)\ \pi_i^{(t)}\left(1 - \pi_i^{(t)}\right)$

$$\text{Var}\left(n_i^{(t)}/N\right) = 1/N\, \pi_i^{(t)}\left(1 - \pi_i^{(t)}\right).$$

Then for large N

$$\sqrt{N}\left[W - 1/\sqrt{(k-1)}\ \sum_i \sqrt{\left[((N-1)/N)\, \pi_i^{(t)}\left(1 - \pi_i^{(t)}\right)\right]}\right] \cap N(0, V(w)).$$

where

$$V(w) = \left(1/\sqrt{(k-1)}\ \sum_i \partial/\partial\ \pi_i^{(t)}\sqrt{\left[((N-1)/N)\, \pi_i^{(t)}\left(1 - \pi_i^{(t)}\right)\right]}\right)^2 \text{Var}\left(n_i^{(t)}/N\right)$$

$$= (N-1)/(4N^2\,(k-1))\left[\sum_i\left(1 - 2\,\pi_i^{(t)}\right)\right]^2$$

The estimate of the variance is given by

$$V(\hat{w}) = (N-1)/(4N^4\,(k-1))\left[\sum_i\left(N - 2n_i^{(t)}\right)\right]^2$$

Now consider the large sample distribution of the estimate of $J(1, 2)$.

Suppose we have samples of sizes N_1 and N_2 at times t and $t+1$ respectively.

Let $n_i^{(t)}$ = size of the ith class at time t

and $n_i^{(t+1)}$ = size of the ith class at time $t+1$

Then $n_i^{(t)} \cap$ Multinomial $(N_1, \pi_i^{(t)})$

$n_i^{(t+1)} \cap$ Multinomial $(N_2, \pi_i^{(t+1)})$

The $M\ L\ N\ s$ of $\pi_i^{(t)}$ and $\pi_i^{(t+1)}$ are given by $n_i^{(t)}/N_1$ and $n_i^{(t+1)}/N_2$ respectively.

The estimate of $J(1, 2)$ can be taken as

$$J(\hat{1}, 2) = \sum_{j=1}^{k}\left(n_j^{(t)}/N_1 - n_j^{(t+1)}/N_2\right)\log_e\left[\left(n_j^{(t)}/N_1\right)/\left(n_j^{(t+1)}/N_2\right)\right]$$

$$= 1/N_1N_2\sum_{j=1}^{k}\left(N_2\, n_j^{(t)} - N_1\, n_j^{(t+1)}\right)\log_e\left[N_2\, n_j^{(t)}/N_1\, n_j^{(t+1)}\right]$$

$$= 1/N_1N_2\left[(\log_e N_2 - \log_e N_1)\left(\sum_{j=1}^{k}\left(N_2\, n_j^{(t)} - N_1\, n_j^{(t+1)}\right)\right.\right.$$

$$\left. + \sum_{j=1}^{k}\left(N_2\, n_j^{(t)} - N_1 n_j^{(t+1)}\right)\left(\log_e n_j^{(t)} - \log_e n_j^{(t+1)}\right)\right]$$

Then, as given in [2], for large values of N_1 and N_2, $J(1, 2)$ follows a non-central chi-square distribution with $(k - 1)$ degrees of freedom and non-centralty parameter $J(1, 2)$ (which would depend on the extent of mobility or on the transition probability matrix).

6. Testing of Hypothesis

Here our problem is to test the following three hypothesis against specified alternatives

H_{01} : Society is perfectly mobile
H_{02} : Society is perfectly immobile
H_{03} : Society exhibits extreme movement

We can test the above three hypothesis with the help of minimum discrimination information statistic. Let f_{ij} be the number out of those who belonged to class i at time t now belonging to class j at time $t + 1$.

Let p_{ij}s be as in Table 4.1. We choose the test statistic as

$$2\,\hat{I} = 2 \sum_{i=1}^{k} \sum_{j=1}^{k} f_{ij} \log_e [f_{ij}/f_{i0}\, p_{ij}]$$

$$= \sum_{i=1}^{k} \sum_{j=1}^{k} 2 f_{ij} \log_e f_{ij} - \sum_{i=1}^{k} 2 f_{i0} \log_e f_{i0}$$

$$- \sum_{i=1}^{k} \sum_{j=1}^{k} 2 f_{ij} \log_e p_{ij}.$$

Under, null hypothesis, as suggested in [3] $2\,\hat{I}$ follows chi-square distribution with $k(k - 1)$ degrees of freedom while under the alternative $2\,\hat{I}$ follows a non-central chi-square distribution with appropriate degrees of freedom and non-centralty parameter.

Here we assume that in Table 4.1 all $p_{ij} > 0$. If c of the p_{ij} values are equal to zero then $2\,\hat{I}$ follows, under null hypothesis, chi-square distribution with $k(k - 1) - c$ degrees of freedom. Under H_{01} (so that $P = P_1$)

$$2\,\hat{I} = 2 \left[\sum_{i=1}^{k} \sum_{j=1}^{k} f_{ij} \log_e f_{ij} - \sum_{i=1}^{k} f_{i0} (\log_e f_{i0} + r_i) \right]$$

$$\cap\ \chi^2 \text{ with } df = k(k - 1)$$

Under H_{02} (where $P = P_2$) the asymptotic chi-square distribution of $2\,\hat{I}$ has no degree of freedom, and under H_{03} (implying $P = P_3$)

$$2\,\hat{I} = \left[\sum_{i=1}^{k} \sum_{j=1}^{k} f_{ij} \log_e f_{ij} - \sum_{i=1}^{k} f_{i0} \log_e f_{i0} - \sum_{i=j} \sum f_{ij} \log_e p_{ij} \right]$$

$$\cap\ \chi^2 \text{ with } df = k(k - 1) - k = k^2 - 2k.$$

An Example

The empirical study of social mobility by Glass and Hall (1954) based on 3500 pairs of fathers and sons in Britain may be considered to illustrate the

TABLE 3-VALUES **OF** THE VARIOUS MEASURES **OF** MOBILITY CALCULATED FROM THE GLASS AND HALL'S DATA AS ALSO THEIR **LIMITING** VALUES

Measure	*Observed here*	*Values of Measures Observable in Cases of*		
		Perfect Mobility	*Perfect Immobility*	*Extreme Movement*
P	.0034	0	1	1/6
trP	2.1140	1	7	0
D	1.0475	2.2857	0	—2.4602
2	.0041	0.1497	0	-0.4640
R'	.8977	0	1	-0.0278
$J(\hat{1}, 2)$	.023	0.616**	0	0.036*
CAB	0.580	0	.925	0.376*
TAB	0.289	0	1	0.166*

*In the special **case** (2.5).
****In the special case** (2.4).

various measures indicated earlier. Transition probabilities and actual distributions of fathers and sons among 7 social groups arc as follows :

0.388	0.146	0.202	0.062	0.140	0.047	0.015
0.107	0.267	0.227	0.120	0.260	0.053	0.020
0.035	0.101	0.188	0.191	0.357	0.067	0.061
0.021	0.039	0.112	0.212	0.430	0.124	0.062
0.009	0.024	0.075	0.123	0.473	0.171	0.125
0.000	0.003	0.036	0.083	0.364	0.235	0.274

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