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Measuring multidimensional poverty in a complex environment; identifying the sensitive links

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Abstract

The central hypothesis of this study is that a holistic, systems-based approach employing multiple analytical tools is useful for identifying the most sensitive links within complex communities to down-scale global development priorities such as the United Nations Sustainable Development Goals. Results of latent factor regression, canonical correlation analysis, and structural equation modeling were compared for multiple, publically-available data sets for two rural regions in Brazil and Guatemala. The results of this study confirm previously reported findings, and collectively support the central hypothesis demonstrating a pathway for linking global priorities with the complex realities of 'on-the-ground' development conditions in specific communities.

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Keywords: multidimensional poverty; complex systems; latent factor regression; canonical correlation analysis; structural equation modeling;

1. Introduction

Priorities and practices for global development continue to evolve. In 2015, the world will transition from the United Nations Millennium Development Goals (MDGs) [1] to the United Nations Sustainable Development Goals (SDGs) [2], [3], that will prioritize sustainable development through 2030. Along with this change in priorities, there has been a similar change in practices including the transition from an emphasis on log frame project management to the alternative of systems thinking [4] as well as a transition from best practice to the alternative of best approach [5]. These changes in development priorities and practices aim to improve the lives of

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those less fortunate through improved access to water, sanitation, and hygiene; gender equality; nutrition; livelihoods; and other areas of development. To successfully link the global agenda with improvements in local communities, it is important to recognize the multidimensional nature of poverty. A narrow focus on a single intervention is not likely to lift a community out of poverty, and the success of the SDGs will require an improved understanding of the multivariable interactions occurring within complex community structures during development.

Structural equation modeling (SEM) provides a platform that allows a development professional to evaluate interventions that are simultaneously simple, complex, and chaotic. SEM allows the user to model multiple hypotheses at the same time utilizing path analysis. By including latent variables, SEM allows the user to represent difficult or complex hypothesized constructs such as ‘socio economic status’ or ‘cognitive ability’. An additional advantage of SEM is the use of regression analysis that offers tests of fit, confidence intervals, and additional empirical based characteristics [6]. One limitation of SEM is initial model specification that is based on the practitioner’s experiences, literature reviews and expert opinions, and therefore is susceptible to error. As SEM is used as an analytical tool in the development field, it is important to employ secondary tools such as latent factor regression (LFR) and canonical correlation analysis (CCorA) to increase user confidence in the results. An advantage of LFR and CCorA is the ability to handle large data sets with large numbers of variables. LFR creates a latent variable from a set of hypothesized dependent variables and regresses this ‘new’ variable or factor on a set of independent variables. CCorA identifies linear combinations between the dependent and independent variable sets and maximizes the correlation between the two sets of variables [7]. Coupled with SEM, CCorA and LFR can help to inform or confirm a practitioner’s hypothesis.

Previously, Divelbiss and co-workers provided the first example of utilizing SEM in an iterative confirmatory approach within the field of development [8]. They assessed the intervention of a biosand filter (BSF) within the larger community system in northern Guatemala. The BSF was hypothesized to be the most effective intervention to reduce diarrheal occurrences in the household. In a post hoc analysis, Divelbiss rejected this hypothesis. The results showed that education was the most important factor to reduce diarrheal occurrences. To confirm this result, Voth-Gaeddert and co-workers repeated the study evaluating a similar use of the BSF to reduce diarrheal occurrences in households in a community in rural Brazil [9]–[12]. With a slightly modified SEM structure, Voth-Gaeddert and co-workers confirmed that education was more important than the BSF for reducing diarrheal occurrence. The current study expands the prior work with SEM by examining the value of utilizing CCorA and LFR to confirm the model structure. Further, through the use of a more extensive, publically-available dataset it was hypothesized that a holistic, systems-based approach employing multiple analytical tools is useful for identifying the most sensitive links within complex communities to down-scale global development priorities such as the SDGs.

2. Methodology

2.1. Data collection.

As previously reported, site-specific, orally-administered household surveys were used to collect data from rural communities in Guatemala [8] and Brazil [9]-[12]. For LFR and CCorA analysis, raw data was retrieved from the Demographic and Health Survey (DHS) Program. Data preparation included the removal of extraneous variables, and re-coding that were all performed in Microsoft Excel. To compare the prior results of Divelbiss and co-workers to the data retrieved from the DHS, the northern highlands region of Guatemala was analyzed. To compare the prior results of Voth-Gaeddert and co-workers to the data retrieved from the DHS, the area around Santarem, Para, Brazil was analyzed. While the areas of Guatemala examined in the prior work included linguistically isolated villages where the main livelihoods were subsistence agriculture and the primary mode of transportation was motor bike, Brazil provided a substantially different environment. Due to yearly flooding, above ground structures in Brazil are constructed on stilts, the main livelihoods were subsistence fishing and the primary mode of transportation was motorized boat. Figure 1 provides a Google Earth image of a homestead in

Brazil that was analyzed in the prior research study. As observed in Figure 1, seasonal flooding creates a different landscape within the community.

The data collected in the DHS survey is a secondary data source, and accordingly this research study had no influence over the type or amount of data collected. When comparing between the prior household survey data and the DHS data, the only two variables that were not available in the DHS data were improved water treatment and improved water storage. It is important to note also that the DHS data was reported at a regional level, while the prior household survey data was collected at the community level; hence geographic differences in scale are present for the two data sources. None the less, despite these constraints the DHS data were selected as the best available secondary data source to compare with the prior research.

Fig. 1. (a) High season and (b) low season along the Amazon River

2.2. LFR analysis.

To perform LFR, six health variables were examined for DHS data retrieved for Guatemala and seven health variables were examined from DHS data retrieved for Brazil. These health variables were regressed on the latent factor to construct a single latent variable named 'health factor'. Subsequently, the 'health factor' was regressed on a larger set of variables including topics of education, socio economic status, water supply, sanitation, living arrangements, and family history, and significant variables (p-value<0.1 and 0.05) were identified. As LFR was being used as an additional analytical tool to increase confidence in the SEM model structure, it was important to examine LFR as a negative control wherein the variables were included randomly to produce the latent factor. A total of five random pulls were used to confirm that no systematic bias is present in the tool. MPLUS Version 7.2 was utilized for the analysis [13].

2.3. CCorA analysis.

Finally, CCorA is a statistical technique that is the general procedure and origin of many parametric tests of significance between two sets of variables. Similar to the LFR procedure, six health variables for Guatemala were designated as the first data set while the remaining variables (described in 2.2) were designated as the second data set. The same dichotomous designation was given to the Brazil data set. The Wilk's Lambda Test and Eigenvalues were then used to identify significant linear combinations of variables ($p<0.05$ and significant separations in values, respectively). Once linear combinations are identified canonical correlation values and correlations between specific variables across data sets were analyzed. This allowed for an identification of what variables were most important to each other between sets [7]. Excel's xlstat was utilized for the analysis.

2.4. Limitations of statistical methods.

Limitations for LFR include: (1) the health factor is solely dependent on the relationships between the observable indicator variables; and (2) only minimal prior adjustments can be made to weight the indicators to the researchers preference. While this condition reduces researcher bias, the concern is that certain variables may be less influential than desired. A large number of independent variables in regression can cause power issues; however, the sample size for both data sets is sufficient for adequate analysis (n for Guatemala was 1038 and n for Brazil was 807). Limitations for CCorA include the importance of proper coding within the data that influences the absolute meaning of a positive or negative correlation. During data preparation, a limited number of variables within the DHS data sets were recoded into binary variables for analysis; however, information loss within these variables is minimal as the sample size is adequately large.

3. Results

The LFR results are presented in Tables 1 and 2. Table 1 identifies what variables were important within the latent factor. For Guatemala, children under six and deaths of sons or daughters create the underlying latent variable. Brazil's latent variable identified child diarrhea, fever, and cough issues as the underlying concept. Some variables are different between Guatemala and Brazil, and it is speculated that this is due to the site-specific surveys distributed by the DHS. As the comparison is between prior published results with SEM and LFR results with DHS data, no concerns should be present in the analysis.

Table 2 presents the most significant variables from the full set (see Appendix A). For Guatemala, significant variables included respondent's age, respondent's relation to the head of the household, the age of the head of the household and the education level of the respondent. For Brazil, significant variables included respondent's education, number of color TVs in the household, respondent's age, and the total number of rooms in the household.

Table 1. Significant indicator variables used to create the latent health factor for each country data set in the LFR.

Variable Name	Coefficient Estimate	P-Value
Guatemala		
Household with a son who have died	0.851	0.000
Household with a daughters who have died	0.850	0.000
Children under 6	0.037	0.000
Brazil		
Child had diarrhea in past 2 weeks	0.564	0.000
Child had fever in past 2 weeks	0.798	0.000
Child had cough in past 2 weeks	0.727	0.000

Table 2. LFR results from MPLUS 7.2 ($p<0.10$). Significant variables have a close relationship with the latent health factor identified above.

Variable Name	Coefficient Estimate	P-Value
Guatemala		
Respondents age	0.518	0.000
Ethnicity	-0.091	0.081
Education in years	-0.131	0.072
Relation to head of household	-0.176	0.012
Sex of head of household	-0.067	0.090

Age of head of household	-0.136	0.012
Menstruated in last 6 weeks	-0.062	0.071
Age at first marriage	-0.093	0.011
Brazil		
Respondents age	-0.198	0.002
Literacy of respondent	0.127	0.031
Reads once a week	0.129	0.008
Has a refrigerator	-0.126	0.022
Education in years	-0.331	0.000
Number of women 15-49	0.126	0.011
Number of color TVs	0.206	0.042
Has a vacuum cleaner	-0.099	0.055
Has a washing machine	0.096	0.071
Total rooms in household	-0.168	0.010

The CCorA results are presented in Tables 3 and 4. Wilk's Lambda test identified the first two factors (F1 and F2) as providing some explanation to the variance within the Brazilian model. The results with the Guatemalan model were less convincing; however, F1 and F2 were selected again for analysis. The canonical correlation for F1 and F2 were 0.494 and 0.334, respectively for Brazil and 0.531 and 0.455, respectively for Guatemala. Table 3 shows the set of health variables and the subsequent loadings (structural correlations) assigned for each factor. For Guatemala, F1 loaded strongly on sons and daughters deaths, where in F2 (which is orthogonal) children under six was strongly weighted followed by child deaths and health facility visits in the past year. For Brazil, the first factor was similar to the Guatemalan F1, namely loading on child deaths and children under six living in the household. F2 shifted to load on children under six, daughters deaths and if a child within the house has had a fever in the past two weeks.

Table 3. Health variable set for CCorA. Bold numbers identify the import variables in the two linear combinations F1 and F2.

Variable Name	Factor 1 – Structural Correlation	Factor 2 – Structural Correlation
Guatemala		
Sons who have died	-0.79449	0.25771
Daughters who have died	-0.71448	0.292318
Children under 6	0.372347	0.893308
Visited health facility past year	0.055986	0.266941
Drinking pattern response to child diarrhea	-0.05411	-0.00286
Eating pattern response to child diarrhea	0.04182	0.007428
Brazil		
Sons who have died	0.708868	-0.07316
Daughters who have died	0.624722	-0.37944
Children under 6	0.487097	0.750976
Had STD in past year	-0.21857	0.298384
Child had cough in past 2 weeks	-0.06753	-0.13501
Child had fever in past 2 weeks	-0.0371	-0.31488
Child had diarrhea in past 2 weeks	0.021972	0.007479

Table 4. CCorA for Brazil and Guatemala, F1 and F2 in order of importance. r = structure correlation. r^2 = linearly shared variance

Factor 1 Names	r	r^2 (%)	Factor 2 Names	r	r^2 (%)

Guatemala					
Age of respondent	-0.927	86.0	Menstruated in past 6 weeks	-0.567	32.1
Relation to head of household	0.417	17.4	Age of household head	-0.535	28.6
Education in years	0.345	11.9	Age at first marriage	-0.349	12.2
Marital status	-0.253	6.44	Education in years	-0.317	10.0
Education of partner	0.214	4.61	Reads once per week	-0.299	8.95
Knowledge of ovulatory cycle	-0.163	2.68	Sex of household head	-0.286	8.20
Household language	-0.162	2.63	Got pregnant and not wanted	0.277	7.70
Reads once per week	0.160	2.58	Type of toilet facility	-0.246	6.09
Age of household head	-0.153	2.35	Ethnicity	-0.239	5.75
Ethnicity	0.149	2.23	Respondents occupation	-0.214	4.61
Brazil					
Education in years	-0.496	24.6	Number of toilets in household	-0.334	11.1
Literacy of respondent	-0.488	23.8	Wall material of house	-0.326	10.6
Age of respondent	0.436	19.0	Household has washing machine	-0.309	9.53
Household has a TV	-0.388	15.1	Household has electricity	-0.283	8.01
Number of color TVs in household	-0.373	13.9	Household has a radio	-0.283	7.99
Household has a refrigerator	-0.345	11.9	Watches TV weekly	-0.283	7.98
Household has washing machine	-0.344	11.8	Roof material	-0.275	7.57
Age of household head	0.336	11.3	Household has a car	-0.269	7.24
Highest year of education	-0.335	11.2	Number of cars in household	-0.256	6.55
Age at first marriage	-0.328	10.7	Eligible women 15-49 in house	0.235	5.52

Table 4 presents the four different sets of 'other' variables, two for Guatemala and two for Brazil, that had high loadings in relation to the high loadings presented in Table 3 for the respective set and location (top left health variable set matches with the top left 'other' set). For example in Guatemala F1, high loadings on child deaths corresponded with high loadings on age of respondent and the head of the household as well as the education of the respondent. Trends identified in each of the pairs of factors highlights significant variables for each of the locations. LFR provides a p-value for individual variables that is similar to the basic regression model. CCorA identifies linear combinations and therefore provides variance explanation measures through the Wilk's Lambda Test and canonical correlation levels.

4. Discussion

The LFR analysis was able to identify key links to diarrheal occurrences on a regional level within north and northwest Guatemala and the central Amazon region of Brazil. For Guatemala, the underlying latent factor was created around children under six and number of child deaths in the household. The respondent's age had the highest significant parameter estimate in a positive relationship. This means that as the respondent got older there were more children under five and more of them had died. The second highest significance was the relationship to the head of the household. As this was a maternal survey, practical interpretation of this relationship is limited. The age of the partner (ie husband) was also significant but produced a negative estimate. This indicates that as the husband becomes older, fewer children die. This could possibly imply that as male's age, they gain understanding of how to better take care of their children or perhaps have increased financial resources or community connections to ensure adequate nutrition and healthcare. Finally, the respondent's education in years was shown to be significant in a negative parameter estimate. This indicates that as the mother's education increases, the death of her children is reduced. Several other variables were also significant including the age at the time of the mother's first marriage.

The LFR for Brazil offered a similar yet different latent construct. For Brazil, the household's child health including diarrhea, fever, and cough occurrences within the previous two weeks were shown to be most significant. The variable with the largest significant parameter estimate was education of the respondent. This result appears to support the previous observation regarding the importance of education in improving health outcomes within households. The second most important variable was the number of colored TVs within the household; however, it was a positive parameter estimate meaning that an increase in the number of color TVs (or money to buy color TVs) corresponds to an increase in the issues of child ill-health within a household. This result is counter intuitive, but may be related to the complex connection between household income and leisure activity with more income corresponding to greater leisure. Alternatively, this result may imply that those who are sick more often engage in additional leisure activities as they are unable to work. Two additional significant variables included the ownership of a refrigerator and the ownership of a vacuum cleaner. These were both negatively weighted which may imply that since these two items were not leisure items, families who cared about healthy children also invested in items to improve living conditions within the home. Within the parameter estimate levels, the respondent's age and the total number of rooms within the household were less significant than color TV. Both age and number of rooms had negative parameter estimates suggesting that older mothers were better care givers of younger children. As the factor was focused on specific health issues of children, the experience of mothers (older mothers have more experience) proved important in reducing health issues among their children. The total number of rooms within a house suggests that as a house has more money for rooms, those children within those particular households are healthier. Alternatively, it could imply that households with healthier children, less money is invested in healthcare and an increased amount of money may be invested on housing infrastructure.

The CCorA analysis also provided insights for both Guatemala and Brazil. Within Guatemala Factor 1 (F1G) was only a little more informative then Factor 2 (F2G), meaning that both sets of variables offer useful insights but F1G should be utilized initially. The health set of variables loaded similar to the LFR for Guatemala, focusing initially on the deaths of sons and daughters in households and secondly on children under six. This result for CCorA was similar to the results reported for LFR. The age of the mother and education of the mother were the most important followed by the marital status of the mother and the education of the husband. Increase in age was a negative influence (similar to LFR Guatemala). There was a negative effect of marital status, suggesting that divorce contributes to childhood mortality; however, as no time component is included it is important to note that causality cannot be assumed. The two positive variables were education of the mother and the father. For F2G, the health variable focused primarily on the number of children under six while deaths of children and number of visits to the health clinic were less important. The most significant variables from the 'other' data set were menstruation in the past six weeks, age of household head, age at first marriage and education of the mother. All variables were negatively weighted.

The CCorA for Brazil was more highly loaded on the first factor (F1B) as compared to the second factor (F2B) and therefore more focus should be assigned to F1B. The health variable set loaded across death of children, children under six and acquiring sexually transmitted diseases (STDs) in decreasing levels, respectively. The variables identified as most important were mother's education, literacy of the mother and the age of the mother. The education and literacy variables were negatively loaded suggesting that an increase in these variables correlates with a reduction in child deaths as well as a reduction in the number of children. Age was positively correlated (similar to what was discussed above for Guatemala). The final health variable set (F2B) loaded primarily on number of children under six but also included daughter deaths, child fevers in the past two weeks and STD occurrences. The important variables from the 'other' set included number of toilets within the household, what type of wall material was used for the house structure, and if the household owned a washing machine. The number of toilets were negatively correlated suggesting that poor hygiene may correlate to an increase in the number of children. The wall material and presence of a washing machine should be explored further to increase the understanding of the relationship among household income and household investments of income. For example, it appears that households that invested limited resources in household infrastructure may correspond to households with fewer childhood deaths.

Collectively, the findings from the LFR and CCorA analysis of the DHS data sets for Guatemala and Brazil confirm the prior results and suggest additional mechanistic insights. As discussed above, Divelbiss and co-workers identified education and improved water sources as more important than the presence of a BSF to reduce diarrheal occurrences within households in Guatemala. Similarly, Voth-Gaeddert and co-workers reported on the results of SEM and Mahalanobis Taguchi Strategy (MTS) to identify several key variables to reducing diarrheal occurrences in Brazil including: education, improved sanitation, and socio economic status. For Brazil, it was noted previously that the communities have multiple approaches available to reduce the transmission of diarrheal diseases that are unrelated to water supply and sanitation; hence this is why education and socio economic status are crucial for mitigating the transmission of diarrheal occurrences.

Collectively, these results support the notion that education is a strong, positive influence on household health. This result is consistent with the larger body of literature [14]–[17]. Furthermore, these results collectively support the notion that investments in the education of mothers and future mothers (ie young girls) can contribute to improve health of future children. As compared to prior studies, the current study provides a statistical framework to assess the level of importance of education as compared to the level of importance of other variables. When selecting what type of intervention is appropriate for a specific area, it would appear that education should be considered strongly as a part of all programs. A second consistent theme is that the age of the parents is important. This fact was demonstrated clearly in the results of the current study including the importance of the age at first marriage. Older parents appear to have greater success in raising healthier children that supports multigenerational family structures as well as delayed child bearing and rearing. A third theme that emerged in the results was the apparent link among household investments and healthy children; namely: wise investments in household infrastructure appear to correspond to less illness among children. Finally, while the importance of addressing water and sanitation is evident in the results of this study, a balanced understanding of the technical and social solutions is crucial to maximizing returns on investment for all stakeholders and beneficiaries included.

5. Conclusion

The original hypothesis for this paper was that a holistic, systems-based approach employing multiple analytical tools is useful for identifying the most sensitive links within complex communities. This was tested by comparing prior results from SEM and household surveys with alternative data from the DHS and by exploring LFT and CCorA as alternative analytical tools. As this paper has identified education, age and socio economic status as the three most important variables. Collectively, these results support this hypothesis and suggest that complexity, rather than simplicity, is the approach that should be used when assessing the interventions being considered in particular communities. As shown in this paper and previous publications, many communities around the world exhibit complexity. It is then critical to approach all development problems holistically, for it is easier (and cheaper) to narrow ones focus on a project rather than to step back after the fact.

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