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Measurement biases in panel data

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Key words: attrition, measurement error, mobility, multi-day diaries, panel, surveys

Abstract. The objective of this paper is to examine reporting errors in panel data obtained from multi-day travel diaries. A distinction is made between within and between wave biases. The former leads to an increase in under-reporting associated with the number of days the diary is kept. The latter is related to the number of waves respondents have been participating, so-called panel experience. These biases imply that observed mobility changes between waves are partly due to reporting errors: without controlling for them, changes in mobility can not be inferred from the data. An important cause of these measurement errors is the increase in the number of days on which no trips at all were reported. In addition, shorter trips and less complex chains are more susceptible to underreporting. The methodology used in this paper provides a means of dealing with these problems. Attrition is taken into account by a rather simple measure. The paper concludes with a number of suggestions for sample and survey design.

1. Introduction

Panel surveys, in which mobility on a number of occasions is measured on the same units, have several analytic advantages over cross-sectional data. For example, panel data enable the analyst to deal with the effects of unobserved variables that vary across individuals, but that remain constant over time (Hsiao 1984; Meurs 1989). Another advantage is that aspects of dynamics in travel behaviour may be examined, such as habit formation and persistence, learning or anticipation of changing circumstances (Clarke et al 1982; Goodwin & Layzell 1985; Goodwin 1987). These points suggest that the usefulness of relationships derived from cross-sectional data may be limited (Goodwin 1977; Clarke et al. 1982; Kitamura 1987; Meurs 1989). In addition, there is a statistical advantage, because sampling errors of net change may be lower than in repeated cross-sectional surveys.

These advantages led to the decision to start the Dutch Mobility Panel. Since March 1984 seven waves of data have been collected in connection with this survey that is being carried out in The Netherlands. This project has been organized in the form of a panel survey involving households. Twice a year, members of the approached households of twelve years and older were asked to keep a seven-day travel diary detailing the salient features of the trips and related activities undertaken during this period

(Golob et al. 1985; Meurs et al. 1987). The intention was to spread the starting-days of diary-keeping evenly over the days of the week. Stratification variables in the selection of households are income, location of residence ("big cities" to "rural communities") and family lifecycle.

There are also potential problems associated with panel surveys, which might bias the results if not properly accounted for. One of the best known problems is the issue of attrition bias. (Maddala 1978; Hausman & Wise 1979; Bureau Goudappel Coffeng (BGC) 1986; Kitamura & Bovy 1987). This also applies to the Dutch panel. Especially between the first and second wave of participation, there was a high drop-out of respondents. Golob et al. (1985) note that the group of likely drop-outs include, among others, households of old persons, single-person households, low-income households, and those without cars. Kitamura and Bovy (1987) and BGC (1986) also note that attrition is related to mobility characteristics, leading to biases in model coefficients. Kitamura and Bovy (1987) show that attrition is related to unobserved factors influencing its members' prospensities to make and report trips.

Following an assessment of attrition in the Dutch mobility panel, new households are recruited for successive waves, to maintain a comparable number of respondents per sample stratum as present in the first wave of the study. So, this panel may be considered as a specific form of a rotating panel. This replacement procedure has always been introduced after a delay of one wave, as data concerning the drop-out levels are not immediately available at the following round.

Another problem is associated with the way mobility is measured. Multi-day diaries are presented to the respondents. The use of these diaries is motivated by the opportunity to gain insights in day-to-day variation in travel patterns and to obtain more accurate information about less frequently made trips (Scheuch 1972; Goodwin 1979; Koppelman & Pas 1984). It is a well known phenomenon that the use of multiday diaries may lead to biases in response due to a decline in the accuracy of reporting (Szalai 1972; Brög & Meyburg 1980, 1981; Golob & Meurs 1986; Kitamura & Bovy 1987). These reporting errors are due to a decline in the participants' motivation or fatigue (Hanson & Huff 1982; Golob & Meurs 1986). In this paper these biases will be referred to as *within wave biases.*

The use of multi-day travel diaries in a panel context may lead to additional problems (Neter & Wakesberg 1964; Scheuch 1972; Bailer 1975, 1979; Tanur 1981). If the accuracy of reporting differs across waves, biased aggregate mobility trends will be found. In this paper these are the *between wave biases.* They are related to the number of waves respondents are participating in. The seriousness of the biases depends on the objectives of the analysis, on the methodology used and on the characteristics of the biases. If for example, the objective is to examine differences in the change of trip rates among population segments and if there are no differences in the biases among these segments, the results of the analysis will not be biased. One could expect that with an increase in the number of waves respondents are participating in, a between wave fatigue develops, leading to a decline in reporting accuracy. These between-wave biases are equivalent to what are commonly referred to as panel effects (Bailer 1975, 1979; Tanur 1981). Experienced panel-members may keep their diaries differently than new members. A panel may also have an effect on attitudes and behaviour, if the members become aware of their travel habits. This, however, cannot be analyzed with the available data. If such an effect exists in the present case, it will be confounded with other "between wave biases".

The objective of this paper is to examine reporting errors in panel data using multi-day travel diaries. The presence of biases will be examined and characterized. Attrition will be taken into account by a rather simple measure. The consequences for aggregate mobility trends will be examined and a methodology to correct for these biases will be outlined. The paper concludes with a number of suggestions to minimize these measurement problems in the phase of sample and survey design.

2. Methodology

Within and between wave biases

Evaluating the exact magnitude of reporting errors in travel diaries is an impossible task, as Kitamura and Bovy (1987) note, simply because the number and characteristics of the trips actually made ("true mobility") cannot be known. However if one is willing to make some reasonable assumptions insights into the nature of reporting errors can be obtained at the aggregate level.

First consider the within wave biases. It is assumed that these biases are related to the number of days the diaries have been kept (referred to as sequence-days). With an increase in sequence-days reporting errors tend to increase. Reporting on the first day is assumed to approach the "true" mobility best. Therefore, comparing reported mobility on other days with this first day provides an indicator of the amount of change in reporting bias.

Apart from variation due to reporting bias, a true day-to-day variation is present in the data. Mobility patterns differ from day-to-day (Hanson & Huff 1982). Proper control for these day of the week effects is necessary to obtain a proper insight into reporting bias. The panel under investigation allows the analyst to take this true variation into account because households start keeping their diaries on different days of the week. This means that different parts of the sample report their mobility on different days of the week with a different sequence number. By averaging mobility on a certain sequence-day over the entire sample, weighted by the number of individuals starting on the same day, a mean mobility for that specific sequence-day can be obtained, not affected by days-of-the week. If we compare the mean "sequence-day mobility" with the "mean mobility" over all days of the week for the first sequence-day, a measure of reporting quality is obtained. If this measure is less than one, mobility is underreported.

The same procedure applies to the descriptive analyses of the between wave effect. Mobility reported in the first wave of the panel may be taken as a point of reference. Comparing mobility of successive waves with the first provides insights into the nature of between wave biases. If respondents report less trips in the second wave, a decline in mobility may be inferred which is not reflected in the population. However, there may be a true change present in mobility over the waves. These are labelled wave or period specific effects. To seperate these from the reporting errors, mobility of respondents who start in a certain period is compared with mobility of respondents who did already participate before that period. The hypothesis is that, controlling for differences between "starters" and "stayers", the mobility differences between these groups are due to reporting biases.

One complication that might arise is that within wave biases relatively decrease if respondents participate longer. This means that there might be an interaction between the number of waves that respondents have participated in and the amount of within wave bias.

Figure 1 summarizes the main hypothesis outlined in this section.

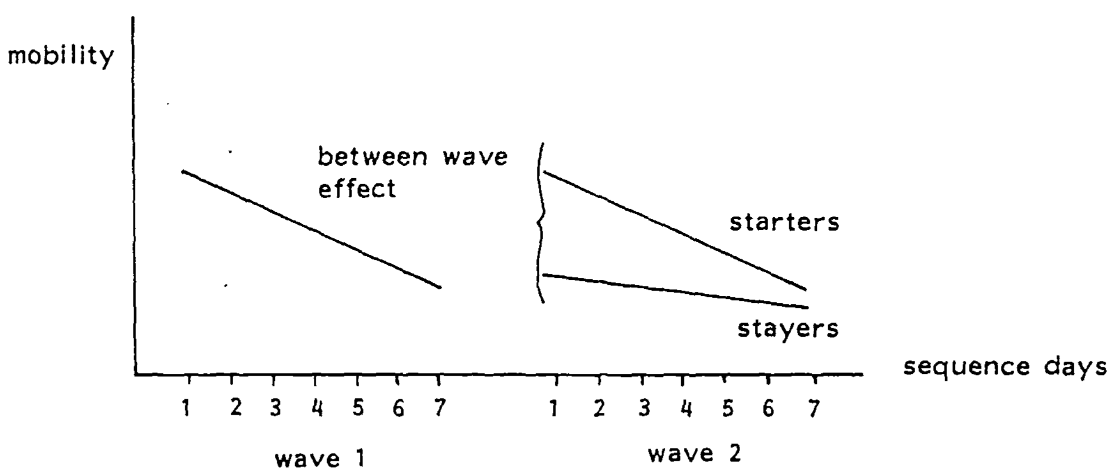

Fig. 1. A hypothetical illustration showing the effects of bias introduced by "fatigue" over sequence day and successive registration periods for "starters" and "stayers".

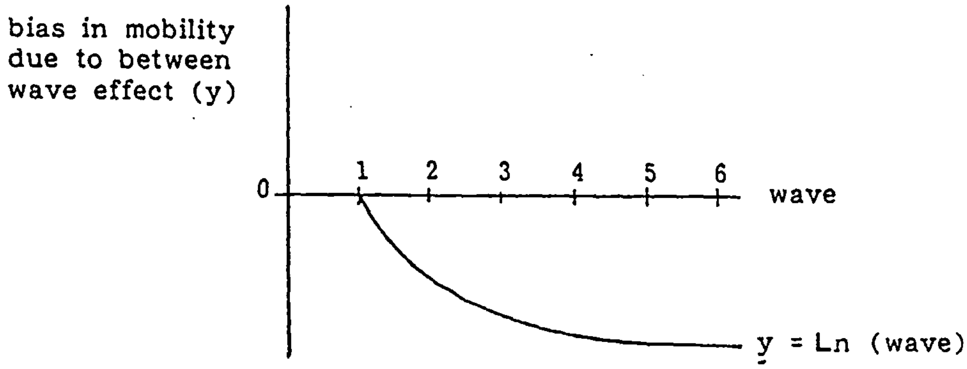

Fig. 2. The underestimation of mobility due to between wave reporting biases.

The curves demonstrate the hypothesis that respondents who are new to the survey in waves 1 and 2 (starters) show the same within wave biases. Although the number of trips recorded by respondents who remained in the study in wave 2(stayers) is initially lower than that of other groups, the effect of sequence day is less pronounced. This picture arises from a hypothesis that respondents who remain in the survey are more motivated to complete the diary.

For the within and between wave biases logarithmic shapes of the biases were hypothesized. This hypothesis was confirmed by some preliminary work using dummy-variables for wave $K(K = 2, \ldots, 7)$. Figure 2 represents the shape of these between wave biases. The shape indicates that the most severe biases occur relatively at the beginning of the panel participation and decline with an increase in the number of waves that respondents have been involved with. The same shapes were hypothesized to represent within-wave reporting errors.

Testing and estimating the within and between wave biases

The data used for the empirical testing and estimation of the biases are from the 1984 to 1987 surveys of the Dutch Mobility Panel. Four waves were used, covering four weeks in March, from 1984 to 1987. More details about the data are given in Section 3.

To test the hypothesis outlined in the previous section the following characteristics have to be taken into account:

- There are differences in the characteristics between groups of respondents defined on the basis of their participation characteristics. Respondents who participate longer generally have higher incomes and more cars. Partly, this can be attributed to characteristics of attrition, but also to the refreshment strategies used.

- There is a selectivity in mobility of respondents who drop-out, even after differences in characteristics of the respondents are taken into account (Kitamura & Bovy 1987; Meurs et al. 1987).
- There are specific characteristics of the periods in which the mobility was measured. For example, the first wave was held in March 1984 shortly before an increase in public transport fares. This implies that circumstances in the periods after the first wave are not directly comparable with the conditions of the first wave.
- There are differences in mobility between different days of the week, which have to be taken into account.

In order to examine the between and within wave biases controlling for these effects Ordinary Least Squares (OLS) regression may be used:

$$\begin{aligned} Y_{ibtd} &= \nu\alpha + \beta X_{it} + \sum_{t=2}^{4} \delta_t W_t + \sum_{d=2}^{7} \phi_d D_d + \mu V_i + \lambda B_b + \nu N_i \\ &\quad + \tau M_{it} + \rho B_b * M_{it} + \sigma B_b * N_i + E_{ibtd} \end{aligned} \tag{1}$$

where

Y_{ibtd} = mobility that is reported by respondent i at sequence day b in wave t at day-of-the-week d

X_{it} = a vector of person and household characteristics of respondent i in wave t

D_d = day-of-the-week specific dummies (Tuesday is taken as reference)

W_t = period specific dummies in wave 3, wave 5 and wave 7

V_i = started in odd or even waves

B_b = the logarithm of sequence day b

N_i = the logarithm of the *total number* of waves that respondent i has participated in up to wave 7.

M_{it} = the log of the number of waves respondent i has participated including wave t (for starters $t = 1$ respondents who participate for the second time, $t = 2$, etcetera)

$B_b * M_{it}$ = the interaction between the log of sequence day and the log of the number of waves a respondent has participated in at wave t

$B_b * N_i$ = the interaction between the log of the total number of waves a respondent has participated in and the sequence day effect

E_{ibtd} = an error term

The variables are defined as follows:

- Mobility is characterized using trip rates in total and by modes, the number of reported home-based trip-chains, travel distances in kilometers and minutes, and number of rides.
- Household and person characteristics are introduced to control for differences among respondents other than on the basis of their participation characteristics. A preliminary analysis was performed to discover whether respondents approached for the first time in successive periods differ on a number of person and household characteristics. These are income-group, lifecycle, community type, car-ownership, household size, working status, license-holding, education, age and sex. These variables are introduced as explanatory variables in equation (1) to correct for potential differences among the groups. However, we shall restrict ourselves in the remainder of this paper to the coefficients associated with reporting biases and period effects.
- Period specific dummy-variables are introduced to control for the specific circumstances which were present in the different waves. For the assessment of both within and between wave effects only the waves surveyed in the spring were used. These are renumbered wave 1 to wave 4.
- To control for the limitation that only the reporting of mobility in the spring-waves is analyzed, while some of the respondents started in autumn waves, a dummy variable indicating whether they started in spring (odd) or in autumn (even) waves was included.
- The sequence day of reporting within each wave is transformed logarithmically to obtain a curved shape.
- The number of waves in which respondents have participated is transformed the same way. Respondents who participate in wave t for the first time have consequently a value log (1) = 0 on this variable, those who participate for the second time have a value log (2), and so on.
- The former variable has to be distinguished from the variable representing the total number of waves in which respondents have participated in all seven waves. This variable is introduced to control for the effects of attrition. Respondents who participate only once and dropped out may have different reported mobility characteristics. Note that this is not an entirely satisfactory manner to correct for the effects of attrition. Because only seven waves of data are available, respondents who start participating in wave 7 have only once reported their mobility. This is due to censoring of the total period of the panel. But for the present application, only a small bias is expected because the size of the initial sample is much larger than the refreshment samples.

- Finally, two interaction effects are included. The interaction between the sequence-day and the number of waves in which the respondents participated (prior panel experience) represents a possible decline of the within-wave reporting errors with an increase in panel experience of participating. The interaction-effect between the sequence-day and the *total number* of participated waves provides a means of testing whether drop-outs have a different within-wave effect than respondents who remain in the survey.

Although serial correlation may be expected, this was not taken into account because the sample size is large. Consequently hardly any problems are to be expected in judging the standard-errors of the parameters.

From the estimated parameters, an estimate of the total aggregate bias can be deduced, using the second part of the equation:

$$V_{ibt} = \lambda B_b + \nu N_i + \tau M_{it} + \rho B_b * M_{it} + \sigma B_b * N_i \tag{2}$$

Where V_{ibt} is the total bias at sequence day b in the t-th wave of participation by respondents.

Note that this equation implies that reporting errors cannot be estimated for different segments within the sample. This would require interaction-terms of the household and person characteristics with the variables characterizing sequence-days (B_b) and panel experience (M_{it}). Additional analysis revealed that these interaction-effects cannot be interpreted meaningfully. possibly due to the resulting complexity of the equation.

3. Data

The panel sample is stratified when it was sampled according to community type, household income and lifecycle. All individuals of 12 years and older living in these households form the units for this analysis. Since 1984 seven waves of data have been collected. The fourth wave is a special one because no mobility information was obtained for budgetary reasons. For an initial descriptive analysis of the within wave effects all other 6 waves were used.

Not all households/individuals remain in the panel for the full period. Approximately 15 to 20% of the households involved in each wave of the survey, drop out in the following round. This group is not randomly distributed over the sample. Following an assessment of the characteristics of the drop-outs, new participants were recruited for the successive wave, to maintain a comparable number of respondents per category as present in the first wave of the study. Table 1 presents the number of respondents with respect to the wave in which participation started and the total number of waves that they have participated in.

Table 1. Number of respondents classified by wave in which participation started and total number of waves they have participated in.

Starting wave	Number of waves of participation							
	1	2	3	4	5	6	7	Total
1	1,149	394	228	214	243	263	1,372	3,863
2	219	126	80	96	108	490		1,119
3	116	79	77	56	306			634
4	19	9	6	57				91
5	187	145	671					1,003
6	79	451						530
7	792							792
Total	2,561	1,204	1,062	423	657	753	1,372	8,032

Although the objective of the fieldwork was to get an even distribution of starting days over all days of the week, this was not achieved, as is evident from Table 2.

Table 2. Number of respondents classified by day of the week in which mobility reporting started, by first wave of participation.

	First wave of participation				
Day of week	1	3	5	7	Total
Monday	53	118	161	40	372
Tuesday	890	161	151	63	1,265
Wednesday	727	106	188	69	1,090
Thursday	801	79	191	56	1,127
Friday	728	74	132	53	987
Saturday	401	58	120	213	792
Sunday	263	38	60	298	659
Total	3,863	634	1,003	792	6,292

It is clear that Mondays have a low share in starting days, especially in the first wave. Also, on weekend days less respondents start their participation. The analysis should take care that this uneven distribution does not affect the results.

4. Descriptive assessment of reporting errors

For all seven waves within wave bias indices were obtained. These represent average reporting on sequence-day two to seven with respect to the first day of mobility reporting. Groups are defined based on the number of waves that people have participated in. Average indices were calculated for all respondents who participated for the first time, for the second time, and so on. Here, no distinction is made between the periods in which the measurements occurred. Table 3 presents the mean index of the within wave effect. Bus, tram and metro are referred to as "BTM".

The mean index for the total number of trips in the first wave of participation is .92. This means that on average on sequence day 2 to 7 about 8% trips less were reported in comparison with the first day. For respondents who participate for the second time the index equals .95. This means that on average about 5% less trips were reported on day 2 to 7 while participating for the second time.

Table 3. Mean mobility relative to the first diary-day by wave of participation.

Mobility variable	Number of waves of participation (status = 1)					
	1	2	3	5	6	7
Total trips	0.92	0.95	0.98	0.96	0.96	0.96
Number of rides	0.96	0.96	1.00	0.97	1.00	0.95
Distance	0.97	0.97	1.06	0.98	0.97	0.92
Trips by mode						
Car driver	0.93	0.95	1.00	0.96	0.97	1.02
BTM	0.92	1.02	0.96	0.96	1.09	0.92
Bicycle	0.94	0.97	0.98	0.99	1.00	0.97
Passenger	0.92	0.97	0.99	0.93	0.92	0.90
Walk	0.85	0.91	0.93	0.94	0.95	0.92
Number of respondents	2,561	1,204	1,062	657	753	1,372

The first wave of participation clearly suffers more from underreporting than the other waves. In the other waves this phenomenon is about equal. To discover whether this might be related to a high drop out after the first wave, after which respondents who are more motivated continue participating, indices for the stayer were constructed. The mean indices for day 2 to day 7 are presented in Table 4. Comparison of the indices with those in Table 3 reveals no major changes, except for BTM trips. This implies that most differences with respect to the number of waves respondents have participated in are not due to selection of the more motivated respondents in the sample.

Table 4. The mean indices for stayers with respect to the first sequence day.

Mobility variable	Wave of participation (starters = 1)					
	1	2	3	5	6	7
Total tripmaking	0.92	0.95	0.98	0.96	0.96	0.97
Number of rides	0.96	0.95	1.00	0.98	1.00	0.95
Distance	0.98	0.97	1.06	0.98	0.97	0.91
Trips by Modes						
Car driver	0.96	0.99	0.96	0.95	1.01	0.94
BTM	0.93	0.95	0.99	0.95	0.97	1.02
Bicycle	0.97	0.97	0.98	0.99	1.00	0.97
Passenger	0.94	0.97	1.00	0.93	0.93	0.90
Walk	0.84	0.93	0.92	0.95	0.95	0.92

5. Estimating the within and between wave effects

This section contains the results of the OLS estimation of the coefficients of model (1) associated with within and between wave effects and selectively in the total number of waves respondents participated in. As mentioned in Section 2, the coefficients of the other variables are not presented for clarity of the exposition. In Table 5 the results are presented. The models are estimated using all respondents who participated in the panel, including the refreshment samples in later waves. Only waves 1, 3, 5 and 7 are used in the analysis.

The first column in Table 5 contains the coefficients denoting the effect of the logarithm of sequence day on mobility. For example, the total number of trips on day 2 is about $0.27 \cdot \log(2)$ lower than on day 1. The number of trips on day 3 is about $0.27 \cdot \log(3)$ lower than on day 1, etc. The second column denotes the relationship between the number of waves that the respondents have participated in up until a given wave and the reported mobility. The total number of reported trips in the second wave of participation is about $0.48 \cdot \log(2)$ lower than in the first wave of participation and in the third wave about $0.48 \cdot \log(3)$ lower than in the first wave. The third column represents the relationship between the total number of waves that respondents have participated in and the reported mobility. Respondents who participate 2 waves in total have a mobility which is about $0.32 \cdot \log(2)$ higher than respondents who participate only 1 wave. The last column in Table 5 represents the relationship between the number

Table 5. The results of the estimation of within and between wave effects and selectivity in drop-out, controlling for household and person characteristics (absolute values of t-statistics between parentheses).

Mobility variable	Within wave effect (λ)	Between wave effect (τ)	Duration of participation (ν)	Inter action (ρ)
Total trips	−0.27(18.3)	−0.48(20.4)	0.32(23.0)	0.03(6.5)
Number of rides	−0.22(11.3)	−0.52(16.3)	0.30(16.2)	0.04(7.6)
Travel time (in min)	−3.10(7.2)	−5.78(8.8)	2.43(6.4)	0.29(2.5)
Travel distance (in km)	−1.94(5.2)	−1.18(1.0)	−0.21(0.6)	0.18(0.5)
Number of chains	−0.12(16.6)	−0.23(9.3)	0.14(20.7)	0.03(4.3)
Mode				
BTM	−0.02(3.7)	−0.00(0.6)	−0.02(5.6)	0.00(2.0)
Train	0.00(0.4)	−0.00(0.2)	−0.01(2.9)	0.00(0.2)
Car driver	−0.06(6.3)	−0.09(5.3)	0.02(2.0)	0.01(2.2)
Car passenger	−0.01(1.7)	−0.04(3.8)	0.05(8.6)	−0.00(1.8)
Bicycle	−0.09(9.0)	−0.15(8.9)	0.16(16.6)	0.01(4.3)
Walk	−0.12(12.6)	−0.22(14.4)	0.08(9.3)	0.01(5.1)

of reported trips on a certain sequence day and the number of waves that were already participated in, the effects of the interaction between within wave bias and total duration of participation. The coefficients 0.03 means that respondents who participate for example for the second time have a lower within week effect ($-0.27 + 0.03 = -0.24$). Respondents who participate for the third time have a within week effect which is even less pronounced.

For all mobility variables, with the exception of train and car passenger trips, there is a significant decrease in reporting due to within wave reporting bias effects. The exceptions are possibly due to the special character of trip making with these modes. Trip making by train is rather rare and trips as car passenger are highly concentrated around the weekend when the car is not used for work purposes.

A significant decrease in reporting is noted for total trip making, number of segments and total travel time. No significant decrease is observed in travel distance. This suggest that the slower modes have more reporting errors than the mechanized ones. This is also manifest in the coefficients of the models describing reporting errors by mode: the underreporting related to the number of waves that were participated in shows a higher decrease for walk and bike. Reporting for public transport does not show a significant between wave effect.

Respondents who participate longer in the panel generally have a higher mobility than drop-outs. Exceptions are public transport trips and travel distance.

The interaction between the within wave effect and the number of waves in which was participated is positive, with the exception of train and trip making as a car passenger. This implies that for all mobility variables with a significant decrease in reporting associated with sequence day, this effect becomes less pronounced with an increase in participation experience.

Based on these coefficients, estimates of the total biases due to underreporting can be obtained by formula (2). With this formula, estimates of the total underreporting over seven days can be estimated. In this application only between and within wave effects are estimated, the effects of the number of waves in which respondents in total have participated is not taken into account. The results are displayed in Table 6.

Table 6. Estimates of the under-reporting of trips due to within and between wave effects.

	Wave of participation (starters = 1)						
Mobility variable	1	2	3	4	5	6	7
Number of trips	−2.27	−4.44	−5.70	−6.60	−7.30	−7.87	−8.35
Number of rides	−1.90	−4.16	−5.48	−6.41	−7.14	−7.73	−8.23
Travel time	−26.45	−52.80	−68.22	−79.16	−87.64	−94.57	−10.43
Trips by modes							
BTM	−0.11	−0.11	−0.12	−0.12	−0.12	−0.12	−0.12
Train	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00
Car driver	−0.55	−0.94	−1.17	−1.33	−1.45	−1.56	−1.64
Car passenger	−0.10	−0.32	−0.44	−0.53	−0.60	−0.66	−0.71
Bicycle	−0.81	−1.47	−1.86	−2.13	−2.34	−2.52	−2.66
Walk	−1.03	−2.04	−2.63	−3.04	−3.37	−3.63	−3.85

From Table 6 it is evident that a considerable underreporting takes place. In the first wave respondents participate in, trip reporting is for total 2.27 trips underreported, when they participate for the second time, 4.4 trips are reported less than expected, due to measurement error.

To obtain insights in the effects of reporting on observed aggregate mobility trends, the outcomes presented in Table 6 are used to get corrected estimates of the aggregate changes in mobility. The results are presented in Table 7.

The total number of trips reported decreases between wave 1 (March 1984) and wave 7 (March 1987) (about a 13% decrease). The estimated trend, taking within and between wave reporting biases into account, shows a corresponding increase of 11%. Due to within wave reporting biases the total mobility over the entire week is underestimated with 7% in the first wave. Clearly, reporting of trips on bike and by foot are most severely

Table 7. The observed estimated changes in mobility for respondents who participated in all waves.

	Observed				Corrected			
Wave	1	3	5	7	1	3	5	7
Total trips	25.42	23.82	23.77	22.57	27.69	29.52	31.07	30.92
Segments	29.70	27.32	26.85	25.84	31.60	32.80	33.99	34.07
Travel time	235.21	228.83	238.98	216.96	261.66	297.05	236.62	317.39
Modes								
BTM	0.84	0.74	0.79	0.77	0.95	0.85	0.91	0.89
Train	0.31	0.33	0.29	0.29	0.31	0.33	0.29	0.29
Car driver	7.89	7.33	7.60	8.03	8.44	8.50	9.05	9.67
Car passenger	3.16	2.94	2.94	3.17	3.26	3.38	3.54	3.88
Bicycle	8.76	8.14	7.60	6.44	9.57	10.00	9.94	9.10
Walk	6.66	5.97	5.87	5.55	7.69	8.60	9.24	9.39

biased. Trends in the number of trips by public transport are hardly affected by reporting biases. Due to the within week biases, trips by BTM are underestimated with respect to the average number of trips made by this mode.

From the results presented in this section it is evident that considerable bias exist in aggregate developments in mobility. It is expected that not all trips are equally likely to be underreported. With respect to this three main hypotheses may be formulated:

- an increase will take place in the number of days on which no trips at all are reported. This hypothesis was confirmed by Golob and Meurs (1986) in their analysis of the first wave of the panel;
- shorter trips are more easily forgotten than longer trips;
- part of the biases can be explained by a simplification of entire trip chains or omission of simple chains. For example, it might happen that respondents tend to report the main purpose of an entire chain, instead of each of the links as separate trips units.

In the next section, we will test these hypotheses.

6. Characteristics of within and between wave effects

Immobile days

Previous research, reported in Golob and Meurs (1986), revealed that the principal cause of temporal biases is the increasing tendency over time for respondents to report no travel at all on a given day. Here we address the issue whether this also explains the existence of between wave effects. Table 8 presents the percentage of respondents who report no travel at all on a given sequence day by wave.

Table 8. The percentage of respondents who participated in all waves recording days with no trips by sequence-day and wave.

Sequence day	Wave 1	3	5	7
1	9.5	10.4	10.9	10.0
2	12.2	12.1	14.8	13.4
3	15.9	15.7	14.8	14.5
4	18.1	15.0	14.9	16.6
5	15.1	15.9	15.2	16.1
6	17.0	17.5	16.7	17.3
7	12.3	13.3	12.6	12.3

In the first wave 9.5% of the respondents report no trips on the first sequence day. This percentage increases to 18.1% on the fourth day the diary is kept; a considerable increase. In all waves, this increase in the percentage of respondents who reported no trips at all takes place, with a small decrease towards the end of the diary-period. Differences among the waves are present. The first wave of participation has a smaller percentage of respondents who did not report trips. The increase over the reporting period is more even over the sequence days if respondents participated longer in the panel.

To test for within and between wave effects, selectivity of drop-outs and interaction-effects between the within wave effects and the number of periods respondents did participate, a discriminant analysis was performed (Morrison 1967; Tatsuoka 1971). The objective was to discover whether a linear combination of the same variables used in the linear regression analysis could serve as a basis for classifying reporting days of the respondents into mobile and immobile (i.e. no trips reported). Especially, the effects of the variables associated with reporting bias are of interest. Table 9 presents the coefficients of the standardized discriminant functions. These are obtained after rescaling all the variables to a zero mean and unit variance. Combining these results with those of Table 5 indicates that the fraction of the sample reporting no mobility on a day increases with the sequence days and with the number of waves they have participated in. The effect of not reporting trips on certain days is much higher with an increase in the number of waves they have participated in than within a wave.

Table 9. Coefficients of the standardized discriminant functions classifying days into mobile and non-mobile.

	Within wave effects	Between wave effects	Duration of participation	Interaction
Coefficient	−0.33	−0.63	0.41	0.07

Respondents who remain in the panel have fewer days without trips reported, than respondents who drop-out. There are hardly any differences between the within wave effects among the different waves.

Summarizing, there is strong evidence that within and between wave effects are related to the phenomenon of reporting no trips at all on certain days. Respondents who remain in the panel seem to keep their diaries more faithfully than drop-outs.

Omitting short trips

The second hypothesis is related to the characteristics of the trips not reported. It is expected that mainly short trips are underreported. Therefore, changes in the mean length of trips, rides and chains are investigated using equation (1). Table 10 presents the results of the estimation.

Table 10. Estimates of coefficients indicating biases in reporting by mean trip length (absolute values of t-statistics between parentheses).

Mobility variable	Within wave effects (λ)	Between wave effects (τ)	Duration of participation (υ)	Interaction (ρ)
Escl. immobile days				
Mean trip distance	0.49(3.37)	1.45(2.91)	−1.19(8.46)	−0.16(1.78)
Mean ride distance	0.41(3.01)	1.02(2.22)	−1.10(8.74)	−0.10(0.80)
Mean chain distance	−0.04 (.13)	2.66(2.12)	−2.51(7.08)	−0.31(0.93)
Incl. immobile days				
Mean trip distance	0.07(0.59)	0.67(1.62)	−0.47(4.10)	−0.04(0.35)
Mean ride distance	0.04(0.32)	0.38(1.00)	−0.45(4.25)	0.00(0.02)
Mean chain distance	−0.83(2.66)	0.99(0.96)	−0.90(3.14)	−0.06(0.20)

Excluding immobile days, the mean trip and ride distance clearly increases with an increase in the diary period and with the number of times in which respondents did participate. This confirms the hypothesis that mainly short trips were underreported. Respondents who participate longer in the panel have reported a smaller average distance. This could be the result of a more accurate reporting of short trips by stayers. There is a tendency for a diminishing within-wave effect with an increase in the number of periods in which the respondent participated. This leads to a reduction of the within-wave reporting error. The mean chain distance only increases due to the between wave effect. No significant within-wave effect could be established. This might be explained by an increase in the number of short trips included in the chains.

Including immobile days leads to insignificant within and between wave effects, although the signs of the coefficients are still positive. This implies that the main reason for an increase in the trip-length is the omission of short trips made on days in which no longer trips were reported. The respondents who remain in the panel report smaller trips better; their mean trip-rates are lower, even after exclusion of days without mobility reporting. The coefficients associated with mean distance of chains show the same effects as those including immobile days. They are only lower, indicating that a substantial bias was caused by omission of trip reporting on immobile days. There are no significant interaction effects present.

Summarizing the results with respect to trip lengths leads to a confirmation of the hypothesis. Especially on days on which only short trips were made the reporting biases exist.

Decreasing complexity of reporting

The third hypothesis is related to the complexity of the reporting. It is expected that less complex trips are underreported, that more complex trips are simplified and that more complex chains are simplified. Table 11 provides the results of the estimation.

Table 11. Reporting errors for variables associated with the complexity of the chain.

Mobility variable	Within wave effects (λ)	Between wave effects (τ)	Duration of participation (υ)	Interaction (ρ)
Excl. immobile days				
no trips per chain	−0.06(9.49)	−0.06(2.65)	−1.19(8.46)	−0.16(1.78)
no rides per chain	−0.06(4.69)	0.06(1.62)	−1.10(8.74)	−0.10(0.80)
no rides per trip	0.01(1.65)	0.07(4.74)	−2.51(7.08)	−0.31(0.93)
Incl. immobile days				
no trips per chain	−0.13 (1.70)	−0.18(6.99)	0.09(12.98)	0.03(4.13)
no rides per chain	−0.14(12.09)	−0.09(2.40)	0.06 (5.22)	0.03(2.99)
no rides per trip	0.04 (7.97)	−0.01(0.65)	0.02 (5.76)	0.01(2.22)

The within wave effect indicates that with an increase in sequence day reporting errors increase. The differences between the analysis including and excluding days on which no mobility was reported leads to the conclusion that no reporting explains about half of the total underreporting. The between wave effects reveals some interesting results. With an increase in the number of waves in which was participated, underreporting increases. No reporting at all explains about one third of this. However, the number of rides per trip increases if days without trip reporting are excluded, also leading to an increase in the number of rides per chain. This might be explained by an omission of simple short trips. Another reason might be that a simplification in reporting takes place, in which respondents report more rides within a chain and tend to forget to report minor purposes.

7. Conclusions

In this paper various biases in reporting in multi-day panel data were examined. It is concluded that biases exist in these data. These biases have a within and a between wave component. In addition, also selectivity with respect to drop-out of respondents exist, related to mobility variables, even after controlling for household and person characteristics.

Except for trips by train and as car passenger, clear within wave biases exist, leading to a substantial underreporting of trips. With increasing experience in participating, this effect diminishes to some extent. In addition to this, also between wave biases were observed, except for public transport trips. This leads to the observation that without taking these biases into account, the sample mobility shows a considerable decline. However, if these effects are controlled for, a considerable increase in mobility may be observed in the period 1984–1987. This increase is matched by results from other external data sources, like traffic counts, repeated cross-section surveys to mention a few.

An important cause of these effects is an increase in the number of days on which no trips at all were reported. There are some indications that especially days with only short trips are omitted. Also, shorter trips and less complex chains were more susceptible to underreporting. There is evidence that a simplification of reporting of more complex trips and chains took place. Also, more often the main purpose of an entire trip chain was reported, omitting minor links.

The methodology used provides a means of dealing with the problems of underreporting in multi-day panel data on an aggregate basis. A requirement for the application of the methodology is that a sufficient large sample of starters is added to the sample at each wave. This amounts to the requirement of a planned or unplanned rotating panel. Further refinements of the methodology may be useful with respect to the correction of attrition. One way is to extend the methodology provided by Heckman (1979) and Hausman & Wise (1979) and applied by Kitamura & Bovy (1987) on the first two waves of the panel. Each observation is provided with a correction term taking the selectivity in response into account.

It is difficult to conclude with general recommendations with respect to a proper sample and survey design in order to minimize biases. This depends on the objectives of the panel. A clear statement of the objectives is needed. If the panel is concerned with a short term descriptive analysis of mobility trends, short panels in which respondents participate for only a few waves may be considered. A rotating panel may be advisable, applying the methodology described in this paper. However, if the objective is to analyse the effects of long term developments, then a panel with a long participation is required.

With respect to the diary, efforts could be made by the interviewers to discourage respondents from deleting entire days from the diary. Also, it may be considered to stop asking respondents to report all trips, asking only about specific trips. Perhaps a more detailed registration of activities would limit the biases, but then a survey period of a week is rather long.

Finally, the optimal period between two waves is an important issue to address. It may be expected that between wave biases are related to the length of the period between registration periods.

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