

Modeling Poverty Classification Using the Supplemental Poverty Measure

MTH 7393 - Bayesian Statistics

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Introduction

Background and Motivation

Poverty is a multifaceted phenomenon. It is one many of us have experienced. Some of us have escaped and others have perhaps fallen back into it. It's something I have lived through for a good portion of my adulthood. It's a complex topic and thankfully there are a lot of people dedicated to understanding it. The Census Bureau is one of those groups, though, I suppose they have an interest in most everything we as a society get up to.

Anyway, for some crucial background, how we quantify poverty has changed over time. The Census Bureau's own official poverty measure was crafted back in 1960 and was far simpler than I would ever assume. To quote the SSA, "The poverty thresholds associated with the official measure are the minimum amounts of such income that families of particular sizes and compositions need in order to be considered not poor. When they were developed, the official thresholds represented the cost of a minimum food diet multiplied by 3 (to allow for expenditures on other goods and services)" (Source). This measure of course resulted in a good degree of criticism and eventually the Census Bureau developed an alternative measure of poverty, the Supplemental Poverty Measure, or the SPM, back in 2011.

This new measure added a lot more nuance and they are still actively developing it to this day. What's useful about this is that, using their data, we get an insight into the variables impacting poverty that they have deemed as meaningful. This gives me a great jumping off point for digging into what affects the odds of a poverty classification. And what things matter is only part of the question. To what degree do those things matter is also very important. I want to identify the demographic variables that are most associated with the SPM poverty measure and to really see what those effects look like from a bayesian perspective. I aim to do that using logistic regression, so we'll be examining which variables influence the odds of a poverty measure from the SPM.

Data Tables and Sources

For this project I am pulling data directly from the census bureau. They have a list of enormous 900MB tables dating back to 2009 for the supplemental poverty measure. The table I am using is from their 2023 research table and so all of my analysis is limited to that year specifically. Thankfully this time I do not need to join to many tables; almost everything I need is contained in here. The only other table I need comes from the **tidycensus** package, which allows for the conversion of state FIPS codes to the corresponding state acronym. All of the datasets I used are linked in the github repository for this project.

It is worth pointing out again that this data is a simple snapshot from 2023. There are no year-over-year trends to examine or compare against and also no historical grounding in results. As such, it may be risky to generalize these results beyond the scope of 2023. I do believe there is still value at examining these snapshots and seeing what results they produce, however.

Results

Data Exploration

Data Reduction

The data taken from the Census Bureau has one row per person, containing approximately 3.2 million observations. This was obviously far too large for a bayesian analysis so a lot of data reduction was done. For starters, 800k rows were removed that had the educational category "NIU" or "Not In Universe". This was the only column that had any "missing" data and I felt it best to narrow down to the subset of the data that fell into the remaining educational categories.

After this, I performed stratified sampling on the categorical covariates. This was done to ensure that the same ratios for all of the categories are maintained while reducing the row count. This process is extremely important when working with many unbalanced categories, especially when doing a row reduction as extreme as what I am doing. I used a proportion of 0.005 to bring the sample size down to around 11000 rows. Without stratified sampling I likely would have lost many of the entire categories I need to keep for my analysis. So with this I

have a far more manageable dataset that at least maintains the information in the categorical covariates.

Variable	Description	Variable Type
spm_poor	Poverty status under SPM	Binary
spm_povthreshold	SPM poverty threshold for the unit	Continuous
region	Region of residence	Categorical
age	Age of individual	Continuous
mar	Married	boolean
sex_female	Is individual female	binary
education	Educational attainment	Categorical
race	Race	Categorical
hispanic	Hispanic ethnicity	Binary
agi	Adjusted gross income	Continuous
hi_premium	Health insurance premium	Continuous
moop_other	Medical out-of-pocket expenses	Continuous

Table 1: Variable Descriptions and Types

Response Variable: spm_poor

To start we will look at our response variable which represents a simple yes or no indicator on whether an individual is classified as poor by the SPM. All there really is to see here is a poverty rate of around 13%, roughly matching the Bureau's own reported numbers for the SPM. With boolean variables such as this there isn't a ton to say so that just about covers it. What'll be more interesting is seeing how it relates to other variables.

Covariate Candidates

Note that the below tables are created using only values from the stratified dataframe.

Covariate	Min	1st Quartile	Mean	Median	3rd Quartile	Max
Pov Threshold	11420	18236	26805	23626	33282	113199
Age	25	40	54.2	55	67	96
AGI	-5000	19966	89629	60000	118000	1520000
HI Premium	0	0	1782	540	2400	70259
MOOP	0	151	1302	500	1375	54586

Table 2: Summary of numeric candidates.

For this project I have quite a number of possible covariates to include and a lot of variation in data types as well.

Covariate	# Levels	Most Common Levels (Count)
Education	4	C: 4246, SC: 3155, HS: 2887, <HS: 966
Race	4	Wh: 8058, Oth: 1685, Bl: 852, Asi: 659
Region	4	S: 4335, W: 2623, MidW: 2346, NE: 1950

Table 3: Summary of categorical candidates.

Covariate	TRUE	FALSE
Hispanic	1379	9875
Married	6864	4390
Female	5914	5340

Table 4: Summary of boolean candidates.

Looking at our numeric candidates first, all of them have radically different scales and distributions. None of them are normal, not even close. Health insurance premium and medical out of pocket expenses both have nearly all of their density at 0 and then comically long tails. I think it would be extremely generous to even think of these as log-normal. I was immediately concerned about my ability to make these two candidates work. Adjusted gross income and the spm poverty threshold have a lot more variety going on in their distributions at least; they're both either bi-modal or multi-modal with a far right tail with AGI having a far more extreme maximum. Lastly, age is a lot more calm. It's more of a demographic variable so it's fairly even in density across the board with a steep dropoff after 75. To account for all of this variety I considered scaling all of these variables but I didn't want to deal with the additional issues with interpretation problems so I kept them as is. We will discuss this decision more later.

As for our categorical and boolean candidates, those are a lot easier to write about. Starting with married, it used to be marital status. However, it was extremely unbalanced and I wanted to keep the information from those smaller categories like divorced, widowed and separated. Similarly, region used to be state. Bringing that from 50 down to 4 categories is far more manageable, especially for stratified sampling. As for relationships to the response variable, the big one that jumps out to me is education. Less than a high school degree has a far larger proportion of those in poverty than the other options. So at first glance I would assume that candidate would end up mattering a lot.

Variable and Model Selection

For variable selection I initially tried a LASSO method. The goal here was to start with the full model and let the lasso penalty drag unnecessary covariates to zero. This method allowed me to greatly reduce the complexity of the model without hindering performance. However, two things got in the way of that at the last minute. The most important thing is that I made an enormous mistake. As of writing this report, I noticed that I had somehow forgot to include the binomial family in my rstanarm code. Rstanarm had been treating what I thought of as a logistic regression with a gaussian family. On top of that, fixing that little mixup caused the lasso regression to no longer work. It mostly just got stuck. So in my panic I have a new, sloppy, variable selection method to discuss.

For my new and hastily thrown together method, I simply ran the model and looked for possible candidates for removal. Any of the intervals that straddled or appeared extremely close to 0 were removed. I created 3 models this way. The first model is the full one and I noticed that I could potentially removed some of the messier numeric columns. So for the second model I got rid of health insurance premium, AGI, out of pocket medical expenses and age. From here I removed hispanic as it is highly correlated with race_other.

To compare the 3 models I looked at their WAIC scores and R_b^2 which are shown below. What shocked me was the drastic difference in model performance. Under my original and incorrect method this barely changed anything, but here we see the performance drop off of a cliff instantly. It is worth pointing out here that I did attempt running these models with the numeric variables scaled and their importance becomes far more obvious. For the sake of this project that is now falling apart at the seams I decided to keep them unscaled as it leads to some more interesting results and decisions.

Model	WAIC	Standard Error
Model 1 (Full)	4931.8	96.3
Model 2	7310	132.1
Model 3	7308.6	132.1

Table 5: Model Scores

So it goes without saying that I stuck with the full model here.

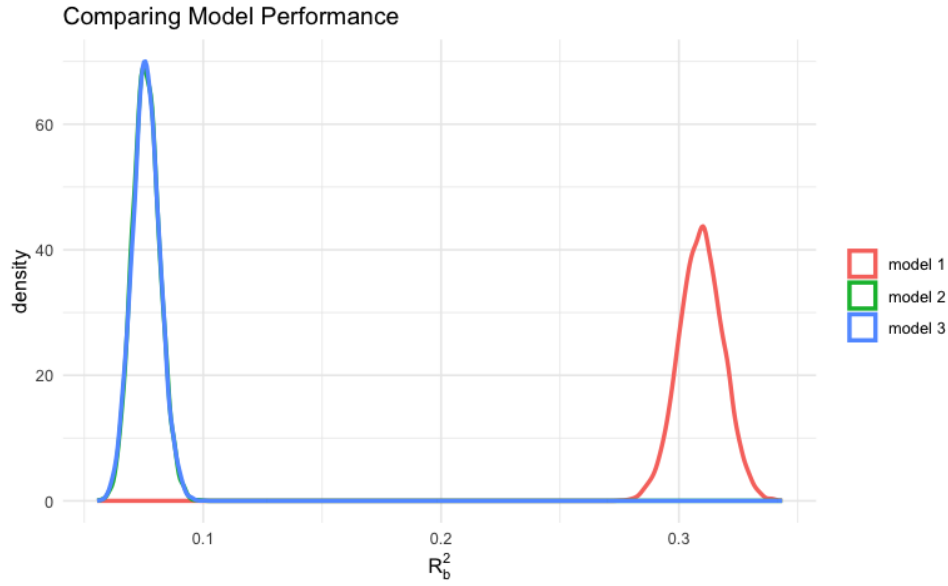


Figure 1: B^2_b Density Plot

Model Assessment

When checking the model, I was primarily interested in convergence diagnostics. I wanted to see whether any of the covariates exhibited strange behavior or failed to explore their parameter space effectively. I created several diagnostic plots, and all appeared well-behaved.

For the trace plots, the chains looked dense and well-mixed, with no obvious signs of them getting stuck or failing to explore the posterior. The posterior violin plots looked good too. For these, we expect the violins from different chains to have similar shapes and no unusual or highly skewed distributions. This is exactly what we got which is good.

I also examined the autocorrelation plots. These showed a steep drop off, suggesting low autocorrelation and good mixing across all covariates.

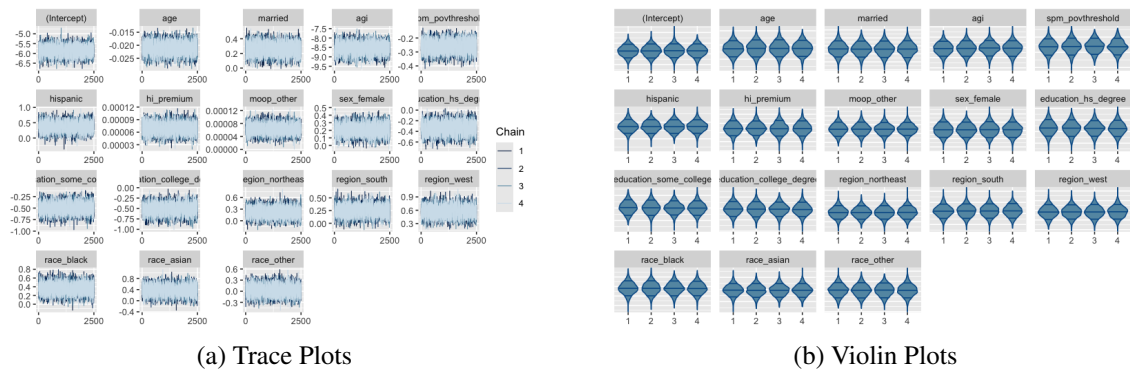


Figure 2: Model Assessment Examples

Final Model and Coefficient Interpretation

Covariate	Mean	5%	95%	Relation to 1
(Intercept)	3.77833	2.64188	5.42084	Above
age	0.97903	0.97536	0.98271	Below
married	1.29719	1.14371	1.47316	Above
agi	0.99992	0.99992	0.99993	Below
spm_povthreshold	0.99998	0.99997	0.99998	Below
hispanic	1.45169	1.12085	1.88613	Above
hi_premium	1.00007	1.00005	1.00009	Above
moop_other	1.00006	1.00004	1.00009	Above
sex_female	1.23250	1.09489	1.38985	Above
education_hs_degree	0.71205	0.59852	0.84880	Below
education_some_college	0.60940	0.50724	0.73408	Below
education_college_degree	0.59683	0.48618	0.73218	Below
region_northeast	1.24877	1.01936	1.53665	Above
region_south	1.27648	1.08145	1.51053	Above
region_west	1.76111	1.45638	2.13829	Above
race_black	1.43318	1.17342	1.74935	Above
race_asian	1.45619	1.08720	1.92860	Above
race_other	1.02326	0.80546	1.29865	Straddles

Table 6: 95% Credible Intervals for Model Covariate Odds Ratios: $\exp(\beta_i)$

Now that we know our final model seems to be well behaved we can discuss the actual results it has provided. Let's take a look at the posterior credible intervals. The table provided shows all of the intervals taken out of the log scale. So what we're looking for is whether an interval is above or below 1 as that will indicate to us how to interpret its effect.

Let us start with the intervals below 1. These covariates decrease the odds of being classified as in poverty by the supplemental poverty measure. The covariates here are age, adjusted gross income, spm poverty threshold, and all of the education categories with respect to the reference category.

For age, we see a reduction of 2.1% [1.7%, 2.5%] in the odds of being classified as in poverty per year increase. An important note here is that this type of relationship is not additive. This coefficient does not imply that someone who is 50 has 0 odds of being in poverty. This simply means that, given all other variables kept static, that someone who is older has lower odds of being classified as in poverty than someone who is younger.

AGI and poverty threshold I won't go into too much detail about. Their coefficients seem

extremely non-impactful, however we need to remember their values can get very large. The general interpretation is that as someones adjusted gross income and the poverty threshold assigned to them by the spm go up dollar by dollar, that their odds of being classified as in poverty decreases.

As for education, all of these categories reduce the odds of poverty classification quite a lot when compared to someone with less than a high school degree. For those with a high school degree, we see a reduction of 29%[15%,40%]. Similarly, we see reductions of 39%[27%,49%] and 40%[27%,51%] for some college and college degree respectively. Interestingly, some college and a college degree overlap almost entirely under this model. In my old model college degree was quite a bit more impactful.

The ones above 1 are quite interesting. Married in particular jumps out to me. The coefficient indicates an increase of 30%[14%,47%] in the odds of being classified as in poverty. What's so weird about this is every other model I have fit has married comfortably below 1. For reference, model 2 (a simplified version of this model) has married showing a decrease of around 65% in the odds. This final model showing an increase in the odds is very shocking to me both mathematically and practically. Even looking at a bar plot of this variable, there is a far higher proportion of those classified as in poverty in the not married category. I'm really not sure what's going on here.

Medical out of pocket expenses and health insurance premium are similar to agi and poverty threshold yet these increase the odds of a poverty classification as they increase. Again, these coefficients seem extremely close to 1 but these variables get large enough that they still have a large impact when you start reaching realistic values.

For our binary variables, being female shows an increase in the odds of a poverty classification by 23%[9%,39%]. Of note that this increase is a large jump from my older non-logistic regression models. This one used to be a small enough impact that I just removed it entirely. As for hispanic, we have an extremely large interval. We see an increase in the odds of a poverty classification by 45%[12%,89%]. It is worth noting that this large interval is likely due in part to its correlation to race_other and them fighting over their impact.

For region, the reference category being used is the midwest. So all of the odds ratio

changes are with respect to that. We see a ranking of west, south, northeast in terms of their increases in the odds of a poverty classification with west having the highest increase of 76% [46%, 114%] when compared to the midwest. I think many would assume that the south would have the highest increase in these odds however it is just slightly higher than the northeast showing of 28% [8%, 51%] in the odds of a poverty classification when compared to the midwest.

Lastly we have race which has white as the reference category. All the categories excluding other show an increase in the odds of a poverty classification. Black shows an increase of 43% [17%, 75%] and asian shows an increase of 46% [9%, 93%]. I believe it's worth pointing out that the large interval of asian. This is surprising due to it having a similar sample size in the final dataset as black with $n = 659$ and $n = 852$ respectively. As for the other category, this one straddles 1 but this almost certainly due to its correlation to hispanic. Models with an without hispanic shift its distribution quite a lot.

Conclusion

The conclusions from this project have become a little muddier than I had originally thought just a few days ago. This was a project that had gone remarkably smoothly and without issue up until today. To be frank I didn't have much in mind for the conclusion; many of the results were difficult for me to discuss beyond a surface level due to a lack of education in the realm of poverty. However, now that I am actually doing the project I thought I was doing all along we have more to discuss.

First, let's cover some limitations and concerns I have about my variable selection process. This wasn't something I was ever really able to nail down. Until I thought about lasso regression I was kind of just throwing models at the wall and comparing WAIC scores. This is extremely inefficient and non-rigorous and I can't help but feel desperate for a better method. With how computationally complex bayesian modeling is I am cautious over fitting many models. I know that I am definitely not using all of the tools for gauging model performance at my disposal so I wish I was better about that with this project. I want to carry this frustration forward to learn

the basic modeling workflow of people who use these types of models professionally.

I think this frustration also comes from this dataset just being very well thought out. The census bureau has had a long time to craft a clean dataset with the variables they are confident are important. What this means is I rarely had covariates actually straddling zero, so a lot of my model simplifications were done purely off of the desire to try something. What a fascinating problem to run into.

I am also curious about scaling vs. not scaling the numeric variables. I definitely needed to do something to them, many of their distributions were so awkward that I wasn't quite sure how to handle them. Scaling them seems like a good call, but it hurts interpretation and I'm not sure if there is more I should have done on top of that. Adjusted gross income is a good example of this awkwardness. One may reasonably look at that distribution and find a log transformation appropriate for addressing its extreme right tail. However, that variable contains many zeros and negative values making that no longer feasible.

As for the results themselves, they actually make me ask more questions. I am now very curious to see what this model trained on different years would look like. How would the intervals for the 2015 model compare to this one? What would happen if I looked at a specific region or state and dug into more granular details? I am now also so extremely curious about the enormous flip the marriage variable made. It makes no sense to me how it could have such a strong increase in the odds of a poverty classification. My only hunch is that it has a relationship I hadn't accounted for in the numeric variables because it flips to an odds decrease when they are removed. If I had found this sooner I would have dug into this very deeply.

Overall though, to actually do some thinking on the topic it is always surreal to see statistics you're used to hearing reflected in the data. People of color are disproportionately affected by so many aspects of poverty and we see that odds increase here in my simple model. Women also experience higher rates of poverty and face many employment struggles in male dominated spaces and we see the odds increase here. Part of me also worries about how the hispanic poverty rate may change in the coming years with frequent ICE raids and mass deportations. Obviously there is more nuance to it and I didn't even include the bulk of the information contained in the original dataset but these thoughts remind of what I was really looking at here.

I think often it's easy to work on a dataset and forget what it really is. It's easy to get lost in the methods, the numbers and the errors. We shouldn't forget that in this table each row is a person with a life and a family. This isn't just data, these are people and I think that's part of what can be so sobering about seeing reality reflected in the analysis. This dataset is so recent that many of the people classified as in poverty then are probably still there. In a way it almost feels wrong to use their suffering for a simple class project I threw together on a whim. I suppose this is just another reminder that I need to do something good with what I've learned over the years.

Appendix

As with my regression final project all of the data/code/etc are contained in the repository below.

Github Repository: [Link](#)