How Do Extreme Schools Change the Interpretation of Results in School Effectiveness Research? Effects of Outlying Second-Level Variables in HLM.


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Fixed Effects; Hierarchical Linear Modeling; Multilevel Analysis; Outliers

This study examined the robustness of the estimation of fixed-effects in multilevel analysis, as might occur in the conduct of school-effects studies with outlying schools. Outlying values for both intercepts and slopes for individual schools were modeled separately to determine the effects of extreme values of second-level variables on the fixed-effect parameter estimation. A total of seven data sets were generated for the simulation. Under the conditions investigated in this study, adding a cluster of outlying schools had little effect on the estimation of gamma 10 and gamma 11. However, the standard error of gamma 01 increased, thereby increasing the conservativeness of the test of significance of gamma 01. This occurred for clusters of outlying slopes, intercepts, or a combination of both. Introducing a single outlying school also increased the standard error of gamma 01, the effects being more dramatic when the outlier was an extreme slope. (Author/SLD)
How do Extreme Schools Change the Interpretation of Results in School-Effectiveness Research?: Effects of Outlying Second-Level Variables in HLM.

Janet K. Sheehan & Tianqi Han
Northern Illinois University

This paper was presented at the Annual Meeting of the American Educational Research Association, New York, NY, April, 1996
Abstract

This study examined the robustness of the estimation of fixed-effects in multilevel analysis, as might occur when conducting school-effects studies with outlying schools. Outlying values for both intercepts and slopes for individual schools were modeled separately to determine the effects of extreme values of second-level variables on the fixed-effect parameter estimation. Under the conditions investigated in this study, adding a cluster of outlying schools had little effect on the estimation of $\gamma_{10}$ and $\gamma_{11}$, however the standard error of $\gamma_{01}$ increased, thereby increasing the conservativeness of the test of significance of $\gamma_{01}$. This occurred for clusters of outlying slopes, intercepts, or a combination of both. Introducing a single outlying school also increased the standard error of $\gamma_{01}$, the effects being more dramatic when the outlier was an extreme slope.
How do Extreme Schools Change the Interpretation of Results in School-Effectiveness Research?: Effects of Outlying Second-Level Variables in HLM.

Theoretical Perspective

Multilevel analysis has recently replaced multiple linear regression (MLR) as the method of choice for school-effects research (Mendro, Webster, Bembry, & Orsak, 1995; Webster, Mendro, & Almaguer, 1993). Bryk and Raudenbush, (1992) give at least two explanations for the appropriateness of multilevel analysis for school-effects research. First, random variation and structural effects may exist at more than one level, and therefore a correctly specified model is a multilevel model in which fixed and random effects can be estimated at each level. Second, the assumption of independence of errors in MLR is violated when there is intraclass correlation, as one would find in such hierarchically nested data.

The models for a simple multilevel analysis with one level-1 and one level-2 fixed-effect variable would be:

\[ Y_{ij} = \beta_{0j} + \beta_{1j}X_{ij} + r_{ij} \]  

(1)

for the level-1 model and

\[ \beta_{0j} = \gamma_{00} + \gamma_{01}W_j + u_{0j} \]  

(2)

\[ \beta_{1j} = \gamma_{10} + \gamma_{11}W_j + u_{1j} \]  

(3)

for the level-2 models. The level-1 model is analogous to a simple regression model, where \( r_{ij} \) is the level-1 error. The parameters from level-1 become outcome variables in the level-2 models, which are predicted by second-level effects. \( u_{0j} \) and \( u_{1j} \) are the random error components of level 2. Upon inspection of these
models, it is apparent that aberrant or extreme values for $\beta_0$ and $\beta_1$ will affect the estimation of parameters in the second-level models. These discrepant schools could have an undue influence on the estimation of the second-level fixed effects of the model. Therefore, Bryk and Raudenbush (1992) suggested that cross-level exploratory analyses be performed when conducting school-effects studies to determine if there are schools with outlying intercepts or slopes.

The effects of outliers have been extensively studied in ordinary least squares regression analysis. Rousseeuw and van Zomeren (1990) identify three types of outliers: a) vertical outliers in which there is a large residual, b) leverage point outliers, which are consistent with the relationships found in the rest of the data and c) leverage point outliers, which significantly alter the relationships by their inclusion, as well as having high leverage. Outliers exert effects in not only the results of the main and interaction-effects significance tests from GLM, but also in the estimation of the model parameters (Douzenis & Rakow, 1987; Hecht, 1991).

This study is designed to examine the robustness of the estimation of fixed-effects in multilevel analysis, when conducting school-effects studies with outlying schools. Outlying values for both intercepts and slopes for individual schools are modeled separately to determine the effects of extreme values of second-level variables on the fixed-effect parameter estimation.

Data Source

A total of seven data sets were generated for this study. Data set I was simulated to serve as the major body of data. This dataset consisted of 250 schools with 50 students in each school. Three datasets were generated based on the original dataset, but containing 10%: a) schools with extreme intercepts, b) schools with extreme slopes, or c) schools with extreme intercepts and slopes. The extreme intercept is analogous to adding vertical outliers. These were generated by increasing the mean approximately 3 standard deviations units
higher. The slope outliers were generated by reducing the correlation between X and Y from .7 to .4, holding $s_x$ and $s_y$ constant. The dataset size was maintained at 250 level II observations or schools. The three new datasets were termed Outlier-I, Outlier-S, and Outlier-SI, respectively. Multiple regression diagnostics tests of the schools, were examined to determine the most extreme outliers for each of the three datasets, as well as to determine that each dataset contained 10% outliers. Specifically, the intercept and slope DF Betas were checked to ensure that they increased for the outlying observations.

To produce the last three data sets, extreme outlying observations were substituted for observations in the original dataset. One school was removed from the original data set, and the most extreme outlying school found in the analysis of Outlier-I was inserted in its place. This new dataset was termed Single-I. This process was repeated for Outlier-S, and Outlier-SI, producing the new datasets Single-S, and Single-SI, respectively.

**Procedures and Results**

A two-level hierarchical linear modeling program (HLM) was used to conduct the multilevel analysis for this study. Separate HLM analyses were conducted for each dataset. Table 1 presents the descriptive statistics of the seven datasets. It can be seen that adding the 10% outlying schools increased the standard deviations of the original dataset. However, adding the one outlying school had little effect on the standard deviations.
### Table 1

**Descriptive Statistics**

<table>
<thead>
<tr>
<th>Outlier</th>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
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<td>X</td>
<td>12,500</td>
<td>180.04</td>
<td>9.04</td>
<td>142.51</td>
<td>214.02</td>
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<tr>
<td></td>
<td>Y</td>
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<td>192.03</td>
<td>13.02</td>
<td>140.30</td>
<td>241.76</td>
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<tr>
<td></td>
<td>W</td>
<td>250</td>
<td>5.60</td>
<td>0.14</td>
<td>5.21</td>
<td>5.99</td>
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<tr>
<td>10% Outliers</td>
<td>Intercept</td>
<td>X</td>
<td>12,500</td>
<td>180.04</td>
<td>9.04</td>
<td>142.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Y</td>
<td>12,500</td>
<td>197.03</td>
<td>19.34</td>
<td>140.30</td>
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<tr>
<td></td>
<td></td>
<td>W</td>
<td>250</td>
<td>5.60</td>
<td>0.14</td>
<td>5.21</td>
</tr>
<tr>
<td></td>
<td>Slope</td>
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<td>26.89</td>
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<td>5.60</td>
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<td>5.21</td>
</tr>
<tr>
<td></td>
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<td>180.05</td>
<td>9.07</td>
<td>142.51</td>
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<td>17.25</td>
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<td>0.14</td>
<td>5.21</td>
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<tr>
<td>Single Outlier</td>
<td>Intercept</td>
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<td>9.04</td>
<td>142.51</td>
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<tr>
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<td>192.23</td>
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<td>0.14</td>
<td>5.21</td>
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<tr>
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<td>X</td>
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<td>180.05</td>
<td>9.05</td>
<td>142.51</td>
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<td>191.73</td>
<td>13.87</td>
<td>94.20</td>
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<td>191.89</td>
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<td>127.53</td>
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<td>5.60</td>
<td>0.14</td>
<td>5.21</td>
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</table>
Table 2 presents the level I regression coefficients and the corresponding reliability estimates. It can be seen that the reliability estimates for all the datasets with outliers were increased. The increase in the school differences in the parameter estimates increased $t_{qq}$ which increased the reliability estimates. The average parameter estimate for $\beta_0$ changed when outliers were added. This occurred for both 10% outliers and single outliers. The average coefficient estimate for $\beta_1$ did not change when intercept outliers were added. However, it did change the average estimate of $\beta_1$ when 10% slope or slope and intercept outliers were added.
Table 3

Regression Coefficient for Level II

<table>
<thead>
<tr>
<th>Outlier Type</th>
<th>$\gamma_{00}$</th>
<th>SE $\gamma_{00}$</th>
<th>$\gamma_{01}$</th>
<th>SE $\gamma_{01}$</th>
<th>$\gamma_{10}$</th>
<th>SE $\gamma_{10}$</th>
<th>$\gamma_{11}$</th>
<th>SE $\gamma_{11}$</th>
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</thead>
<tbody>
<tr>
<td>No Outlier</td>
<td>192.0*</td>
<td>0.116</td>
<td>4.51*</td>
<td>0.804</td>
<td>1.01*</td>
<td>0.009</td>
<td>0.07</td>
<td>0.066</td>
</tr>
<tr>
<td>10% Outliers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>197.0*</td>
<td>0.911</td>
<td>-10.7</td>
<td>6.333</td>
<td>1.01*</td>
<td>0.010</td>
<td>0.07</td>
<td>0.066</td>
</tr>
<tr>
<td>Slope</td>
<td>184.2*</td>
<td>1.498</td>
<td>1.06</td>
<td>10.412</td>
<td>0.97*</td>
<td>0.013</td>
<td>0.05</td>
<td>0.091</td>
</tr>
<tr>
<td>Intercept</td>
<td>188.3*</td>
<td>0.726</td>
<td>2.54</td>
<td>5.048</td>
<td>0.97*</td>
<td>0.013</td>
<td>0.08</td>
<td>0.089</td>
</tr>
<tr>
<td>&amp; Slope</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Outliers</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>192.2*</td>
<td>0.217</td>
<td>4.18*</td>
<td>1.505</td>
<td>1.01*</td>
<td>0.010</td>
<td>0.06</td>
<td>0.067</td>
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<tr>
<td>Slope</td>
<td>191.7*</td>
<td>0.328</td>
<td>2.15</td>
<td>2.277</td>
<td>1.01*</td>
<td>0.010</td>
<td>0.06</td>
<td>0.067</td>
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<tr>
<td>Intercept</td>
<td>191.9*</td>
<td>0.187</td>
<td>4.21*</td>
<td>1.301</td>
<td>1.01*</td>
<td>0.010</td>
<td>0.07</td>
<td>0.068</td>
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<tr>
<td>&amp; Slope</td>
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</tr>
</tbody>
</table>

Table 3 shows the regression coefficients estimates for level II, equations 2 and 3. The standard error estimates of all parameters increased relative to the dataset with no outliers. The outliers had little effect on both $\gamma_{11}$ and $\gamma_{10}$ and did not alter the statistical test results. This indicates that the outliers generated under these conditions had little effect on the relationship between X and Y when $W=0$, $\gamma_{10}$, or the mean difference in the X-Y slopes across levels of W, $\gamma_{11}$. However, the outliers did have an effect on $\gamma_{01}$, the mean difference in Y across levels of W. Both the values for $\gamma_{01}$ and its standard error changed such that in all datasets with 10% outliers the statistical test of $\gamma_{01}$ was no longer significant. The net effect of the outliers then, was making the tests of $\gamma_{01}$ more conservative. For the single outlier datasets, only the outlying slope changed the results of the significance tests of $\gamma_{01}$.
Discussion

When a cluster of outlying level-II observations are added to a multilevel analysis, the effects on the estimation of level II fixed effects can be dramatic. In school-effectiveness research, this would be manifested if a cluster of schools had extreme means on Y, aberrant relationships between X and Y in a cluster of schools, or if a cluster of schools had both extreme means and extreme X-Y relationships. Under the conditions investigated in this study the changes in the parameter estimates and their standard errors resulted in conservative tests of significance. Adding a single outlying school naturally had less of an effect, however, results of tests of significance were still changed in the presence of a single outlying slope. Further, it is conceivable that similar results could arise for single outliers of the intercept and the slope and intercept for more extreme outliers.

Future Research

This study suggests a more extensive study to ascertain how outliers of differing magnitudes affect parameter estimation in multilevel analysis is needed. It would also be of interest to study the effects of other types of outliers, such as leverage point outliers, on parameter estimation in multilevel analysis.
References


Footnotes

¹Reliability in HLM refers to the ratio of parameter variance to total variance.

$$\hat{\beta}_q = \frac{1}{J} \sum_{j=1}^{J} \tau_{qq} / (\tau_{qq} + \nu_{qq})$$  \hspace{1cm} (4)

for each $q=0,...,Q$ (Bryk & Raudenbush, 1992, p.43) and where $\tau_{qq}$ = parameter variance and $\nu_{qq}$ = error variance (Bryk & Raudenbush, p.34).
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Position: Assistant Professor

Printed Name: Janet K. Sheehan

Organization: Northern Illinois University

Address: EPCSE
Northern Illinois University
DeKalb, IL 60115

Telephone Number: (815) 753-8523

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