

Accounting for the “Known Unknowns”: Incorporating Uncertainty in Second-Stage Estimation

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Abstract

Recent political science research has seen a surge in interest in estimating latent variables (including ideal points of legislators and judges, political sophistication, and democratization) using item-response theory modeling and other factor-analytic techniques. These models offer several advantages over summated scales and other techniques, but one of these advantages—having an estimate of the uncertainty in our measurement of the latent variable—is often discarded when these estimates are used in second-stage models.

Here I demonstrate a technique known as simulation-extrapolation estimation (SIMEX) for incorporating uncertainty into latent variable estimates. I then compare estimates using standard estimators such as ordered logit and binary probit to their SIMEX counterparts incorporating uncertainty. These results demonstrate the value of including known error variance in second-stage estimates without the added complication of using structural-equation model approaches.

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1 Background

One of the more desirable trends in recent political science research has been an increasing concern with quantifying measurement error when determining the likely quantities of variables that cannot be directly observed, such as legislators' and Supreme Court justices' ideal points (Clinton et al., 2004; Martin and Quinn, 2002; Poole and Rosenthal, 2007), the level of democracy of a state (Bollen, 1993; Treier and Jackman, 2005), and the level of political sophistication of voters (Levendusky and Jackman, 2003). Many, but not all, of these measurement approaches are based on the use of item-response theory models (Johnson and Albert, 1999), a factor-analytic technique originating in psychological and educational testing which has been shown to have application to the measurement of a wide variety of other phenomena as well.

However, this emerging concern with measurement error has not been matched with a concern for incorporating estimates of measurement error into subsequent analysis, despite evidence that not accounting for this measurement error may introduce unknown bias into inferences.¹ The most common approach in the literature to date is to use the mean, or occasionally median, estimate of the ideal point (or level of sophistication or democracy) recovered from the IRT procedure or other scaling method as either an independent or dependent variable in subsequent analysis. While the best-guess expected value of the estimate is the mean, if the true value is different the estimated effect of the variable is likely to be understated, particularly when included in a model with other, correlated covariates.

One potential approach to solving this problem is to use latent-variable structural equation models (Bollen, 1989) to incorporate known uncertainty in the second-stage

¹See e.g. Martin and Quinn (2005), who only discuss the importance of accounting for uncertainty in a footnote; the bulk of their paper is concerned with other potential problems with the use of their Supreme Court scores as predictors, including endogeneity and non-random case selection.

modeling process. However, structural equation modeling has not been widely used in the political science literature (perhaps due to the stigma associated with its predecessor, path analysis), generally requires specialized software, provides only indirect significance testing of coefficients (via nested model tests), and copes poorly with discrete data, particularly when dependent variables are discrete, which is the case in most voting and public opinion models.

A second potential approach is to estimate the latent variable model and the second-stage model simultaneously, typically through a Markov chain Monte Carlo process. The primary disadvantage of such an approach is that the computational demands of estimating latent variables via MCMC remain very high, despite advances in computing power. These costs mean efforts to refine combined models remain very time consuming, even with high-end computing hardware. A second drawback of this approach is that a combined estimation procedure will reconstruct the latent variable rather than reusing existing latent variable estimates. For example, the researcher may wish to rely on the published NOMINATE scores for Congress, rather than constructing a different model of legislator ideal points that is not as likely to be as widely accepted as a measure of ideology and may not be comparable with the results of other research. Even if the researcher is willing to produce new first-stage estimates, if those values are difficult to estimate or rely on data not directly available to the researcher, the simultaneous estimation approach is not viable.²

Instead I demonstrate a technique known as simulation-extrapolation estimation (or SIMEX), developed by Cook and Stefanski (1994) and implemented in the R

²Shor et al. (2008), for example, report on producing ideal points for state legislators that are directly comparable with Congressional ideal points. It is unlikely that a researcher studying legislative voting in Florida or another state would estimate an elaborate model to redetermine existing estimates of ideal points when the naïve approach of reusing published estimates' means directly is available, especially given the current state of the literature that diminishes the importance of measurement error in covariates.

simex package (Lederer and Küchenhoff, 2009, 2006) and also available in Stata since version 8.³ This procedure produces nearly asymptotically unbiased and efficient estimates for virtually any regression-based model (including OLS, limited-dependent variables models, and fixed- and random-effects models), through either the jackknife or an asymptotic approximation. The SIMEX procedure is also much less computationally intensive than a combined-model approach based on MCMC or other methods; while the simulation step does require the iterative re-estimation of the second-stage model, the more costly first-stage estimation to recover estimates and their estimated error distribution needs only to be conducted once.⁴

In short, the SIMEX technique accounts for known measurement error in interval-measured explanatory variables; the related Misclassification SIMEX (Küchenhoff et al., 2006) corrects for classification error in binary covariates. As such, these techniques would appear to have wide application in quantitative political analysis.

2 The Simulation-Extrapolation Method

In a standard generalized linear model, the dependent variable (or a function thereof) is given by:

$$Y = \beta X + \epsilon$$

In this model, it is typically assumed that the covariates X are measured *without error*. Thus it is likely that if some covariates are measured with error, our estimates of the

³Instructions for installing simex for Stata are available at <http://www.stata.com/merror/>.

⁴If the researcher is using published estimates, such as existing NOMINATE scores for Congress, those estimates can just be re-used without running any first-stage model.

coefficient vector β are likely to be biased as a result.⁵

In repeated samples, per the central limit theorem, the estimated coefficient vectors $\hat{\beta}$ would eventually produce a distribution where the expected value of $\beta = \bar{\hat{\beta}}$; however, accurate estimates would require multiple measurements of the same sample, which is likely to be very expensive or downright impossible to achieve in the social sciences. Thus it is necessary to find a way to estimate what β would be in repeated measurements without measuring the sample multiple times. The Simulation-Extrapolation method (SIMEX) is designed to do just this.

First, we define $G(\sigma_u^2)$ as the limit of $\bar{\hat{\beta}}$ as the number of measurements approaches infinity, for a given vector σ_u^2 reflecting the (known) measurement error of the covariates X .⁶ If $\sigma_u^2 = 0$ (no measurement error), it follows that the estimates $\hat{\beta}$ will all be the same in each measurement and thus $G(0) = \beta$. But in the general case there is no way to directly find G . Instead we can approximate G with $G(\sigma_u^2, \Gamma)$, where Γ is a simple function of β which can be used to extrapolate an estimate of G . One possible approximation of G is a quadratic function,

$$G_{\text{quad}}(\sigma_u^2, \Gamma) = \gamma_0 + \gamma_1 \sigma_u^2 + \gamma_2 (\sigma_u^2)^2.$$

The first stage, simulation, requires us to find an estimate of Γ . In each simulation pass, first an artificial measurement error (distributed normally) with variance $\lambda \sigma_u^2$ is added to the existing covariate(s) that are measured with known error; λ is a positive scaling factor that varies based on the simulation pass. Then, the underlying model is estimated to recover the coefficient vector $\hat{\Gamma}$. The simulation is repeated B times. The mean of the estimated coefficient vectors is then taken and used as the estimate for $G((1 + \lambda)\sigma_u^2)$. Simulations are conducted for a number of values

⁵The consequences of measurement error in Y are similar; while ordinary least squares regression is fairly robust to measurement error in Y , this property may not hold for other estimators. Regardless, SIMEX and MC-SIMEX can be used in the case where Y is measured with error as well.

⁶I follow the notation used by Lederer and Küchenhoff (2006).

of λ to attempt to find a function G that fits other values of λ .⁷

The second stage is extrapolation, which is comparatively simple. The estimates of G for each λ are combined with an estimate of G with $\lambda = 0$ (corresponding to the “naïve” underlying model, where X is assumed to be measured without error) to attempt to extrapolate an estimate for $G(0)$ —which would correspond to $\lambda = -1$ —using a parametric curve-fitting technique. This extrapolated estimate is thus an estimate of what β would be in the absence of measurement error among the independent variables.⁸ Thus we have now recovered estimates of the model parameters that account for the known measurement error, in particular the likely attenuation bias in the parameters associated with the covariates measured with known error.

I now proceed to apply the method in two settings: a model of legislators’ roll call voting and a model of voter opinionation.

3 Application: Legislator Ideology and Impeachment

The study of Congressional roll call voting has a rich history in political science. One of the debates that has emerged from this line of research has concerned whether or not legislators engage in *shirking*—departing from being agents of their constituents, as the “delegate” model of representation suggests they ought to be (Burke, 1774)—and under what conditions legislators are likely to shirk. While most political

⁷Lederer and Küchenhoff (27) report that λ values of 0.5, 1.0, 1.5, and 2.0 produce good estimates in their simulations. While the `simex` R package defaults to using 100 simulated passes, my work with the procedure suggests that for consistent estimates using 500–1000 simulations per λ is more appropriate, particularly in the presence of interaction terms.

⁸Estimates of the standard errors of the parameters may also be obtained, either through the jackknife (Stefanski and Cook, 1995) or asymptotically (Carroll et al., 1990; Küchenhoff et al., 2006). While not demonstrated in this paper, this procedure can also be used when multiple covariates are measured with known error.

scientists and other observers *believe* legislators shirk, finding solid empirical evidence of this has been challenging at best (see e.g. Lott and Bronars 1993; Bender and Lott 1996; Rothenberg and Sanders 2000b; and Jenkins and Nokken (2008), as well as the debate among Carson et al. 2004; Rothenberg and Sanders 2004b; Herron 2004; and Rothenberg and Sanders 2004a). Thus scholars of Congress have focused on situations where legislators are *most likely* to shirk—votes with low public salience and those cast by retiring or otherwise non-returning members, particularly during lame duck sessions (for example, Bianco et al. 1996).

The 1998 votes on articles of impeachment against former President Bill Clinton by the House of Representatives are an example of such a situation. Rothenberg and Sanders (2000a) found that retiring Republican members, controlling for district support for Clinton in the 1996 race and legislator ideology (W-NOMINATE scores from the 105th Congress), were significantly more likely to support articles of impeachment than those who returned in the 106th Congress. Lawrence (2007) instead found that the evidence for shirking in this instance was lacking, as Rothenberg and Sanders' conclusion regarding the behavior of Republican members was due to the behavior of one *Democrat*.⁹ Rothenberg and Sanders (2007) then produced a respecified model omitting legislator ideology in which they found (again) that shirking had taken place.

The central question, however, would not seem to be whether or not members departed from constituency preferences, but whether or not the impeachment vote was *unusual* in this regard—and whether or not retiring members were particularly unusual. Thus it would be appropriate to control for ideology—but we know that NOMINATE estimates are just that, *estimates*, but were taken as given in the estimates

⁹The choice to use an ordered logit model rather than an ordered probit model also had an effect on the estimated standard errors, and thus the statistical significance of the findings.

by Rothenberg and Sanders and Lawrence. Use of the SIMEX procedure might conceivably produce different results that could lend more credence to Rothenberg and Sanders' original findings, as *all* of the estimated coefficients are likely to be biased in unpredictable ways due to the specification error in the original model.

For sake of comparability, I follow Rothenberg and Sanders' original specification of an ordered logit model with the dependent variable being the number of articles of impeachment the member supported (ranging from 0 to 4), with the independent variables being a dummy variable indicating the member's "lame duck" status and continuous variables indicating the percentage vote share Clinton received in the district in 1996 and the member's W-NOMINATE score, updated from Poole (2009). The SIMEX model also includes the mean estimated error of each legislator's position, based on the bootstrap estimated standard errors for W-NOMINATE derived according to Lewis and Poole (2004).

The ordered probit model from Rothenberg and Sanders (2000a) was re-estimated, along with the SIMEX-corrected ordered probit model, using the `polr` procedure in the MASS package for R (R Development Core Team, 2009; Venables and Ripley, 2002); the results are presented in Table 1.¹⁰ While the estimated *p*-values for each coefficient change relatively little (in particular, the estimated interaction effect between lame-duck status and Clinton's district support remains insignificant in a two-tailed test), the substantive effects of the coefficients show a notable change, with the effect of district support for Clinton diminishing in importance relative to member ideology.

Because the known measurement error associated with member ideology

¹⁰As of this writing the current R `simex` package does not support ordinal dependent variable models "out-of-the-box"; a modified version of the package adding support for `polr` models is available from the author.

| | Standard Model | SIMEX Model |
|----------------------------------|--------------------|--------------------|
| Clinton vote in dist. | -3.269* (1.210) | -2.792* (1.266) |
| Legislator ideology | 4.996* (0.419) | 5.451* (0.504) |
| Clinton vote \times Lame Duck | 1.423 (0.819) | 1.663 (0.881) |
| Leg. ideology \times Lame Duck | -0.771 (0.745) | -1.010 (0.794) |
| μ_1 | -0.658 (0.706) | -0.262 (0.754) |
| μ_2 | -0.425 (0.713) | 0.007 (0.522) |
| μ_3 | 0.321 (0.716) | 0.812* (0.294) |
| μ_4 | 1.424* (0.710) | 1.957* (0.266) |
| McFadden R^2 | 0.602 | |
| Cox-Snell R^2 | 0.760 | |
| Nagelkerke R^2 | 0.838 | |
| Likelihood-ratio | 617.449* | |
| Log-likelihood | -204.328 | |
| Deviance | 408.656 | |
| AIC | 424.656 | |
| BIC | 457.222 | |
| N | 433 | 433 |

- Estimates are based on an ordered probit model.
- Significance tests are two-tailed (* corresponds to $p < .05$).

Table 1: Support for articles of impeachment against Bill Clinton, November 1998

estimates was omitted in the standard model, the effect of ideology was understated by about 9 percent while the effect of Clinton’s district support on members’ votes was overstated by about 15 percent; as discussed above, the likely effect of not specifying measurement error in a variable is attenuation bias towards zero in its substantive effects, and this is what is found in this model. These findings would suggest that member ideology was a more critical component of the votes on impeachment than previously estimated, and that constituency preferences (as measured by district-level support for Clinton in 1996) were less important in determining legislators’ voting—whether retiring or not.

4 Application: Who Thinks Barack Obama is a Muslim?

When compared to legislator ideology measures, estimates of voter sophistication tend to have relatively high levels of measurement error, in large part because most surveys administered to voters have relatively few (if any) knowledge items, despite some evidence that “test fatigue” among respondents is not particularly problematic (Delli Carpini and Keeter, 1996).

However, one recent study with a wealth of knowledge items was the 2008–09 American National Election Studies (ANES) panel study (2009).¹¹ The study, administered over 11 waves (as of this writing) in a computer-based interviewing format to a random sample of U.S. adult citizens, included several waves in which

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questions regarding knowledge of American politics and the policy positions of presidential candidates Hillary Rodham Clinton, John McCain, and Barack Obama were asked of respondents. In addition, respondents were asked to identify the ideological leanings of these presidential candidates, allowing for the construction of “relative position” items in which respondents were scored on their ability to correctly identify that McCain was more conservative than either Clinton or Obama, similar to those described by Luskin (1987).

While not every respondent was asked to respond to every item in every wave, nonetheless the survey produced 135 political knowledge items.¹² These knowledge items were then used to construct a single-dimension item response theory model using the `MCMCirtKd` procedure in the `MCMCpack` package for R (Martin et al., 2009), including estimates of respondents’ sophistication and (crucially, for the SIMEX procedure) standard errors of these estimates.¹³

These estimates of respondents’ sophistication and the associated standard errors were then used to estimate a second-stage model of voter *misinformation*, attempting to identify what voter characteristics would explain the misapprehension that Barack Obama is Muslim.¹⁴ The 2008–09 panel study asked respondents in two waves—conducted in September and November 2008—a question asking respondents to identify Obama’s religion from a list of choices. In both waves, approximately 20%

¹²Questions regarding Clinton were only asked in Wave 6 of the survey. The 135 questions include several identical items that were administered at different times.

¹³The estimated level of sophistication from the model was validated against self-reported political interest and education level, and was positively correlated with both related measures as expected (Pearson’s r of 0.42 and 0.41, respectively). The average standard deviation of respondents’ sophistication estimates was approximately 0.298; the sophistication measure itself had a mean of 0.520 and standard deviation of 0.943.

¹⁴The study of the effects of political misinformation has been of recent interest to political scientists; examples include Gilens (2001); Kuklinski et al. (2000); and Nyhan and Reifler (2008).

of respondents identified Obama as a Muslim.¹⁵ In addition to the measure of sophistication derived above, other potential explanatory variables were included in the model: the respondents' party identification on a seven-point scale (coded from the traditional "branching" party identification questions), liberal-conservative self-identification (also coded from a branching format introduced in the panel study),¹⁶ level of formal education, and two constructed dummy variables: one indicating whether or not the respondent was African-American, and the other indicating whether or not the respondent believes the Bible to be the literal word of God (expected to correspond with adherence to fundamentalist Christianity).

A binary logit model was estimated using the covariates listed above, as well as selected interaction terms, using the `glm` procedure in R; in addition, a second SIMEX-corrected logit model was also estimated. The results from the models, estimated using the November wave responses to the question regarding Obama's religion, appear in Table 2.¹⁷ Although both models perform poorly in terms of classification accuracy, as we might expect in a situation with a lopsided outcome, several covariates (including, as expected, political sophistication) have statistically significant effects on the respondents' probabilities of believing Obama to be Muslim. Perhaps the most interesting finding is in the interaction between voter sophistication and belief in Biblical literalism; the combined effect of the interaction and main effects suggest that fundamentalist belief attenuates the influence of political knowledge on

¹⁵Interestingly, these figures are significantly *higher* than those encountered in other surveys, which pegged the percentage of Americans with this false belief around 10%; see e.g. Dimock (2008). Approximately 15% of respondents professed belief that Obama was Muslim in both waves, with approximately 25% indicating that Obama was Muslim in at least one of the waves.

¹⁶Both party identification and ideology were centered at 0; thus, party identification ranges from -3 (strong Democrat) to +3 (strong Republican) and ideology ranges from -3 (strongly liberal) to +3 (strongly conservative).

¹⁷The results of the September wave response model are very similar.

| | Standard Model | SIMEX Model |
|-----------------------------|--------------------|--------------------|
| (Intercept) | −0.113 (0.270) | −0.240 (0.279) |
| R’s sophistication | −0.870* (0.103) | −0.995* (0.118) |
| R’s party ID | 0.138* (0.036) | 0.139* (0.036) |
| R is black | −1.708* (0.374) | −1.727* (0.377) |
| R’s education | −0.284* (0.060) | −0.261* (0.061) |
| R’s ideology | 0.095* (0.046) | 0.100* (0.047) |
| R’s political interest | −0.085 (0.060) | −0.053 (0.062) |
| R belief in bib. literalism | 0.178 (0.129) | 0.144 (0.131) |
| Soph. × party ID | 0.089* (0.043) | 0.104* (0.050) |
| Soph. × ideology | −0.084 (0.052) | −0.099 (0.061) |
| Soph. × bib. lit. | 0.376* (0.128) | 0.427* (0.141) |
| McFadden R^2 | 0.147 | |
| Cox-Snell R^2 | 0.136 | |
| Nagelkerke R^2 | 0.216 | |
| Likelihood-ratio | 332.866* | |
| Log-likelihood | −963.175 | |
| Deviance | 1926.350 | |
| AIC | 1948.350 | |
| BIC | 2011.368 | |
| N | 2273 | 2273 |

- Estimates are based on a logistic regression (logit) model.
- Significance tests are two-tailed (* corresponds to $p < .05$).

Table 2: Misbelief about Barack Obama’s religion, 2008–09 ANES Panel Study

“correcting” false beliefs about Obama’s religious association. A similar, although less dramatic, interaction also appears associated with party identification.

Comparing the SIMEX and standard logit models, we find a similar pattern to that found previously in the model of House voting on impeachment: namely, that while the statistical significance of the effects does not appear to be affected by the use of simulation-extrapolation, the substantive effect of the variables measured with error is stronger in the SIMEX model. The most noteworthy effects are in sophistication and its interaction terms; all of these effects are less attenuated by the measurement error: sophistication is about 14% stronger in its direct effect in the SIMEX model, while the interactions with party identification and biblical literalism become 17% and 14% stronger respectively. It is also worth noting that the effect of self-reported political interest, which is correlated with sophistication, is diminished by 37% and the effect of education (also associated with political knowledge) decreases by 8%. Thus the SIMEX-corrected model suggests that political sophistication has a more dramatic effect on false belief in Obama’s adherence to Islam than we might otherwise have expected.

5 Conclusion

This paper has demonstrated the value of incorporating known measurement error in second-stage estimation when using estimates recovered from item-response theory models (or other techniques) using a simulation-extrapolation procedure established in the statistical literature and currently available in a number of statistical packages, including Stata and R.

In general, the SIMEX method reveals, as we would expect from statistical

theory, that the effects of covariates measured with error are *understated* in second-stage models that do not account for measurement error. While the present examples do not demonstrate dramatic differences in the statistical significance of the effects, they do reflect greater *substantive* significance of the effects of ideology and voter sophistication, respectively, as well as larger effects of estimated interaction terms. Even though statistical significance testing is an important element of social scientific research—allowing us to determine if the substantive effects we observe in our samples are likely to be replicated in the population at large—nonetheless the substantive effects themselves are important and should not be neglected, particularly in cases where we know the parameters are likely to be biased.

While the SIMEX technique does reduce bias in second-stage estimates, it could be improved to better account for *observation-level* uncertainty in the estimates. The procedure as currently described presently assumes that uncertainty is constant across observations, but in the case of using first-order measurement models that produce estimates of observation-level uncertainty (such as item-response theory models and W-NOMINATE with bootstrapped standard errors) we have additional information that could be used to improve second-stage estimates further. This would be particularly helpful when using observations where there is a great deal of missing information—whether they be absent or ill legislators, or survey respondents who only participated in a single wave of a panel study.

There are also potential applications of a related procedure, the misclassification SIMEX (Küchenhoff et al., 2006), particularly in addressing response bias problems in public opinion surveys, that are not addressed in this paper but may be of value. The misclassification SIMEX (MC-SIMEX) is an extension of the basic simulation-extrapolation procedure that allows the researcher to specify uncertainty in

nominal variables. For example, we know that respondents in surveys are likely to report voting when they did not and to misreport past votes (typically in favor of the winner); if we know the overall rate of misreporting—often possible by comparing the aggregate survey results with the known totals—the MC-SIMEX could be used to refine models of voter turnout and vote choice.

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