Conditional wealth to estimate association of wealth mobility with health and human capital in low- and middle-income country cohorts

Jithin Sam Varghese

Emory University

Clive Osmond

University of Southampton

Aryeh D. Stein (✉ aryeh.stein@emory.edu)

Emory University

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Abstract

Temporally harmonized asset indices allow the study of changes in relative wealth (mean, variance, social mobility) over time. Conditional measures are the unexplained residuals of an indicator regressed on its past values. Using such measures, previously used to study the relative importance of key life stages for anthropometric growth, we can identify specific life stages during which changes in relative wealth are important. We discuss the assumptions, strengths and limitations of this methodology as applied to relative wealth. We provide an illustrative example using a publicly-available longitudinal dataset and show how relative wealth changes at different life stages are differentially associated with body mass index in adulthood.

1. Introduction

Wealth is a robust measure of socio-economic position where individuals are vulnerable to economic shocks from unemployment and lack of social safety nets (1). Asset-based indices have been widely used in national, sub-national and community surveys as proxies for household wealth and material wellbeing, due to their relative ease of data collection and computation. Typically, household asset indices are estimated as the first principal component of a dataset comprising of a household's possession of durables (assumed public goods), housing characteristics, and public utilities (2). In societies where food expenditures constitute a minority of total expenditure and where households do not experience transitory shocks to expenditure, household asset indices are correlated with non-food expenditures (3, 4). Asset indices as measures of wealth have several limitations. First, asset indices are usually estimated from an instrument that ascertains possession of a restricted number of contextually relevant assets. Thus, asset indices may not capture non-asset wealth (such as savings or financial instruments) nor the quantity, quality, functioning, availability of substitutes and technological generation of these assets. Second, the distribution of asset indices may not reflect the true distribution of wealth due to issues of clumping (many households having the same value of the index) and truncation (failure to differentiate households at the ends of the distribution) (5). Third, asset indices may include community infrastructure items that display an urban bias (4, 6–10). To address this issue, methodologists have suggested creating urban and rural indices separately (1). Despite these and other criticisms, asset indices are a reliable marker of one's societal standing in countries where many individuals do not have access to basic goods and services (1, 11).

A longitudinal measure of wealth is useful if it could describe both individual and population level characteristics of wealth distribution over time. Although both cross-sectional asset indices for birth cohorts as well as harmonized asset indices for serial cross-sectional studies are useful in their own right, a temporally-harmonized asset index allows us to examine distributional characteristics beyond these indices (Table 1). The application of the methodology to create cross-sectional indices for cohort studies, as proposed by Filmer and Pritchett, may provide an opportunity to examine redistribution in relative position (change in rank) but cannot capture mean changes in wealth, changes in asset inequality or magnitude of redistribution of relative position (2). This is because, firstly, such indices are standardized

to zero mean and unit variance. Secondly, a unit change may have different interpretations between two cross-sectional study waves due to differences in asset loadings. However, application of methods previously used for serial cross-sectional data to longitudinal data may allow us to study other properties of wealth over time. We review these methods (Section 2), define the characteristics of wealth distributions (Section 3) and extend the temporally harmonized index to explain relative wealth mobility over time in cohort studies using conditional measures in later sections.

Table 1
Comparison of approaches and their relative contributions

	Study type	Change in mean wealth	Change in individual wealth	Change in asset-based inequality	Change in individual's relative position	Magnitude of change in individual's relative position
Cross-sectional asset index (independent construction)	Serial cross-sectional surveys	No	No	No	No	No
	Cohort	No	No	No	Yes	No
Harmonized asset index (pooled construction)	Serial cross-sectional surveys	Yes	No	Yes	No	No
	Cohort	Yes	Yes	Yes	Yes	Yes

2. Cross-sectional And Temporally-harmonized Asset Indices

2.1 Serial cross-sectional studies

Asset indices, as originally developed, can reliably measure one’s relative position at a single point in time, but by nature of their construction can capture neither a change in asset scores nor a change in asset-based inequality in populations. To address these issues, efforts have been made to harmonize asset indices to compare relative wealth between or within countries using cross-sectional data (10, 12). The International Wealth Index (IWI) is the first component of a PCA applied to data on 12 standard items (seven consumer durables, three housing characteristics, two public utilities) in 165 cross-sectional surveys from 97 countries. The IWI demonstrates an increase in mean wealth over time, and is robust to dropping assets and surveys. The Comparative Wealth Index (CWI) uses as an anchor a reference survey (Vietnam 2002 DHS in the original paper) to compute the relative position of households in space and time (13). The Absolute Wealth Estimate (AWE) uses the asset index, national GDP per capita and a measure of inequality to compute a household’s income based on their relative position on the asset index (14).

Asset indices created using different dimensionality reduction techniques (PCA, exploratory factor analysis, multiple correspondence analysis, categorical PCA) may vary in their estimate of wealth even after standardization to unit variance. However, these indices are often rank correlated (10), signifying the importance of sensitivity analyses using alternate methodologies while dealing with estimates of small magnitude for association of asset indices with health.

2.2 Longitudinal studies

Previous methodological approaches used to compare cross-sectional studies of populations over time do not permit an exploration of individual wealth trajectories, but could be extended to longitudinal studies. As an example, using five longitudinal birth cohorts, we previously constructed temporally-harmonized indices from a common set of contextually-relevant assets and polychoric PCA, separately for each cohort, using an approach similar to the International Wealth Index (15). Similar to harmonized indices from serial cross-sectional studies, temporally-harmonized indices allow us to quantify mean gains in wealth and changes in variance of wealth distribution over time. However, temporally-harmonized indices additionally allow us to identify the changes in individual level wealth, magnitude of changes in relative position and relative importance of wealth at different life stages for later-life outcomes. Others have used similar approaches to track material standards of living, and relative distribution of wealth (16–19). The harmonized indices for the birth cohorts were robust to dropping assets and study waves, were correlated with cross-sectional or region-stratified (by urbanicity) indices, and were rank correlated with indices constructed using alternate dimensionality reduction techniques (PCA, EFA, MCA).

3. Changes In Wealth, Asset Inequality And Relative Position

We define the key characteristics of the wealth distribution for a longitudinal study as follows for an individual 'i' at two time points 't'. First, a positive change in wealth for the population (Eq. 1) and an individual (Eq. 2) are reflected as an increase in the factor score of the temporally-harmonized asset index. This could be either due to an increase in number of assets that load positively or accumulation of higher value assets. Second, an increase in asset-based inequality is equivalent to a positive difference in the relative variance (Eq. 3; fraction of variance attributable to each time point) between study waves of the longitudinal cohort as defined by McKenzie et.al. (20). Third, the net relative position (Eq. 4) for individuals in the cohort is zero since the cohort is closed. We define the following quantities:

Change in mean wealth: $E[w_{i,t=2}] - E[w_{i,t=1}]$ [1]

Change in individual wealth: $w_{i,t=2} - w_{i,t=1}$ [2]

Change in asset-based inequality: $\sqrt{\frac{\text{Var}[W_{t=2}]}{\sum \text{Var}[W_{t=T}]}} - \sqrt{\frac{\text{Var}[W_{t=1}]}{\sum \text{Var}[W_{t=T}]}}$ [3]

Change in relative position for an individual: $\text{Rank}(w_{i,t=2}) - \text{Rank}(w_{i,t=1})$ [4]

Harmonized asset indices created from serial cross-sectional surveys have demonstrated an increase in mean wealth over time in low- and middle-income countries (5). Results using a temporally harmonized index constructed using polychoric PCA from China Health and Nutrition Survey showed a consistent increase in mean wealth over time while asset-based inequality trended upward from 1989, similar to consumption inequality in a cohort of 4400 households, with a peak in 2000 (21). Asset-based inequality subsequently decreased, driven by a decline in inequality among urban households. Consistent with a methodology proposed earlier by McKenzie (2005) that considered the lack of scale invariance for PCA-derived indices, that study partitioned the total temporal variance into variance by study wave (20). A comparative cross-sectional analysis of Demographic and Health Surveys estimated Gini coefficients for asset-based inequality using an index similar to the International Wealth Index (22). A study using pooled cross-sectional surveys from South Africa identifies issues while computing asset-based inequality using the McKenzie approach and indices created from a PCA, including how rare assets may distort index estimation and negative loadings on the index (from negative correlation of assets) that may not satisfy axioms of inequality analysis (10). The authors propose using an uncentered PCA (UPCA) that does not produce such loadings and inspecting the joint distribution of assets before any substantive analysis.

4. Conditional Wealth: Magnitude Of Change In An Individual's Relative Position

4.1 Conditional measures versus adjusting for exposure

An 'unexplained residuals' (UR) modeling framework allows examination of the association of several measurements of an exposure and their relative importance over time with the outcome (23). These measures are often operationalized as residuals from a linear regression. However, one could use non-linear approaches to estimate conditional measures while compromising interpretability as residuals absent of correlations with all previous measures of wealth. The below equation (Eq. 5) describes the mathematical quantity of conditional measure ($c_{i,t}$) for an exposure ($w_{i,t}$) as the difference beyond what is predicted by previous measures of the exposure from time 1 to $t-1$.

$$c_{i,t} = w_{i,t} - \hat{w}_{i,t} = w_{i,t} - f(w_{i,1}, w_{i,2}, w_{i,3}, \dots, w_{i,t-1}) \quad [5]$$

We demonstrate the use of conditional measures with a simple example using two time points ($t = 1, 2$) and exposure $w_{i,t}$ measured at time 't' for individual 'i'. A fixed effects approach for repeated measures of the exposure is provided in Eq. 6. The conditional measures approach is provided in Eq. 7. Previous research has demonstrated how both models are equivalent for w_2 such that $a_2 = a'_2$ (23). However, $a_0 \neq a'_0$ and $a_1 \neq a'_1$, leading to debates (see Section 8. **Limitations of the approach**) over the relevance of the anchor measure (w_1 in our case) that is used as the predictor for other measures (such as w_2), rendering it different from the fixed effects approach with repeated measures of the exposure.

$$E[y_i] = a_0 + a_1 E[w_{i,1}] + a_2 E[w_{i,2}] + \text{Covariates} [6]$$

$$E[y_i] = a'_0 + a'_1 E[w_{i,1}] + a'_2 E[c_{i,2}] + \text{Covariates} [7]$$

4.2 Conditional growth

Conditional measures have been used to study the relative importance of anthropometric growth during different life stages for adult outcomes. Positive conditional growth is a marker of faster than expected anthropometric growth. In a model to predict a later life outcome, conditional growth at each life stage has a direct interpretation, since it represents growth during a specific interval (24). For example, conditional length in first 2 years has been associated with adult height, while conditional weight between 2 and 5 years has been associated with adult BMI (25). Other studies have shown differential associations of conditional measures of growth with IQ, blood glucose, blood pressure and offspring growth (25–28).

4.3 Conditional wealth

We extend the conditional growth model to a measure derived from asset-based indices, which we call a conditional asset index. We henceforth refer to it as conditional wealth given that asset-based indices are a proxy for wealth in LMICs. Similar to conditional growth, conditional wealth would allow us to identify stages in the life course at which changes in wealth beyond that predicted by past measures of wealth are differentially associated with health outcomes. This is especially important as LMICs experience slow economic growth, high or rising wealth inequality, and intergenerational social persistence to identify sensitive periods when relative social mobility (positional mobility) is important. The importance of positional mobility assumes that relative position in the wealth hierarchy matters.

We propose that conditional wealth ($c_{i,t}$) for a life stage 't' and individual 'i' is the difference in wealth in that life stage from that which could be predicted by all prior individual measures of wealth and the overall wealth trajectory of the population under study (Eq. 8). For our previous example with two time points, which could be extended to more than two time points, where $g(w_{i,1}) = \hat{w}_{i,2}$, we propose:

$$w_{i,2} = g(w_{i,1}) + c_{i,2} [8]$$

Conditional wealth is the unexplained residual of the regression of wealth at time 2 as the dependent variable on all previous measures of wealth (in this case time 1) as linearly associated independent variables (Eq. 9).

$$w_{i,2} = b_0 + b_1 w_{i,1} + c_{i,2} [9]$$

$$\text{such that } E[c_{i,2}] = 0; \text{Var}[c_{i,2}] = \sigma^2_{t=2}$$

Re-writing Eq. 9, we define conditional wealth as the magnitude of change in relative position for an individual: $c_{i,2} = w_{i,2} - [b_0 + b_1 w_{i,1}]$. The above example could be extended to more than two time points

easily and we demonstrate the same empirically in Section 7.4.

A previous study by Arnold et. al. has clearly demonstrated appropriate confounder adjustment mathematically and using causal diagrams for conditional measures (or unexplained residuals) (23). Arnold et. al. recommend adjustment for confounders at both stages, i.e. during construction of conditional measures and during estimation of association with outcomes (Eq. 10). The conditional wealth derived using the Arnold et. al. approach would then be uncorrelated with previous measures of wealth and with the confounders (23). Assume X_1 is a predictor of wealth at time 1 (e.g. maternal schooling), and X_2 is a predictor of conditional wealth, and is partly predicted by w_1 (e.g. attained schooling). A directed acyclic graph (DAG) for how wealth, conditional wealth, schooling and outcome are related is provided in Fig. 1. The outcome regression as per Arnold et. al. (Eq. 11) is fit with the anchor measure, confounders, and conditional wealth.

$$w_{i,2} = b'_0 + b'_1 w_{i,1} + b'_2 X_{i,1} + b'_3 X_{i,2} + c'_{i,2} \quad [10]$$

$$E[y_i] = a'_0 + a'_1 E[w_{i,1}] + a'_2 E[X_{i,1}] + a'_3 E[X_{i,2}] + a'_3 E[c'_{i,2}] \quad [11]$$

We deviate from the approach by Arnold et. al. during the first stage (using Eq. 9) since we are interested in understanding the 'absorbed effect' of omitted predictors (Eq. 12) on the conditional measures (23). In this case, absorbed effect refers to the variability in conditional wealth explained by predictors of conditional measures, where $u_{i,2}$ is the error term when predicting conditional wealth.

$$c_{i,2} = d_0 + d_1 X_{i,1} + d_2 X_{i,2} + u_{i,2} \quad [12]$$

A path analysis approach (Fig. 1A), where all past measures of the exposure and other covariates are predictors of the exposure at time t , is equivalent to the conditional measures approach (Fig. 1B). Studies estimating the association of conditional wealth with health outcomes should adjust for the first (or anchor) measure of wealth, life course covariates and past measures of conditional wealth, but not for any other wealth measure. Our final outcome regression (Eq. 13) would yield equivalent regression coefficients (i.e. $a_1 = a'_1$, $a_2 = a'_2$ etc.) as Arnold et.al (Eq. 11).

$$E[y_i] = a_0 + a_1 E[w_{i,1}] + a_2 E[X_{i,1}] + a_3 E[X_{i,2}] + a_3 E[c_{i,2}] \quad [13]$$

Given these estimates, our approach is intended to understand how one could intervene on conditional wealth, while at the same time get unbiased estimates of relative position effect on the outcome after appropriate confounder/covariate adjustment. Studies estimating the association of early life variables on conditional wealth should not adjust for the anchor measure since it is assumed to be uncorrelated with the conditional wealth measure (**Supplementary Fig. 1**). There is no covariance between the anchor measure and a predictor of conditional wealth (say X_2) that also covaries with conditional wealth. For example, only the component of attained schooling, say from an intervention such as mandatory schooling, which doesn't depend on early life wealth predicts conditional wealth. Conditional wealth is, in effect, a decomposition of current wealth into explained and unexplained components that are

uncorrelated with each other. Conditional wealth is therefore the magnitude of change in relative position for an individual.

4.4 Conditional wealth versus adjusting for wealth

An advantage of adjusting for conditional wealth over adjusting for wealth at different time points is in ease of interpretability. The coefficient for conditional wealth could be interpreted as the independent contributions of extraneous variations in wealth, resulting in positional mobility, to health disparities. While similar in magnitude, the coefficient for the concurrent wealth variable may alternately be interpreted as the contribution of wealth after adjusting for previous measures of wealth and other covariates.

While reporting the association of conditional wealth and other variables, one should report both (a) the predictors of conditional wealth at a life stage, and (b) the associations of conditional wealth with the health outcome after adjusting for the predictors of conditional wealth that are confounders of conditional wealth and health association. Moreover, one should check if the harmonized wealth measures used to create conditional wealth are suitably distributed continuous variables such that linear regression is an appropriate model formulation.

5. Assumptions For Conditional Wealth

We first state the assumptions for the temporally harmonized index for individuals.

1. Household assets, housing characteristics and public infrastructure items included are public goods, i.e. access by one family member does not prevent the access or availability of others.
2. Household wealth reflects an individual's standard of living. The harmonized index increases with increase in real and asset-based wealth.
3. Asset loadings on the harmonized index are similar over time, i.e., the relative importance of assets as indicators of household wealth are similar over time.
4. Rankings of households is similar between harmonized index and cross-sectional index for any study wave
5. Criterion validity: Positively associated with other measures of socio-economic position such as schooling, subjective social status and income
6. The harmonized index can distinguish household wealth over the range of the index
7. The harmonized index can distinguish household wealth at extrema of distribution (between poor and very poor, between rich and very rich)

The latter two assumptions (clumping and truncation respectively) could be observed from exploratory plots, but are not verifiable due to the absence of a gold-standard marker of wealth.

We now state the following assumptions for conditional wealth to be a valid measure of magnitude of change in relative position beyond that predicted by past measures of wealth.

1. *Temporal consistency*: One unit change in conditional wealth should be interpretable in the same scale at different study waves

2. *Appropriate model specification*: The model for creating conditional wealth (as unexplained residuals) is specified correctly, such that residuals are independently and identically distributed, and free of heteroskedasticity.

3. *Appropriate interval selection*: Conditional wealth should have variance. Canalization of wealth, i.e., high rank correlation between successive time points, would lead to low variance in conditional wealth.

6. Conditional Wealth And Changes In Wealth, Asset Inequality And Relative Position

Negative conditional wealth does not imply that an individual's wealth decreases. Also, positive conditional wealth does not necessarily imply that an individual's wealth increases. As shown in Fig. 2 (additional examples in **Supplementary File 2**) for three example individuals at two time points, mean wealth increases in panels A to D, and decreases in panels E to H. Conditional wealth at time 2 is the vertical distance between the individual trajectory (solid line) and predicted trajectory of each individual based on the cohort (dashed line). For example, in panel A, conditional wealth at time 2 is positive for individual 1, zero for individual 2 and negative for individual 3. In panel D, although the conditional wealth for individual 1 is negative, their overall wealth change is positive due to the large mean change in wealth.

A change in wealth inequality occurs if difference in variance between the two time points is non-zero. Variance of wealth at time 2 consists of explained and unexplained (conditional wealth variance) components as described in Eq. 9. When mean wealth increases, inequality (variance of wealth at time 2) may increase, decrease or stay the same as shown in panels A to C. Similarly, when mean wealth decreases, inequality may increase, decrease or stay the same as shown in panels E to G. The change in inequality depends on the magnitude of slope and variance of conditional wealth.

In all panels except B, C, F and G, the relative position of different individuals stay the same – implying no positional mobility, i.e. change in individuals' relative positions. Panels C and G signify an unusual case when the bottom and top ranked individuals switch places under a case of no change in wealth inequality but changes in mean wealth (increase for panel C, decrease for panel G). One can imagine scenarios when positional changes occur under increasing and decreasing (such as panels B and F) wealth inequality.

An individual with positive conditional wealth is more likely than someone with zero or negative conditional wealth to move up the ranks of wealth. Whether or not they move up or down the ranks depend on their initial wealth relative to mean initial wealth and their conditional wealth relative to predicted change in wealth. However, an important takeaway is that the proportion of variance in wealth at time 2 that is conditional wealth variance explains the extent of positional mobility. Since $(\mathbf{w}_{i,2} = b_0 + b_1 \mathbf{w}_{i,1} + \mathbf{c}_{i,2})$, if b_1 is non-zero, then conditional wealth variance is less than variance of wealth at time 2. If past wealth is unable to explain future wealth (i.e. $b_1 \approx 0$), then positional mobility is high. In a context of rising inequality and no positional mobility, the share of variance unexplained by past wealth may be zero. In such a case, conditional wealth is also zero by virtue of how it is constructed. In such a context, relative social mobility (positional mobility) is non-existent. Associations with health, under a framework where only relative position matters for health, would therefore be entirely explained by past wealth.

7. Illustrative Example Using Conditional Wealth

7.1 Study Population

We used publicly available data from the Cebu Longitudinal Health and Nutrition Survey (CLHNS) – a cohort of women and children in the Philippines (29). The data were downloaded from the Carolina Population Center Dataverse (<https://dataverse.unc.edu/dataverse/cebu>). The CLHNS cohort was established with the identification and recruitment of all pregnant women from a single-stage cluster-sample of 17 urban and 16 rural barangays in Metro Cebu in 1983. Among the 3327 women interviewed at baseline, there were 3080 singleton and 26 multiple births, which followed up during subsequent waves. The harmonized index for CLHNS that we used included seven publicly available study waves (1983, 1991, 1994, 1998, 2002, 2005, 2009) and data on the 2017-18 wave shared privately with the authors, to be consistent with what was previously reported (15). However, a sensitivity analysis that did not include the 2017-18 wave showed rank correlation ($r = 1.00$) with the original reported index. We restricted our analysis to singleton births who participated in 2009 ($n = 1709$; age 26–27). The proportion of missingness for wealth was less than 4% in any study wave. Hence, for ease of analysis and interpretation, we restricted our analysis to a complete-case scenario ($n = 1581$). We compared the early life and adult characteristics of those were included and excluded based on complete-case analysis, and found no systematic differences (**Supplementary Table 1**).

7.2 Variable specification

Exposure

Wealth was measured by using questionnaires on assets and housing characteristics (such as building material, toilet, source of water etc) over the life course. We pooled data on 30 assets (e.g. car, television, house ownership), housing characteristics (e.g. housing material, rooms per resident) and public utilities (e.g. garbage collection) collected during study waves from 1983 to 2018 and created a temporally

harmonized asset index, as reported previously (15). We used a polychoric principal components analysis, extracted the first component and standardized it to unit variance.

We compute the conditional wealth as the residual from a linear regression which predicts wealth at one time point using all previous measures of wealth. We did not adjust for confounders of wealth and outcome association while creating conditional wealth, consistent with the methodology for conditional growth (25).

Outcome

Height and weight were measured in 2005 and 2009 respectively. Since adult height stabilizes after age 20, we used height from 2005 to compute body mass index in 2009 as weight (in kg) per square meters.

Covariates

Maternal schooling, maternal age, birth order, sex and residence (rural or urban) were collected upon enrollment in 1983. Additionally, every survey collected information on current residence that was classified as urban or rural based on administrative databases. Attained schooling and status of formal employment were collected in adulthood.

7.3 Statistical Analysis

We estimated the mean and variance for wealth and conditional wealth at each study wave. We computed change inequality as per the formula in Section 3. We then computed the proportion of variance in wealth that was unexplained, and is an indicator of positional mobility. We first identified the predictors of conditional wealth (as per Section 4.3) using multivariable linear regression. Next, we estimate the association of wealth in childhood and conditional wealth at different life stages with body mass index to identify stages of the life course at which changes in relative position were associated with BMI at 26y. We repeated the analysis after stratifying by sex, since patterns of weight status are known to differ by sex in LMICs (30).

All analysis was carried out using R 3.6.1. The code for the analysis is available on <https://github.com/jvargh7/conditional-wealth>.

7.4 Results

Our results suggest that mean wealth increased over time (Table 2). We display the univariate and bivariate distribution of wealth at different study waves in Fig. 3. As expected, correlations between wealth measures decrease as they are further apart in time. Conditional wealth at different study waves were normally distributed (**Supplementary Fig. 2**). Inequality increased from 1983 to 1991 but then remained steady. The share of variance explained by conditional wealth (or unexplained variance in wealth) was 51% in 1991 and then decreased to nearly 30% afterwards. Maternal schooling was positively associated and whether the participant resided in a rural area in the corresponding study wave was negatively associated with conditional wealth in early life (Table 3). Apart from these measures, both

attained schooling (from 2002 onwards) and formal employment were positively associated with conditional wealth in adulthood. We demonstrate the implications of varying adjustment for wealth and conditional wealth on regression coefficients in **Supplementary Table 2**. Association of body mass index with wealth and conditional wealth at different life stages suggest heterogeneity by sex in 1983, 1998 and 2009 though we did not formally explore this (Fig. 4, **Supplementary Table 3**).

Table 2
Summary of harmonized wealth and conditional wealth for Cebu Longitudinal Health and Nutrition Survey 1983–2009 (n = 1581)

Year	Wealth	Change in mean wealth	Change in wealth inequality from preceding wave	Conditional wealth	Proportion of variance unexplained
1983	-1.04 ± 0.62				
1991	-0.24 ± 0.91	0.80	0.13	0 ± 0.65	0.51
1994	-0.05 ± 0.89	0.19	-0.01	0 ± 0.44	0.25
1998	0.16 ± 0.88	0.22	0.00	0 ± 0.47	0.29
2002	0.25 ± 0.79	0.08	-0.04	0 ± 0.45	0.33
2005	0.44 ± 0.83	0.20	0.02	0 ± 0.47	0.32
2009	0.49 ± 0.85	0.04	0.00	0 ± 0.49	0.34
Values are in mean ± standard deviation for harmonized wealth and conditional wealth (units same as harmonized wealth).					

Table 3

Predictors of conditional wealth for Cebu Longitudinal Health and Nutrition Survey 1983–2009 (n = 1581)

Year	1991	1994	1998	2002	2005	2009
Maternal schooling (y)	0.04 (0.03, 0.05)	0.01 (0, 0.01)	0.01 (0, 0.02)	0 (-0.01, 0.01)	0.01 (0, 0.02)	0 (-0.01, 0.01)
Maternal age (y)	0 (-0.01, 0.01)	-0.01 (-0.01, 0)	0 (-0.01, 0)	0 (-0.01, 0)	0 (-0.01, 0)	0 (0, 0.01)
Birth order	0.02 (-0.02, 0.05)	0.03 (0.01, 0.06)	0.02 (-0.01, 0.04)	0.01 (-0.01, 0.04)	0.01 (-0.02, 0.04)	-0.02 (-0.04, 0.01)
Male	0.02 (-0.04, 0.08)	-0.01 (-0.05, 0.03)	0.09 (0.04, 0.13)	-0.07 (-0.11, -0.02)	0 (-0.04, 0.05)	-0.16 (-0.21, -0.11)
Rural in 1983	0 (-0.19, 0.19)	-0.13 (-0.26, 0.01)	0.08 (-0.07, 0.22)	0.17 (0.03, 0.3)	0.02 (-0.12, 0.17)	0.02 (-0.13, 0.17)
Rural in 1991	-0.20 (-0.39, -0.01)	0.2 (-0.02, 0.43)	-0.24 (-0.48, 0)	-0.26 (-0.49, -0.03)	-0.15 (-0.4, 0.09)	0.15 (-0.09, 0.4)
Rural in 1994		-0.19 (-0.38, 0)	0.17 (-0.06, 0.4)	0.24 (0.02, 0.46)	0.08 (-0.15, 0.31)	0.01 (-0.23, 0.24)
Rural in 1998			0.03 (-0.14, 0.2)	0.01 (-0.18, 0.21)	0.21 (0, 0.42)	-0.1 (-0.32, 0.11)
Rural in 2002				-0.08 (-0.23, 0.08)	0.23 (0.04, 0.42)	0.05 (-0.15, 0.24)
Attained schooling (y)				0.02 (0.02, 0.03)	0.02 (0.01, 0.03)	0.02 (0.01, 0.03)

Values are displayed estimate and 95% confidence interval from multivariable linear regressions with varying precision reported (all independent variables were entered into the regression in their original units).

Year	1991	1994	1998	2002	2005	2009
Rural in 2005					-0.35 (-0.49, -0.21)	0.14 (-0.02, 0.29)
Rural in 2009						-0.20 (-0.31, -0.10)
Formal employment in 2009						0.05 (0.01, 0.10)
Values are displayed estimate and 95% confidence interval from multivariable linear regressions with varying precision reported (all independent variables were entered into the regression in their original units).						

8. Limitations Of The Approach

Firstly, asset-based measures of relative wealth are prone to issues of interference. By virtue of construction of asset-based indices in a study population, an individual's membership in a high wealth stratum leads to another individual's membership in a low wealth stratum and consequently the others' health outcomes (31, 32).

Second, studying SEP (as a function of material, human and social capital) or wealth (as a latent construct measured through the asset index) leads to issues of 'compound treatments with multiple versions', i.e. an exposure that comprises of more than one exposure (in this case, combinations of assets and housing characteristics). The asset index comprises of a data-derived weighted (linear) composite of items such as durable goods, housing characteristics and infrastructure. When calculating the asset index, an individual could arrive at the same score through different combinations of items (perfect substitution) (33). This is a possible violation of the consistency assumption such that individuals who receive an exposure in the real world display the same outcome as they would have if they receive the exposure in the counterfactual world (34, 35). Furthermore, the items comprising the index could be associated with the health outcome through mechanisms other than the latent construct signified by the index. As an example, possessing a television could be associated with social capital (such as during group viewing of sports or peer-interaction during play hours) or information (versus other media such as radio or internet). Another example is flooring or water source, which determine exposure to infections. In our analysis, we assume treatment-variation irrelevance wherein the same associations are observed independent of which set of items contribute to a participant's asset index score. Given the possible alternate mechanisms through which the assets might operate jointly (or

independently) and knowing that they are not well characterized, it might not be possible to develop interventions from our analysis in practice.

Third, similar to the temporally harmonized index, we do not account for individuals selecting themselves into higher wealth because of increased availability of infrastructure items through migration (from rural to urban areas for employment). We also do not account for changes in household composition (through marriage or separation) that may result in higher (or lower) scores than that of their original birth household (15).

Fourth, a limitation of conditional wealth that is not present in conditional growth is the possibility of treatment-confounder feedback (35). Early life wealth and conditional wealth may predict confounders of the association (such as attained schooling) between later life conditional wealth and health outcomes. This may bias the association of early life measures with health outcomes.

Fifth, as opposed to an estimation of the association between life course wealth measures and health using outcome regression, we adopt a two-step approach that first estimates conditional wealth, and then estimates the association of the anchor measure and conditional wealth with health, after adjusting for confounders. Further research into the possibility for incorrect standard error estimation, as is the case with manual two-stage estimation for instrumental variable analysis, ought to be considered.

Finally, coefficients for conditional measures cannot be interpreted independent of the anchor (usually first) measure that was used. Our outcome model assumes that one's absolute wealth at different time points is not associated with health, and all associations are explained by one's relative position and changes in the same. Conditional measures are able to explain the role of relative wealth mobility only conditional on the anchor measure. The coefficient for the anchor measure would be higher if positively correlated with the outcome or lower if negatively correlated with the outcome compared to a model where wealth measures at different time points are entered into the model. This is due to the anchor measure capturing the association of changes in mean wealth with the outcome, while conditional measures capture association of changes in relative wealth with the outcome. Consequently, it may falsely suggest designing only interventions that target only the anchor measure as opposed to measures at other time points. For example, in a context of rising inequality and low positional mobility (or high social persistence) irrespective of changes in mean wealth, the anchor measure entirely explains the association of relative position with health. We could also conceptualize an alternate formulation of conditional wealth with the anchor measure as the last measurement. This may answer a different set of questions such as the relative importance of prior relative wealth mobility, beyond current wealth, for a health outcome (24).

9. Summary

Conditional measures are a useful statistical decomposition of exposures measured longitudinally. Beyond previous established applications such as identifying periods of growth that are associated with health and human capital, applying this technique to harmonized wealth measures may help identify life

stages where changes in relative wealth are associated with health. The nature of conditional wealth implies that longitudinal data at an individual or household level are required to construct such measures. Studies such as the Young Lives cohorts, Millennium Villages Project, WHO SAGE surveys and other cohorts from LMICs that have collected data on asset-based wealth are sources of such data. Although results with and without decomposing wealth into conditional measures are the same, the additional utility of identifying predictors of relative wealth changes at different life stages is important from a public health perspective.

Abbreviations

CLHNS

Cebu Longitudinal Health and Nutrition Survey

EFA

Exploratory Factor Analysis

LMIC

Low- and middle-income countries

MCA

Multiple Correspondence Analysis

PCA

Principal Component Analysis

SD

standard deviation

SEP

Socio-economic position

Declarations

Data availability statement: The raw datasets are available at the Carolina Population Center Dataverse: <https://dataverse.unc.edu/dataverse/cebu>. The code and data for the analysis is available at <https://github.com/jvargh7/conditional-wealth>.

Conflict of interest: None declared

Consent for publication: Not applicable

Author contributions: JSV, ADS: conceptualized the study; JSV: performed the statistical analysis and wrote the first draft; CO, ADS: read and commented on successive drafts; all authors: read and approved the final manuscript.

Ethics approval and consent to participate: All methods were carried out in accordance with relevant guidelines and regulations We did not require ethical review for the analysis of secondary datasets that were downloaded from UNC Dataverse (<https://dataverse.unc.edu/dataverse/cebu>).

Competing interests: None declared

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Figures

Figure 1

Conceptual framework for wealth and conditional wealth in longitudinal studies

W_t are the measures of wealth, Y is the health outcome, X_t are the covariates associated with wealth like schooling and employment, C_t are conditional wealth measures or the magnitude of change in relative position. Panel (A) is the traditional framework for study of wealth with Y . In panel (B), we conceptualize conditional wealth (C_t), an extraneous contribution to current wealth beyond past measures of wealth. W_t and C_t may also be predicted by other unmeasured variables (U_t) that are not confounders of the wealth-outcome relationship.

Figure 2

Examples of changes in wealth at two time points for scenarios of mean, variance and relative position

The different shapes represent wealth of individuals at two different time points. Additional examples are available in **Supplementary File 2**.

Figure 3

Joint distribution of temporally harmonized wealth at different study waves (n = 1581)

All correlations reported are Pearson correlation coefficients. Figure created using GGally v2.0.0.

Figure 4

Pooled and sex-stratified association of conditional wealth with body mass index (kg/m²) in 2009 for Cebu Longitudinal Health and Nutrition Survey 1983-2009 (n = 1503)

Values are estimate and 95% confidence interval from linear regression. All measures (wealth in 1983 and conditional wealth) were in the same units as harmonized wealth. We adjusted for maternal schooling, maternal age, birth order, rural residence (1983 to 2009), attained schooling, and formal employment (in 2009). Pregnant women (n = 77) were excluded from the analysis. BMI missing for one individual (n = 1). Coefficients for all variables are reported in **Supplementary Table 3**.

Supplementary Files

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