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The implementation of cross-sectional weights in household panel surveys

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Abstract: While household panel surveys are longitudinal in nature cross-sectional sampling weights are also of interest. The computation of cross-sectional weights is challenging because household compositions change over time. Sampling probabilities of household entrants after wave 1 are generally not known and assigning them zero weight is not satisfying. Two common approaches to cross-sectional weighting address this issue: (1) "shared weights" and (2) modeling or estimating unobserved sampling probabilities based on person-level characteristics. We survey how several well-known national household panels address cross-sectional weights for different groups of respondents (including immigrants and births) and in different situations (including household mergers and splits). When a new person moves into a household, both "shared weights" and "modeling" lead to reduced individual weights of pre-existing household members, but differences due to the approach arise elsewhere. The implementation of "shared weights" is problematic when the panel contains households without a household member already present in wave 1. Panels also differ in the treatment of immigrants, household merges, and sometimes on how weights are assigned to children born to wave 1 panel members.

Keywords and phrases: BHPS, HILDA, PSID, SHP, SOEP, household panel.

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1. Introduction

Household panel surveys are sample surveys in which the same private households are interviewed repeatedly over time (e.g., once a year). The definition of a household can vary slightly from panel to panel, but people in a household need not be related. For example, roommates are often considered a single household. Household panel surveys are typically general purpose surveys with multiple topics, and have become an important source of socio economic and other micro data.

Many countries around the world are financing household panels, including those given in the timeline of when panels started in Figure 1. Ordered by year of wave 1 panels in Figure 1 are: Panel Study of Income Dynamics (PSID, USA), Survey of Income and Program Participation (SIPP, USA), Socio-Economic Panel (SOEP, Germany), British Household Panel Survey (BHPS, United Kingdom), Russia Longitudinal Monitoring Survey (RLMS, Russia), Survey of Labour and Income Dynamics (SLID, Canada), Korea Labor and Income Panel Study (KLIPS, Korea), Swiss Household Panel (SHP, Switzerland), Household, Income and Labour Dynamics in Australia Survey (HILDA, Australia), European Union Statistics on Income and Living Statistics (EU-SILC, Europe), CASEN (CASEN, Chile), Longitudinal Internet Studies for the Social sciences (LISS, Netherlands), National Income Dynamic Study (NIDS, South Africa), Panel Analysis of Intimate Relationships and Family Dynamics (Pairfam, Germany), Understanding Society (USoc, United Kingdom). Many of these surveys are focused on income and labor. Longitudinal surveys may be especially useful and well-funded in these areas. For some of these panels, cross-national equivalence files that give cross walks from one data set to another exist [3].

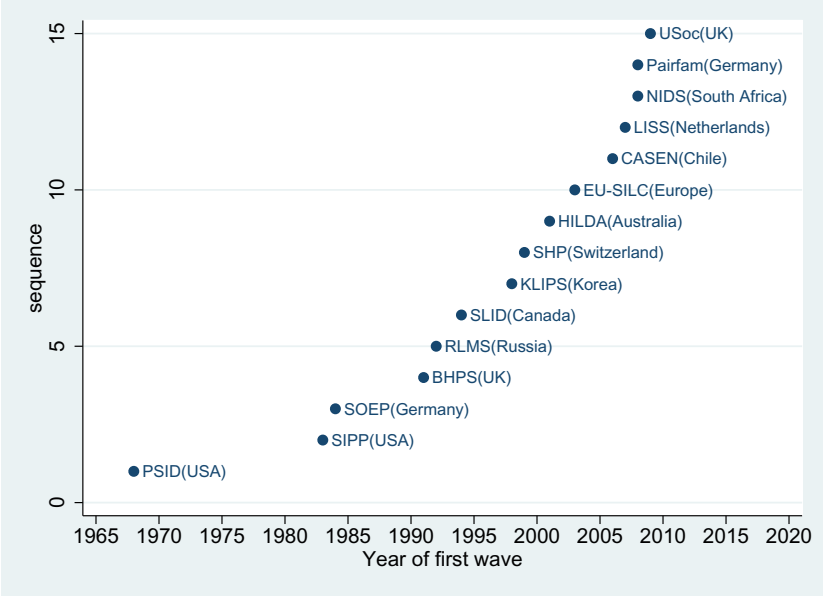

FIG 1. *Timeline of when major household panels conducted their first wave.*

Survey panels are also widespread in developing countries [1] though due to funding constraints many do not conduct interviews every year.

The primary aim of household panels is to provide data for longitudinal analysis. At the same time, there is also an interest in cross-sectional analysis at each wave. Household panels can produce cross-sectional estimates for both households and individual persons. To do so, household panels supply separate household and person level weights.

The initial (wave 1) sampling design selects a sample of households. This is typically done using a multi-stage sampling design. For example, the BHPS selected 250 postcode sectors from the postcode address file for Great Britain [24]. In the second stage, a systematic sample in each of the postcode sectors was selected. Respondents were recruited face-to-face. In countries where a postcode address file is not available, clusters of addresses can still be selected (e.g. based on zip codes). However, the final sampling stage would typically consist of a random route procedure. In a random route procedure interviewers approach every i^{th} (e.g. 7^{th}) household from a random starting point in the cluster. When an intersection in the road is reached, the decision to continue left or right is made based on a predetermined rule. This procedure was employed, for example, by SOEP (samples A "West Germany" and refresher samples E, F, H, J and K) [7]. While multi-stage sampling designs are typical, other designs exist. The sampling frame for the SHP consisted of people with a listed phone line (landline or mobile) in Switzerland [28].

The wave 1 sampling design determines the wave 1 sampling weights of households. Many household panels interview all adult household members in a sam-

pled household (including BHPS, CASEN, HILDA[1], KLIPS, SHP, SLID, SOEP, USoc; PSID is a notable exception; see [21]). If all household members are selected, the probability of a person being selected given that the household is selected equals 1. As a consequence, in wave 1 the selection probabilities and sampling weights of households and persons in that household are identical.

In subsequent waves all wave 1 household members are followed. However, a longitudinal household does not exist: household composition changes over time. We distinguish between panel members that were part of a wave 1 household and new household entrants who joined a household after wave 1. New household entrants include spouses/partners, roommates, new babies (who are eventually old enough to be interviewed) and adoptions. There is a need to collect information about new household members as such household members also become panel members, at least while they live in households with wave 1 panel members. When households split, panel designers need to decide whether to continue to follow panel members who were not part of wave 1. For example, this includes separating spouses who were not present in wave 1. Including former non-wave 1 spouses allows researchers to study the effect of divorce/separation. More generally, from a substantive point of view, following movers-out is desirable because in this case a more complete story about population dynamics can be told with the panel data. It also helps to maintain the sample size which is negatively affected by the cumulative impact of attrition. Similar arguments can be made for other entrant groups not present in wave 1. Disadvantages include problems with sampling weights which are discussed in Section 3.7 in the context of so-called orphan respondents. The policies governing which groups of cohabitants to continue to include in the panel are called the following rules [12, 21].

The target population gradually changes over time due to immigration, emigration, births and deaths. Emigration, births and deaths occur in the wave 1 sample and can be addressed. However, a changing target population due to immigration is more difficult to address because immigrants (after wave 1) had no chance to be selected in wave 1. Over time, the sampling frame from wave 1 will diverge from the target population, and this affects the credibility of cross-sectional estimates [30, p. 25–26]. The solution lies in refreshing the sample either by drawing a refresher sample at a later wave or by drawing a sample consisting only of recent immigrants.

Finally, we do not describe adjustments to design weights, including adjustments for nonresponse and post-stratification. In particular, selective attrition affects the sample composition. Selective attrition is a bigger problem in panels than selective non-response in cross-sectional surveys because of the cumulative effect over many waves. There is a rich literature on attrition in household panels [16, 25, 26] which we do not further address here.

While most panels follow at least wave 1 members indefinitely, some panels (e.g., SIPP, SLID, EU-SILC) are rotational panels in which a new panel is introduced each year to replace a fraction (e.g., one quarter) of the existing sample. Persons in each new panel are followed up until the new fraction is replaced

[1]For convenience, we refer to the "the HILDA Survey" simply as HILDA.

again (e.g., after four years). Because panel members remain in the panel only for a few years, the cumulative effect of attrition in rotating panels is less severe than in regular panels. This may make rotational panels more representative and therefore more suitable for cross-sectional analyses. The downside of the rotation is that longitudinal analyses at the individual level are limited to the length of the rotation. Even though they may be more representative, rotational panels have the same issues related to cross-sectional weights [27].

We compare the implementation of cross-sectional weights of several household panel surveys and in particular how each panel deals with new household entrants and households splits. Section 2 introduces the two most common approaches to cross-sectional weighting, shared weights and modeling. Section 3 contains a comparison of how these approaches are implemented in several large household surveys. Section 4 concludes with a discussion.

2. Cross-sectional weights for new household entrants

Panels are not only used for longitudinal analysis but also for cross-sectional analysis. This requires computing cross-sectional weights. Weights for wave 1 panel members can be derived from wave 1 selection probabilities as usual. However, it is less clear what to do with new household entrants that have arrived after wave 1. One option is to simply assign them weight zero. This is not desirable because it wastes data already collected: "cross-sectional analysis should use all available sample cases at the time concerned" [27].

The probability of selection for new household entrants depends on their household membership history over the life of the panel [22, p. 28]. However, the membership history of new household entrants prior to their entry is often unknown. For example, suppose persons A and B each were in separate one-person households during wave 1. Prior to the second wave persons A and B move in together and form a two-person household. Then there are two paths through which this household may be included in wave 2: by sampling person A or person B in wave 1 (or both). To properly compute the household weight for wave 2, one needs to compute the probability of sampling A or B in wave 1. Failure to make a correction would overstate the number of households with new entrants [29].

One approach is to estimate wave 1 selection probabilities which we call the modeling approach [4, p. 313]. A completely different solution is the shared weights approach [2] which can produce unbiased estimates. An estimate for the population total in wave t is given by

$$\hat{Y} = \sum_{i=1}^{N} w_i Y_i \tag{1}$$

where w_i is the weight of person i and N is the population size. Taking the expectation yields

$$E(\hat{Y}) = \sum_{i=1}^{N} E(w_i) Y_i \tag{2}$$

This estimate is unbiased if the weights are constructed such that $E(w_i) = 1$. Denote by I_i the random variable that indicates whether or not person i was sampled in wave 1. The standard way of constructing weights is to choose inverse selection probabilities as weights $w_i = 1/P(I_i)$ if person I_i was sampled in wave 1 and $w_i = 0$ otherwise. This fulfills the condition above because

$$E(w_i) = P(I_i)\,(1/P(I_i)) + (1 - P(I_i))\,0 = 1$$

Because persons are selected within households we need to compute the probability of selecting households. Further, if all members of a household are selected, then the probability of selecting a person equals the probability of selecting a household $P(I_i) = P(H_i)$. Sometimes more than one person moves as a unit (e.g., a mother with children moving together). A constituent household or a group of household entrants refers to entrants that moved together from their old household to the new household. The probability of selecting household H_i at wave t is the probability of selecting one or more constituent households:

$$P(H_i) = P(h_1 \cup h_2 \cup h_3 \cup \cdots \cup h_L) = 1 - (1 - p_1)(1 - p_2)\cdots(1 - p_L) \qquad (3)$$

where $h_1, \ldots, h_L$ are the constituent households in wave 1 which jointly form the new household at a later wave, and where $p_1, \ldots, p_L$ are the corresponding selection probabilities. In practice, there are usually only two constituent households because typically one man moves in with one woman (if either of them brings children or relatives, they would usually move as a unit from the same household). This simplifies equation 3 considerably:

$$P(H_i) = P(h_1 \cup h_2) = 1 - (1 - p_1)(1 - p_2) = p_1 + p_2 - p_{12}$$

Equation (3) assumes independence between the constituent households [10, Equation 3.3]. Overall, in our opinion, the independence assumption appears reasonable even though it might not hold in some instances, for example, because people who get married might be geographically clustered. The selection probability of the household that was in the original sample, p_1, is known but the selection probabilities corresponding to new entrant groups are unknown because they were not part of the original sample. In other words, the key problem is the wave 1 selection probabilities are only known for respondents that were actually sampled and not for those respondents that later joined into existing households.

At this point the modeling approach and the shared weights approach diverge. The modeling approach estimates the unknown probabilities based on a model from the known probabilities. The shared weights approach does not use inverse selection probabilities as weights and instead chooses a different weighting scheme that yields unbiased estimates.

2.1. The shared weights approach

Shared weights [2, 11, 14, 15] is a strategy for developing cross-sectional weights that only requires selection probabilities of individuals selected in the original

sample. The shared weights approach keeps the sum of individual weights within a household constant, redistributing the weights among the individuals as new individuals enter a household. Weight sharing assigns the weight of person i, w_i, $i = 1, \ldots, N$, as follows:

$$w_i = \sum_{j=1}^{N} a_{ij} u_j \tag{4}$$

where the u_j are the traditional Horvitz-Thompson weights, $u_j = 1/P(I_j)$, if individual I_j was in the wave 1 sample and $u_j = 0$ otherwise. The a_{ij} are arbitrary influence weights that sum to one: $\sum_{j=1}^{N} a_{ij} = 1$ and a_{ij} is independent of u_j. Then

$$E(w_i) = \sum_{j=1}^{N} a_{ij} E(u_j) = \sum_{j=1}^{N} a_{ij} = 1$$

which is the requirement for an unbiased estimate in (2). Equation (4) redistributes the Horvitz-Thompson weights u_j over the population. It implies that respondents who were not part of the wave 1 sample can receive a positive weight w_i. Rather than redistributing weights over the entire population one can restrict this redistribution to person I_i's household. Let the size of the household be n_h and $a_{ij} = 1/n_h$. Then for a given household

$$w_j = \sum_{j=1}^{N} a_{ij} u_j = 0 + \sum_{j=1}^{n_h} \frac{1}{n_h} u_j = \frac{1}{n_h} \sum_{j=1}^{n_h} u_j$$

This is called "equal person weight" or fair shares and is the method implemented in BHPS, EU-SILC [27], PSID [8], SHP (until wave 9), SLID [13], and SIPP. For example, if a single household member was part of the wave 1 sample then his or her weight is distributed evenly among all household members. If multiple household members were part of the wave 1 sample, then the sum of their weights is distributed evenly among all household members. Other weight sharing schemes exist [20] but are not used in practice.

Figure 2 illustrates the fair shares method with five different numerical examples. In the first example a respondent moves into a household with two wave 1 sample members. In wave 1 both respondents have the same weight by design. In wave 2 the weight is redistributed and the fair shares method ensures that the weight is the same across all household members. When the respondent leaves again in wave 3, the redistribution is undone.

In example 2 the household splits in wave 2 (indicated through a horizontal bar). When a new household member joins respondent 2 in wave 3, the weight is only redistributed in that household. In example 3 two one-person households who were both sampled in wave 1 merge. Note that the two respondents had different weights in wave 1 which are redistributed in wave 2. This also illustrates that weight sharing is applied to all households regardless of whether or not they contain members other than wave 1 members. Such an independent merge almost never occurs in practice. However, a merge of two households

	Wave 1	Wave 2	Wave 3	Wave 4
Example 1: move in/out	**2 person household**	**respondent 3 moves in**	**respondent 3 moves out**	
respondent 1	3000	2000	3000	3000
respondent 2	3000	2000	3000	3000
respondent 3		2000	0	0
Example 2: household split	**2 person household**	**split into separate households**	**respondent 3 moves in with respondent 2**	
respondent 1	3000	3000	3000	3000
respondent 2	3000	3000	1500	1500
respondent 3			1500	1500
Example 3: household merge of wave 1 households	**separate one person households**	**move in together**		
respondent 1	3000	2000	2000	2000
respondent 2	1000	2000	2000	2000
Example 4: death	**2 person household**	**respondents 3 and 4 move in**	**respondent 2 dies**	**respondent 1 died**
respondent 1	3000	1500	1000	dead
respondent 2	3000	1500	dead	dead
respondent 3		1500	1000	0
respondent 4		1500	1000	0
Example 5: birth	**2 person household**	**baby is born**	**15 or so years go by; grandma moves in**	**baby reaches minimum survey age**
parent 1	3000	3000	2000	2250
parent 2	3000	3000	2000	2250
baby		too young	too young	2250
grandma			2000	2250

FIG 2. *Illustration of the weight sharing method (Fair Shares approach) for 5 different examples. Weights are shown for each respondent across up to four waves. Respondents in each example are in the same household unless they are separated by a horizontal bar (examples 2 and 3).*

with weights can occur when a grown child moves out to attend college and then moves back in after a few years.

In the case of death (example 4), the design weight of the dead respondent is removed and redistribution of weights among the remaining respondents occurs. In the case of a birth (example 5), the newborn is assigned a weight once he/she reaches interview age. BHPS assigns at birth the average weight of the parents (3000), but other schemes exist. In the last column in example 5, the weight for the child (3000) is weight shared with all four household members. When respondents move out (example 1) or the only respondent with a weight (wave 1 respondents and their progeny) in the household dies (example 4), respondents

are left behind which cannot receive a weight based on the weight share method. We call these respondents orphan respondents and have listed their weight as 0 in Figure 2.

However, the shared weights approach requires that at least one wave 1 respondent (or their progeny) still lives in the household [11, p. 3-1, 6-1][17, p. 28]. This means that associated persons that leave a household — such as a spouse who joined the household in wave 2 and who later divorced and moved out — receive zero weight. This is unproblematic when only wave 1 sample members and their children are followed as is the case in BHPS[2]. This is not acceptable when wider following rules are adopted as is the case in the SOEP, HILDA, and the Swiss Household Panel (SHP) (after wave 9). The shared weight approach implies the sum of the individual weights remains constant over time except for additional weight due to new birth/adoption and recent immigrants. In practice, however, household weights vary from wave to wave because of corrections for nonresponse and post-stratification.

In Figure 2 in each wave no more than one change occurred between any two subsequent waves. Multiple changes may occur between subsequent waves and shared weights would be constructed accordingly.

To the best of our knowledge, all survey panels using shared weights survey all adult household members in a given household. This is not a requirement. If some household members are not interviewed, weights can simply be shared among those household members that are interviewed.

2.2. The modeling approach

Even though the wave 1 selection probabilities of entrants who enter in later waves are generally not known, it is possible to estimate them. We describe here the estimation procedure implemented in HILDA [30] and SOEP [7]; other approaches are possible. Both HILDA and SOEP use ordinary least squares regression with $logit(p)$ as a dependent variable, where p refers to the selection probability in wave 1. The independent variables consist of person-level characteristics of respondents for the wave for which weights are estimated. (For new entrants person level characteristics are only known for that wave). The independent variables are those thought to be linked to the probability of selection and response. For HILDA, these are region, age, sex, dwelling type, number of adults, number of children, marital status, whether a language other than English is spoken at home, employment status, country of birth, broad education level, relationship in household, and type of household change (i.e. split, merger, birth, death, other leaver) [30, pp. 17–18]. The regression model is estimated with wave 1 respondents only (since wave 1 selection probabilities of other respondents are unknown).

The model is then used to estimate wave 1 selection probabilities of new household entrants. Selection probabilities of new entrants are re-estimated for

[2]BHPS also follows parents of children who have at least one wave 1 parent. They are assigned a weight of zero when living in households without a weight to share.

every new wave. The SOEP regressions explain about 90% of the variation in $logit(p)$ ($R^2 = 0.9$) for early waves and about 50% of the variation ($R^2 = 0.5$) for recent waves. HILDA regressions typically explain between 20% and 30% of the variation in $logit(p)$. The R^2 values are not directly comparable as they refer to different sampling designs and nonresponse. Weights are computed as the inverse selection probabilities [9] which are derived from the regression results.

After estimating probabilities for constituent households using regression, the household selection probabilities as indicated in equation (3) are then computed. This is the approach HILDA [30] has taken. The approach taken in the SOEP [4] has two simplifying modifications. First, equation (3) is simplified by removing joint probabilities. Neglecting the joint probabilities, equation (3) can be rewritten as

$$P(H_i) = p_1 + p_2 + \cdots + p_k$$

Second, SOEP fieldwork does not allow differentiating between entrances from different households and groups of new entrants from the same household of origin. For example, if a mother and her grown child move into a respondent household, SOEP would approximate the selection probability as $p_1 + p_2 + p_3$ (probabilities corresponding to the original household, the mother and the child), whereas equation (3) implies $p_1 + p_2 - p_{12}$ (probabilities corresponding to the original household, the mother-child household, and the joint probability of selecting both households). The SOEP approach is less complex to implement in practice — which may make it less error prone.

3. Implementation of cross-sectional weights in survey panels

The two basic approaches to cross-sectional household weights outlined in the previous section have been implemented across a variety of household panel surveys. We consider the effect of new household entrants on both cross-sectional household and cross-sectional individual weights for several panels that reflect the range of approaches:

- The PSID [5, 19] began in 1968 as a representative sample of the US population and the households in which they reside. Just one person (head of household) is sampled per household. The PSID now covers roughly 9000 responding households in the USA.
- The German SOEP [7] began in 1984. Every adult household member is sampled. SOEP has roughly 12,300 responding households with 21,000 responding persons.
- The British BHPS [24] began in 1991. Every adult household member is sampled. The BHPS has roughly 4600 responding households with 8300 responding persons.
- The Swiss SHP [6] started in 1999. Every adult household member is sampled. SHP has roughly 7000 households with 18000 household members.
- The Australian HILDA [31] began in 2001. Every adult household member is sampled. HILDA has roughly 7200 responding households with 13300 responding persons.

TABLE 1
The effect of household changes on cross-sectional individual weights for different household panels. Notation: HH=Household, OSM=Original sample member

	BHPS	**SHP**	**PSID**	**HILDA**	**SOEP**
Method for computing weights	**HH weight := average of individual weights**	**HH weight := average of individual weights**	**HH weight := average of individual weights**	**individual weight := household weight**	**individual weight := household weight**
Method for assigning weight to new Entrants	**Weight Share**	**Weight Share**	**Weight Share**	**Modeling**	**Modeling**
Regular household entrants	down-weighted (shared among more people)	down-weighted (shared among more people)	down-weighted (shared among more people)	down-weighted (multiple paths of selection)	down-weighted (multiple paths of selection)
Immigrants	like regular household entrants	average of (individual) OSM weights	like regular household entrants	unchanged	like regular household entrants
Birth/ adoptions	receive average weight of parents	does not apply (panel is too young)	average weight of parents; if only one parent: 1/2 weight of head of household	receive household weight	receive household weight
Household split	zero in households w/o OSM or offspring, otherwise unchanged	zero in households without OSM, otherwise unchanged	unchanged (respon-dents w/o weight are not followed)	unchanged if all HH members are followed; otherwise recalculated	unchanged (weights are carried forward to new households)
Merging house-holds	unchanged	unchanged	unchanged	"unrelated merge": like regular household entrants	"move back merge": receive weight from new head of household
Death	unchanged for others	unchanged for others	unchanged for others	for others: OSM death unchanged; TSM death upweighted	unchanged for others

Tables 1 and 2 show the effect of the approaches on individual and household weights, respectively. BHPS, SHP and PSID use the weight share method. PSID has had less focus on cross-sectional weights and only started using shared weights recently [8]. SOEP and HILDA use the modeling approach.

TABLE 2
The effect of household changes on cross-sectional household weights for different household panels. Notation: HH= household, OSM = Original sample member, TSM= Temporary sample member

	BHPS	SHP	PSID	HILDA	SOEP
Regular household entrants	down-weighted (shared among more people)	down-weighted (shared among more people)	down-weighted (shared among more people)	down-weighted (accounting for multiple selection pathways)	down-weighted (accounting for multiple selection pathways)
Births/ adoptions	average is recomputed	does not apply (panel is too young)	average is recomputed	unchanged	unchanged
Immigrants	treated like other household entrants	unchanged	treated like other household entrants	unchanged	treated like other household entrants
Household split	average is recalculated	households without OSM: 0. Otherwise weight share	average is recalculated	unchanged if all HH members are followed; otherwise recalculated	unchanged (HH weight is carried over to new households)
Merging households	Average is computed for merged household	Average is computed for merged household	Average is computed for merged household	"unrelated merge" (like regular household entrants) and "move-back merge"	"move-back merge": former household weight of the new head of household is used
Death	OSM death: average is recalcu-lated. TSM death: up-weighted	OSM death: average is recalcu-lated. TSM death: upweighted	OSM death: average is recalcu-lated. TSM death: upweighted	OSM death: unchanged; TSM death: upweighted	unchanged

Table 1 further shows how individual weights are calculated from household weights and vice versa. For the two panels using the modeling approach (HILDA and SOEP), individual weights are derived from household weights. Because both panels select all adult household members, the selection probability of an individual is the same as the selection probability of a household. (In practice, due to individual nonresponse, individual weights may vary from household weights). The three panels using the shared weights approach (BHPS, PSID and SHP) compute the household weight as the average individual weight. For the BHPS, the average is computed over all household members, not just the wave 1 sample members. Because under fair shares all individuals receive the same weight, computing the household weight as the average individual

weight or setting the household weight equal to the individual weight are equivalent.

For discussing the effect of household entrants on weights, we distinguish between regular household entrants, recent immigrants and births/adoptions. Regular household entrants are those that are neither recent immigrants nor birth/adoptions.

3.1. Regular household entrants

When there are new household entrants, the individual weights and households weights of existing household members are down-weighted for both the modeling and the shared weights approach. For the modeling approach, the household weight decreases because multiple paths of entry increase the selection probability of the household (and individual household members). For the shared weights approach, the individual weights decrease because the sum of the individual weights remains by definition constant and the weight is shared among more people.

From wave 2 onward, there are unknown selection probabilities for household entrants. For both HILDA and SOEP, unknown selection probabilities are estimated via regression and used to compute the household weight. All individual weights are then derived from the (down-weighted) household weight, adjusted for attrition and post-stratified. Additional differences arise between HILDA and SOEP in their approach to modeling attrition. Briefly, HILDA models attrition from wave 1 to wave t rather than wave by wave like the SOEP.

3.2. Births and adoptions

Births and adoptions refer to individuals born or adopted after wave 1. By definition, such persons could not have been sampled in wave 1. They represent the changing target population — the part of the population that did not exist in wave 1 — and are not treated like regular entrants. Instead they are given additional weight once they are old enough according to the definition of the target population (also see example 5 in Figure 2).

In the modeling approach, individual weights for births/adoptions are typically set to the household weight. However, unlike for regular entrants, the household weight does not decrease. In the shared weights approach, births/adoptions are also assigned additional weight. The BHPS assigns the average individual weight (not the shared weight) of the parents to births/adoptions. If only one parent is a sample member, that child receives only half that weight [24, p. A5-9]. The PSID also assigns the average individual weights of the parents to births/adoptions, unless only one parent lives in the household. In this case, birth/adoptions are assigned half that weight.

The SHP has not yet set rules for this issue because the children born into the panel are still too young to be interviewed. For the modeling approach, the household weights remain unchanged. For the BHPS and for the PSID,

average household weights are recomputed. For the BHPS, a birth can lead to an increased household weight. Suppose there is a 3 person household: two wave 1 parents with weight 10 each and a grandmother who moved in after wave 1. A child is born and receives the average parent weight (10). The household weight before the birth was $20/3 = 6.7$, the household weight after birth is $30/4 = 7.5$. Understanding Society (USoc), a large recent longitudinal panel of the United Kingdom (co- located with the BHPS whose sample became part of USoc) [18], implements an alternative strategy of assigning weights to children. The expected number of children of two wave 1 respondents who marry spouses outside of the panel is twice as large as the expected number of children of two wave 1 parents. This may lead to an underrepresentation of children of wave 1 parents. USoc assigns positive weight only to children where the mother was a wave 1 sample member, and zero weight to other children.

3.3. Recent immigrants

Recent immigrants are individuals who have immigrated into the target population after wave 1 of the survey. They are not necessarily all foreign nationals. For example, a German employee of a multinational company might be posted for a couple of years in another country. If wave 1 of a panel survey is conducted while the German employee is abroad, on his/her return the employee would be considered a recent immigrant to Germany. Likewise, many European students now study at least one term abroad. If wave 1 occurs during that term abroad they would be considered recent immigrants on their return. If wave 1 occurs before they leave their home country, they would not be a considered recent immigrants. However, in practice such people are not typically identified. When a new person joins a household, data collected in existing panels only identify foreigners moving into the country but not returning nationals.

Both recent immigrants and births represent groups of new entrants that could not have been sampled in wave 1. In principle, new entrants also include people that were not included in the sampling frame for other reasons, such as people in newly built housing units. In practice, imperfections in the sampling frame must be ignored. Because they represent the change in the target population from wave 1, recent immigrants should be treated differently than other panel entrants. However, except for HILDA and SHP, panels treat immigrants just like other panel entrants.

In HILDA, when an immigrant joins a household, the household weight remains unchanged (for a regular entrant the household weight decreases). Therefore, individual weights of all household members are unchanged also (for a regular entrant, individual weights of all household members decrease) and, as with all other household members, the immigrant's weight equals the household weight. In SHP, when an immigrant joins a household, individual weights of existing members remain unchanged (for regular entrants, individual weights decrease). The recent immigrant is assigned the average weight of the original sample members in the household [28, Section 4.2.3b]. The SHP defines the tar-

get population to exclude households composed exclusively of recent immigrants [6, p. 19].

The SOEP and PSID panels contain a special refresher sample consisting exclusively of immigrants. Recent immigrants (into existing households) outside this refresher sample are treated like any other household entrant. To the extent that panels like SOEP and BHPS do not treat recent immigrants differently from regular household entrants, we attribute this to the difficulty and the additional burden of distinguishing between recent immigrants and regular household entrants. The bias introduced by not treating recent immigrants differently is also reduced by calibration or post-stratification.

3.4. Deaths and emigration

Dead panel members are removed from the panel. In SOEP, the weights of surviving household members do not change (except indirectly in a calibration or post-stratification step). In HILDA, the household weight is re-computed without the dead household member. Individual weights are also affected because individual weights equal household weights. For example, if a wave 1 sample member moves in with a partner in wave 2, and that partner dies in wave t, the wave t household weight reverts to the wave 1 weight. A second example: if two wave 1 members (who were living in the same household in wave 1) move in with a third person in wave 2, and one of the wave 1 members subsequently dies, the weights are unchanged after the death. Emigration is treated like death.

In the panels that use weight sharing, individual weights do not change. However, household weights which are computed as the average of individual weights may change. Respondents with a non-zero weight are wave 1 respondents and births/adoptions (and recent immigrants in the SHP). If a household member with zero weight dies the household weight is not affected. If a household member with non-zero weight dies, the household weight may increase or decrease, depending on whether the weight of the original member was smaller or larger than the household weight.

So-called following rules determine whether respondents are re-interviewed in a subsequent survey wave after leaving a household [21]. For all panels, if the last household member who is followed dies, the household is removed from the sample. Because SOEP is the only panel among these five panels that follows all respondents regardless of the presence of a wave 1 or other sample members a death in the SOEP panel never leads to the removal of other household members in subsequent survey waves.

3.5. Household splits

A household split occurs when one or more members of a household leave a household (e.g., grown child, divorced spouse) and form a separate household. In the shared weight approach individual weights (not shared individual weights) remain with the individuals as they move to form new households. For example,

suppose a wave 1 couple each with individual weight 10,000 separates, and the wife moves in with a new partner. Both respondents retain their individual weight of 10,000. The shared weight of the husband –now in a single household– remains 10,000 whereas the (fair shares) shared weight of the wife and her new partner is 5000 each. The weight of all other respondents is zero and their zero weight is carried forward to the new household. Therefore, the shared weight approach does not work well when members with zero weight are followed.

In SOEP, all newly formed households receive the same weight as the existing household. In case there are new household members (e.g., a new partner of a divorced respondent), the new member's probability of selection is modeled and the household weight is computed as for a regular household entrant. As before, individual weights are derived from household weights. In HILDA, if all respondents are followed in their new households, newly formed households also receive the same weight as existing households. HILDA does not follow some groups (e.g., a relative who moves in after wave 1 and subsequently moves out again) [21]. If some of the household members during a household split are not followed, weights are recalculated for the remaining household members. For example, suppose a wave 1 household consists of one woman. In wave 2 her cousin moves in and the cousin moves out by wave 3. The household weight is recalculated in wave 2 to account for multiple paths of selection. In wave 3 it is recalculated again and reverts to the wave 1 weight.

3.6. Household mergers

Our comparison revealed two different approaches under the label of "household merger". On closer inspection, they turned out to correspond to two types of household mergers: 1) unrelated merge: two or more unrelated sample households merge 2) move-back merge: two or more households re-merge after having formed a single household at some earlier time during the lifetime of the panel. For example, a grown child moves out of his/her parents' home to go to college. After college, the grown child moves back in with his/her parents.

For the modeling approach, the unrelated merge is treated just like regular household entrants with the one difference that the selection probabilities in equation 3 are known and need not be estimated. This type of merger is rare but has occurred in and is implemented in HILDA.[3] The second type of merger is different in that the selection probability of a household does not change as the grown youngster moves back into the parent household. SOEP uses the former household weight corresponding to the new head of household (in SOEP, the head of household is the person who fills out the household questionnaire). HILDA also reverts to the former household weight. This type of merge is relatively rare especially for the SOEP where it has occurred less than 20 times in 28 waves. For the shared weights approach this issues does not arise because the household weight is derived from individuals (rather than the other way around).

[3]This type of merger has occurred in SOEP but is currently not treated as such.

3.7. Weights of orphan respondents in the shared weights approach

The shared weights approach is only applied as long as at least one person with a sampling weight (wave 1 members, births and recent immigrants[4]) remains in the household [17, p. 28]. We call respondents in households without a person with a sampling weight orphan respondents. If a panel using the shared weights approach chooses to follow respondents without sampling weights (e.g., spouses/partners who moved in after wave 1), those respondents are not assigned a shared weight when they move out (e.g., due to divorce/separation) by themselves. (If they move out with a child that has a sampling weight, the shared weights approach works fine.) This is not problematic as long as panels using the fair shares approaches do not follow household members without a sampling weight. For the most part, the surveys considered here using the weight share method do not follow people without a weight, however the BHPS makes one exception to this by following parents of newborns and from wave 9 the SHP started following people without a weight after they expanded their following rules. For the BHPS this means if a wave 1 mother gives birth to a child and the father subsequently moves out, the father is followed regardless of whether he has a weight. Such cases are presumably relatively rare.

The Swiss household panel changed the following rules in wave 9 and now follows everyone (spouses, roommates, relatives, etc.) [28, Section 2.3.2]. This creates a problem for the shared weights approach to cross-sectional weights. The option of assigning zero weight to orphan respondents is not appealing because it wastes data already collected and reduces the sample size.

A second option is to adopt a hybrid approach in which shared weights continue to be used except for new orphan respondents. Weights for new orphan respondents are estimated separately using the modeling approach. That is, a model for the probability of selection in wave 1 is estimated via a regression model with wave 1 respondents. The model can then be used to predict selection probabilities of orphan respondents. Selection probabilities of orphan respondents need only be computed once when they first become orphan respondents. Subsequently, they are no longer orphan respondents and the shared weights approach can be applied. As always, weights have to be rescaled to yield the right population total. The advantage of this hybrid approach is threefold: (1) it solves the problem of orphan respondents, (2) it allows for a smooth transition when following rules are expanded like in the Swiss household panel (as compared to switching completely to a modeling approach), and (3) potential bias and variability due to the model-based estimation are restricted to orphan respondents only.

3.8. Effect of refresher samples on weights

As panel surveys age, they sometimes include a refesher or boost sample to keep the sample representative for cross-sectional analyses. Usually the sam-

[4]The SLID panel does not assign weights to births and recent immigrants because it is strictly focused on wave 1 respondents for longitudinal analysis [14].

ples are integrated or combined after applying the modeling or weight share approaches. SLID is an exception and combines the samples before applying shared weights [13].

For the shared weights approach, a refresher sample has no effect on cross-sectional weights of existing panel members. Weights are shared in existing households and a refresher sample adds new households. Whether the samples are combined before the weight sharing (e.g., SLID) or afterwards does not matter.

For the modeling approach, a refresher sample does not affect weights as long as the regression models that estimate unknown weights are based on the original sample only rather than on the combined sample. This is true for HILDA [30] and for the SOEP. A SOEP technical report suggests that an overall estimate for multiple samples should be a weighted combination of the individual sample estimates [23, Section 3].

However, a refresher sample will affect any subsequent post-stratification weights. To the extent that the refresher sample better matches the distribution of post-stratification variables, a refresher sample would mitigate the effect of post-stratfication on the existing sample.

4. Discussion

In household panel surveys the selection probabilities of new household entrants after wave 1 are generally unknown. We have discussed two common approaches to cross-sectional weights, shared weights and modeling addressing this issue. The shared weights approach is limited in that it excludes orphan respondents, i.e. it requires the presence of one sample member with a weight in the household. This is problematic when the panel follows household members who moved in after wave 1 (such as spouses or partners) who later leave the household (e.g., divorce/separation). We have proposed a hybrid shared weights approach that models the selection probability of orphan respondents separately when they become orphans. While this appears to have some advantages, empirical work is needed to evaluate this procedure in practice. More generally, empirical work is needed to examine the differences in cross-sectional weights betweeen the modeling and shared weights approaches and to what extent this affects estimates in practice.

The comparison of approaches to cross-sectional weights has identified similarities and differences between the two approaches and their implementations. When regular entrants join a household, the cross-sectional weights of existing household members decrease for both approaches. There are two different types of household mergers which we have termed the move-back merge and the unrelated merge, the rare merge of two unrelated sample households. Some panels do not distinguish between recent (after wave 1) immigrants and regular household entrants. The administrative burden of distinguishing between recent immigrants and regular respondents is high relative to the potential number of recent immigrants. There are some differences in how weights are assigned

to children of wave 1 respondents. Because the household weight in the shared weights approach is an average of individual weights, some differences in the calculation of cross-sectional household weights arise between the shared weights and the modeling approach as the household composition changes (death, merging households, household split).

We have addressed cross-sectional weights in longitudinal panels. Like all weights, cross-sectional weights are modified to account for item non-response and attrition, and are often subject to post-stratfication. In "fair shares" all household members start with the same weight, but the various adjustments inevitably lead to unequal weights within household. More empirical work is needed to discern whether such adjustments affect the shared weights and the modeling approach differently.

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