Multinomial Discrete Choice: Nested Logit and GEV

Chris Conlon

September 16, 2020

Grad IO

Multinomial Logit: IIA

The multinomial logit is frequently criticized for producing unrealistic substitution patterns

- Suppose we got rid of a product k then $s_{ij}(\mathcal{J} \setminus k) = s_{ij}(\mathcal{J}) \cdot \frac{1}{1-s_{ik}}$.
- Substitution is just proportional to your pre-existing shares s_j
- No concept of "closeness" of competition!

Can we do better?

Multinomial Probit?

- The probit has $\varepsilon_i \sim N(0, \Sigma)$.
- If Σ is unrestricted, then this can produce relatively flexible substitution patterns.
- Flexible is relative: still have normal tails, only pairwise correlations, etc.
- It might be that ρ_{12} is large if $1, 2$ are similar products.
- Much more flexible than Logit

Downside

- Σ has potentially J^2 parameters (that is a lot)!
- Maybe $J * (J-1)/2$ under symmetry. (still a lot).
- Each time we want to compute $s_j(\theta)$ we have to simulate an integral of dimension J.
- I wouldn't do this for $J \geq 5$.

Relaxing IIA

Let's make ε_{ij} more flexible than IID. Hopefully still have our integrals work out.

$$u_{ij} = V_{ij} + \varepsilon_{ij}$$

- One approach is to allow for a block structure on ε_{ij} (and consequently on the elasticities).
- We assign products into groups g and add a group specific error term

$$u_{ij} = V_{ij} + \eta_{ig} + \varepsilon_{ij}$$

- The trick putting a distribution on $\eta_{ig} + \varepsilon_{ij}$ so that the integrals still work out.
- Do not try this at home: it turns out the required distribution is a special case of GEV (more on this later) and the resulting model is known as the nested logit.

Nested Logit

A traditional (and simple) relaxation of the IIA property is the Nested Logit. This model is often presented as two sequential decisions.

- First consumers choose a category (following an IIA logit).
- Within a category consumers make a second decision (following the IIA logit).
- This leads to a situation where while choices within the same nest follow the IIA property (do not depend on attributes of other alternatives) choices among different nests do not!

Alternative Interpretation

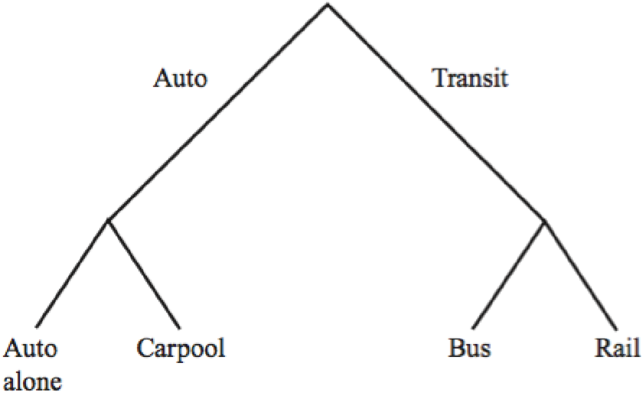

Figure 4.1. Tree diagram for mode choice.

Nested Logit

Utility looks basically the same as before:

$$U_{ij} = V_{ij} + \underbrace{\eta_{ig} + \widetilde{\varepsilon_{ij}}}_{\varepsilon_{ij}(\lambda_g)}$$

- We add a new term that depends on the group g but not the product j and think about it as varying unobservably over individuals i just like ε_{ij}.
- Now $\varepsilon_i \sim F(\varepsilon)$ where $F(\varepsilon) = \exp[-\sum_{g=G}^{G}\left(\sum_{j\in J_g}\exp[-\varepsilon_{ij}/\lambda_g]\right)^{\lambda_g}$. This is no longer Type I EV but a special kind of GEV.
- The key is the addition of the λ_g parameters which govern (roughly) the within group correlation.
- This distribution is a bit cooked up to get a closed form result, but for $\lambda_g \in [0,1]$ for all g it is consistent with random utility maximization.

Nested Logit

The nested logit choice probabilities are:

$$s_{ij} = \frac{e^{V_{ij}/\lambda_g} \left(\sum_{k \in J_g} e^{V_{ik}/\lambda_g}\right)^{\lambda_g - 1}}{\sum_{h=1}^{G} \left(\sum_{k \in J_h} e^{V_{ik}/\lambda_h}\right)^{\lambda_h}}$$

Within the same group g we have IIA and proportional substitution

$$\frac{s_{ij}}{s_{ik}} = \frac{e^{V_{ij}/\lambda_g}}{e^{V_{ik}/\lambda_g}}$$

But for different groups we do not:

$$\frac{s_{ij}}{s_{ik}} = \frac{e^{V_{ij}/\lambda_g} \left(\sum_{k \in J_g} e^{V_{ik}/\lambda_g}\right)^{\lambda_g - 1}}{e^{V_{ik}/\lambda_h} \left(\sum_{k \in J_h} e^{V_{ik}/\lambda_h}\right)^{\lambda_h - 1}}$$

Nested Logit

We can take the probabilities and re-write them slightly with the substitution that $\log\left(\sum_{k \in J_g} e^{V_{ik}}\right) \equiv IV_{ig} = E_\varepsilon[\max_{j \in G} u_{ij}]$:

$$
\begin{aligned}
s_{ij} &= \frac{e^{V_{ij}/\lambda_g}}{\left(\sum_{k \in J_g} e^{V_{ik}/\lambda_g}\right)} \cdot \frac{\left(\sum_{k \in J_g} e^{V_{ik}/\lambda_g}\right)^{\lambda_g}}{\sum_{h=1}^{G}\left(\sum_{k \in J_h} e^{V_{ik}/\lambda_h}\right)^{\lambda_h}} \\
&= \underbrace{\frac{e^{V_{ij}/\lambda_g}}{\left(\sum_{k \in J_g} e^{V_{ik}/\lambda_g}\right)}}_{s_{ij|g}} \cdot \underbrace{\frac{e^{\lambda_g IV_{ig}}}{\sum_{h=1}^{G} e^{\lambda_h IV_{ih}}}}_{s_{ig}}
\end{aligned}
$$

This is the decomposition into two logits that leads to the "sequential logit" story.

Nested Logit : Notes

- $\lambda_g = 1$ is the simple logit case (IIA)
- $\lambda_g \to 0$ implies that all consumers stay within the nest.
- $\lambda < 0$ or $\lambda > 1$ can happen and usually means something is wrong. These models are not generally consistent with RUM. (If you report one in your paper I will reject it).
- λ is often interpreted as a correlation parameter and this is almost true but not exactly!
- Because the nested logit can be written as the within group share $s_{ij|g}$ and the share of the group s_{ig} we often explain this model as sequential choice. It could just be a block structure on ε_i.
- You need to assign products to categories before you estimate and you can't make mistakes!

Parametric Identification

Look at derivatives:

$$\frac{\partial\, s_{ij|g}}{\partial X_j} = \beta_x \cdot s_{ij|g} \cdot (1 - s_{ij|g})$$
$$\frac{\partial\, s_{ig}}{\partial X} = (1 - \lambda_g) \cdot \beta_x \cdot s_{ig}(1 - s_{ig})$$
$$\frac{\partial\, s_{ig}}{\partial J} = \frac{1 - \lambda_g}{J} \cdot s_{ig} \cdot (1 - s_{ig})$$

- We get β by changing x_j within group
- We get nesting parameter λ by varying X
- We don't have any parameters left to explain changing number of products J.
- Estimation happens via MLE. This can be tricky because the model is non-convex. It helps to substitute $\tilde{\beta} = \beta/(1 - \lambda_g)$

A Confusing Gotcha

An alternative version of the nested logit is popular in IO (Cardell 1991) $\sigma \approx 1 - \lambda$:

$$s_{ij|g} = \frac{e^{V_{ij}/(1-\sigma)}}{D_{ig}} \qquad D_{ig} = \log\left(\sum_{j \in \mathcal{G}} e^{V_{ij}/(1-\sigma)}\right)$$

$$s_{ig} = \frac{D_{ig}^{(1-\sigma)}}{\sum_g D_{ig}^{(1-\sigma)}} \qquad s_{ij} = s_{ij|g} \cdot s_{ig} = \frac{\exp\left(\frac{V_{ij}}{1-\sigma}\right)}{D_g^{\sigma}\left[\sum_g D_g^{(1-\sigma)}\right]}$$

Derivatives for nested logit are complicated and worked out at `http://www.nathanhmiller.org/nlnotes.pdf`.

Substitution Patterns

It is helpful to define: $Z(\sigma, s_g) = [\sigma + (1-\sigma)s_g] \in (0,1]$ and note that $Z(0, s_g) = s_g$ and $Z(1, s_g) = 1$. If two products are in the same nest or different nests respectively:

$$-\frac{\frac{\partial s_k}{\partial p_j}}{\frac{\partial s_j}{\partial p_j}} | \text{ same} = \frac{s_{k|g}}{Z^{-1}(\sigma, s_g) - s_{j|g}} \equiv D^*_{jk}$$

$$-\frac{\frac{\partial s_k}{\partial p_j}}{\frac{\partial s_j}{\partial p_j}} | \text{ different} = \frac{s_k(1-\sigma)}{1 - s_{j|g} \cdot Z(\sigma, s_{g(j)})} \equiv D^{**}_{jk}$$

These are related by:

$$D^{**}_{jk} = D^*_{jk} \cdot \frac{s_{g(k)} \cdot (1-\sigma)}{Z(\sigma, s_{g(j)})}$$

GEV Variants

There are more potential generalizations though they are less frequently used:

- You can have multiple levels of nesting: first I select a size car (compact, mid-sized, full-sized) then I select a manufacturer, finally a car.
- You can have potentially overlapping nests: Yogurt brands are one nest, Yogurt flavors are a second nest. This way strawberry competes with strawberry and/or Dannon substitutes for Dannon.

McFadden (1978) and GEV

In case you are wondering where these things come from...

$$s_{ij}(\mathcal{J}) = \frac{y_{ij} \cdot \frac{\partial G_i}{\partial y_j}(y_{i1}, \ldots, y_{iJ})}{\mu \cdot G(y_{i1}, \ldots, y_{iJ})}$$

With conditions on the generator function G:

1. $G(\cdot)$ is homogenous of degree $\mu > 0$ so that $G(\alpha y) = \alpha^{\mu} G(y)$
2. $\lim_{y_j \to +\infty} G(y_1, \ldots, y_j, \ldots, y_J) = +\infty$, for each $j \in \mathcal{J}$
3. the k th partial derivative with respect to k distinct y_j is non-negative if k is odd and non-positive if k is even that is, for any distinct indices $i_1, \ldots, i_k \in \mathcal{J}$, we have

$$(-1)^k \frac{\partial^k G}{\partial x_{i_1} \ldots \partial x_{i_k}}(x) \leq 0, \forall x \in \mathbb{R}_+^J$$

The objects are more mathematical than economic...

McFadden (1978) and GEV

This is much easier with an example:

$$s_{ij}(\mathcal{J}) = \frac{y_{ij} \cdot \frac{\partial G_i}{\partial y_j}\left(y_{i1}, \ldots, y_{iJ}\right)}{\mu \cdot G_i\left(y_{i1}, \ldots, y_{iJ}\right)}$$

- If $y_j = e^{V_{ij}}$ and $G_i = \log \sum_{j \in \mathcal{J}} y_{ij}$ we get the IIA logit.
- If $y_j = e^{V_{ij}}$ and $G_i = \sum_{h=1}^{H} \left(\sum_{j \in B_h} Y_{ij}^{1/\lambda_h}\right)^{\lambda_h}$ we get the nested logit.
- ... if $G_i = \sum_{h=1}^{H} \left(\sum_{j \in B_h} \left(\alpha_{jh} Y_{ij}\right)^{1/\lambda_k}\right)^{\lambda_k}$ we get generalized nested logit (GNL).
- ... if $G = \sum_{k=1}^{J-1} \sum_{l=k+1}^{J} \left(y_{ik}^{1/\lambda_{kl}} + y_{il}^{1/\lambda_{kl}}\right)^{\lambda_{kl}}$ we get pairwise combinatorial logit (PCL).
- there are a number of other cross nested logit variants with slightly different setups (from each other).

GEV and Variants

What's next?

- Many of these GEV and variants are found in the engineering literature (particularly traffic problems, civil engineering, and industrial engineering).
- Economists tend to use either nested logit or mixed logit (next lecture).
- Part of the issue is that it is hard to understand the restrictions on the G function and the economic meaning of the patterns produced by some of these models.
- But they may be more parsimonious and easier to estimate than the alternatives.