

# Defining Effect Methods for Other Models

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March 22, 2020

The **effects** package in R is designed primarily to draw graphs that visualize a fitted response surface of a fitted model in problems with a linear predictor. Many modeling paradigms that can be fit with base R or contributed packages fit into this framework, including methods for linear, multivariate linear, and generalized linear models fit by the standard **lm** and **glm** functions and by the **svyglm** function in the **survey** package (Lumley, 2004); linear models fit by generalized least squares using the **gls** function in the **nlme** package (Pinheiro et al., 2016); multinomial regression models fit by **multinom** in the **nnet** package (Venables and Ripley, 2002); ordinal regression models using **polr** from the **MASS** package (Venables and Ripley, 2002) and **c1m** and **c1m2** from the **ordinal** package (Christensen, 2015); linear and generalized linear mixed models using the **lme** function in the **nlme** package (Pinheiro et al., 2016) and the **lmer** and **glmer** functions in the **lme4** package (Bates et al., 2015); linear and generalized linear mixed models fit with penalized quasikelihood (PQL) (Venables and Ripley, 2002), and latent class models fit by **poLCA** in the **poLCA** package (Linzer and Lewis, 2011). This is hardly an exhaustive list of fitting methods that are based on a linear predictor, and we have been asked from time to time to write functions to use **effects** with this other fitting methods. The mechanism for this is fairly simple. This vignette assumes you are familiar with R's S3 methods.

The default **Effect.default** may work with some modeling functions, as would objects of the class **gls** that we describe below in Section 1, but as illustrated in later sections you may need to modify some of the arguments that are sent to **Effect.default**.

The **effect** package has five functions that create the information needed for drawing effects plots, **Effect**, **allEffects**, **effect** and **predictorEffect** and **predictorEffects**. To add new modeling to the package only a new **Effect** needs to be written; the package will take care of all the other functions.

# 1 Using effects with Other Modeling Methods, with Generalized Least Squares in the nlme package as an Example

Applying `effects` to other than `lm` and `glm` objects may require writing an method for the `Effect` generic function for that type of model object. For example, the `gls` function in the `nlme` package (Pinheiro et al., 2018) fits linear models via generalized least squares. A call to `gls` creates an object of class `gls`. The following function `Effect.gls` provides a method for `gls` objects by finding the information needed to draw effects plots from `gls` objects:

```
Effect.gls <- function(focal.predictors, mod, ...){
  cl <- mod$call
  cl$weights <- NULL
  args <- list(
    type = "glm",
    call = cl,
    formula = formula(mod),
    family = NULL,
    coefficients = coef(mod),
    vcov = as.matrix(vcov(mod)),
    method=NULL)
  Effect.default(focal.predictors, mod, ..., sources=args)
}
```

The `Effect.gls` function has three required arguments, `focal.predictors` and `mod` that match the first two arguments of `Effect.default`, and `...` that matches any other arguments you would like to pass to `Effect.default`; see `help(Effect)` for a list of these arguments.

The body of the function simply harvests the needed information from the `mod` object, and stores them in a list of named elements called `sources`. The `sources` list is then passed as a named argument to the default `Effect` method.

The named elements in `sources` include:

**type** The `effects` package has three basic modeling functions: `type = "glm"`, the default, is used for functions with a univariate response and a linear predictor and possibly a link function. This class includes linear models, generalized linear models, robust regression, generalized least squares fitting, linear and generalized linear mixed effects models, and many others. The `type = "polr"` is used for ordinal regression models, as in the `polr` function in the `MASS` package, and similar methods described below in Section 7. The `type = "multinom"` for multinomial log-linear models as fit by the `multinom` function in `nnet`, and to polytomous latent class models created with the `poLCA` function in the `poLCA` package. The default is `type = "glm"`.

**call** The `Effect.default` method may use the `call` to set additional arguments that it needs. For `type="glm"`, for example, these arguments are `formula`, `data`, `contrasts`, `subset`, `family`, `weights`, and `offset`, although only the `formula` argument is required. The `gls` function includes an optional `weights` argument that is used differently from the `weights` argument for a generalized linear model and is not needed for computing effects or predictor effects plots. In the function shown above the `call` is modified by setting `weights=NULL`.

The default for `call` is `mod$call` for S3 objects and `mod@call` for S4 objects.

**formula** In most cases the formula for the linear predictor is returned by `formula(mod)`, the default, but if this is not the case the value of this argument should be the value of the formula for fixed effects.

**family** The default is `family=NULL`. This argument is required for GLM-like models that include a `family` that specifies both an error distribution and a link function only if `family=family(mod)` is not appropriate. See the `betareg` example in Section 6 below for an example that includes a user-selected link function, but a fixed error distribution.

**coefficients** In many cases the (fixed-effect) coefficient estimates are returned by `coef(mod)`, the default, but if this is not the case then the value of this argument should be the estimates of the coefficients in the linear predictor. The functions in the `effects` package do not use estimates of random effects.

**zeta** Ordinal regression models return both a set of regression coefficients and also a set of *thresholds*. In the `polr` function the regression coefficients and the thresholds are stored in separate vectors, but in other ordinal regression programs, such as `clm` in the `ordinal` package they are stored as a single vector. See Section 7 for an example of the use of this argument for specifying the values of the thresholds.

**vcov** In many cases the estimated covariance matrix of the (fixed-effect) coefficient estimates is returned by `vcov(mod)`, the default, but if this is not the case then the value of this argument should be the estimated covariance matrix of the (fixed-effect) coefficient estimates in the linear predictor.

**method** This argument is used only for methods that use effects graphics based on the `polr` function, where the argument `method` is the name of a link function; see `help(polr)` for a list of the accepted links, and see Section 7.1 below for an example.

The only non-default argument in `sources` in `Effect.gls` is the modification of the `call` to omit weights in the call to `gls`. Had this change not been needed, there would be no need to have written the `Effect.gls` method, as the default method would have worked.

```
library(effects)

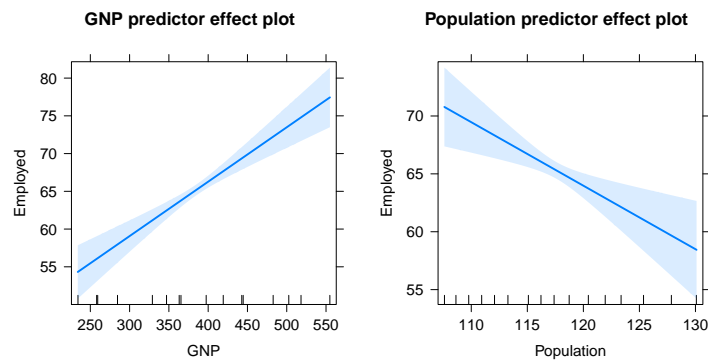
Loading required package: carData

lattice theme set by effectsTheme()
See ?effectsTheme for details.

require(nlme)

Loading required package: nlme

g <- gls(Employed ~ GNP + Population,
         correlation=corAR1(form= ~ Year), data=longley)
plot(predictorEffects(g))
```



## 2 Mixed Effects with lme (nlme package)

The `lme` function in the `nlme` package (Pinheiro et al., 2018) fits linear mixed models. The required function for fitted objects from this function is included in the `effects` package. It is given by

```
print(Effect.lme)

function(focal.predictors, mod, ...){
  args <- list(
    call = mod$call,
    formula = mod$call$fixed,
    coefficients = mod$coefficients$fixed,
    vcov = mod$varFixed)
  Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f871532dc48>
<environment: namespace:effects>
```

The `formula`, `coefficients` and `vcov` arguments are set to non-default values. The other arguments are automatically set to default values, with `call` set explicitly and other arguments set implicitly.

```
data(Orthodont, package="nlme")
m1 <- nlme::lme(distance ~ age + Sex, data=Orthodont,
               random= ~ 1 | Subject)
as.data.frame(Effect("age", m1))
```

	age	fit	se	lower	upper
1	8.0	22.04259	0.4172841	21.21520	22.86999
2	9.5	23.03287	0.3853671	22.26876	23.79698
3	11.0	24.02315	0.3741236	23.28133	24.76497
4	12.0	24.68333	0.3791619	23.93153	25.43514
5	14.0	26.00370	0.4172841	25.17631	26.83110

### 3 Mixed Effects with the lmer (lme4 package)

The `lme4` package (Bates et al., 2015) fits linear and generalized linear mixed effects models with the `lmer` and `glmer` functions, respectively. The same `Effect` function can be used for `lmer` and `glmer` models.

The following method is a little more complicated because it contains an additional argument `KR` to determine if the Kenward-Roger coefficient covariance matrix is to be used to compute effect standard errors. The default is `FALSE` because the computation is very slow. If `KR = TRUE`, the function also checks if the `pbkrtest` package is present.

```
print(Effect.merMod)

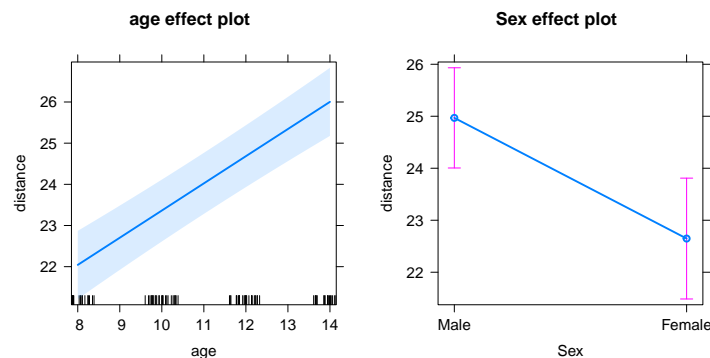
function(focal.predictors, mod, ..., KR=FALSE){
  if (KR && !requireNamespace("pbkrtest", quietly=TRUE)){
    KR <- FALSE
    warning("pbkrtest is not available, KR set to FALSE")}
  fam <- family(mod)
  args <- list(
    call = mod@call,
    coefficients = lme4::fixef(mod),
    family=fam,
    vcov = if (fam$family == "gaussian" && fam$link == "identity" && KR)
      as.matrix(pbkrtest::vcovAdj(mod)) else as.matrix(vcov(mod))
  Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f8715b67fa0>
<environment: namespace:effects>
```

Because `lmer` is an S4 object, the default for `call` is `mod@call`, and this argument would have been set automatically had we not included it in the above

method. The fixed-effect estimates for an object created by a call to `lmer` or `glmer` are not returned by `coef(mod)`, so the value of `coefficients` is the value returned by `lme4::fixef(mod)`. The `vcov` estimate contains its estimated variance covariance matrix of the fixed effects. The Kenward-Roger method is used to estimate the covariance matrix for linear models if the additional argument `KR=TRUE`. The default is `KR=FALSE` because The Kenward-Roger estimate requires a long computation; see `help(Effect)`.

The `formula` for a mixed-effects model in the `lme4` package specifies linear predictors for both the mean function and the variance functions, specified by, for example `(1 + age | Subject)`. The `effects` code will automatically remove any terms like these in any formula, as the effects package only displays the mean function.

```
fm2 <- lme4::lmer(distance ~ age + Sex + (1 | Subject), data
                  = Orthodont)
plot(allEffects(fm2))
```



```
data(cbpp, package="lme4")
gm1 <- lme4::glmer(cbind(incidence, size - incidence) ~ period + (1 | herd),
                  data = cbpp, family = binomial)
as.data.frame(predictorEffect("period", gm1))
```

	period	fit	se	lower	upper
1	1	0.19807921	0.03672693	0.13569522	0.2798569
2	2	0.08391784	0.02363110	0.04775453	0.1433443
3	3	0.07401714	0.02241762	0.04040242	0.1317591
4	4	0.04842565	0.01959184	0.02163871	0.1048199

## 4 Linear and Generalized Linear Mixed Models Fit With glmmPQL

Venables and Ripley (2002) provide a penalized quasi-likelihood function for fitting linear and generalized linear mixed models in their `MASS` package. The

following function added to **effects** in March 2020 allows these fitted models to be used with the **effects** package

```
print(Effect.glmmPQL)

function(focal.predictors, mod, ...){
  args <- list(
    coefficients = mod$coefficients$fixed,
    family = mod$family)
  Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f8716743160>
<environment: namespace:effects>
```

## 5 Robust Linear Mixed Models (robustlmm package)

The **rlmer** function in the **robustlmm** package (Koller, 2016) fits linear mixed models with a robust estimation method. As **rlmer** closely parallels the **lmer** function, an object created by **rlmer** is easily used with **effects**:

```
print(Effect.rlmerMod)

function(focal.predictors, mod, ...){
  args <- list(
    coefficients = lme4::fixef(mod),
    family=family(mod))
  Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f8715c5c220>
<environment: namespace:effects>

require(lme4)
fm3 <- robustlmm::rlmer(distance ~ age * Sex + (1 |Subject),
                        data = Orthodont)
plot(predictorEffects(fm3))
```

## 6 Beta Regression

The **betareg** function in the **betareg** package (Grün et al., 2012) fits regressions with a link function but with Beta distributed errors.

```
print(Effect.betareg)

function(focal.predictors, mod, ...){
  coef <- mod$coefficients$mean
```

```

    vco <- vcov(mod)[1:length(coef), 1:length(coef)]
# betareg uses beta errors with mean link given in mod$link$mean.
# Construct a family based on the binomial() family
fam <- binomial(link=mod$link$mean)
# adjust the varince function to account for beta variance
fam$variance <- function(mu){
  f0 <- function(mu, eta) (1-mu)*mu/(1+eta)
  do.call("f0", list(mu, mod$coefficient$precision))}
# adjust initialize
fam$initialize <- expression({mustart <- y})
args <- list(
  call = mod$call,
  formula = formula(mod),
  family=fam,
  coefficients = coef,
  vcov = vco)
Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f871697c820>
<environment: namespace:effects>

```

Beta regression has a response  $y \in [0, 1]$ , with the connection between the mean  $\mu$  of the Beta and a set for predictors  $\mathbf{x}$  through a link function  $\mathbf{x}'\boldsymbol{\beta} = g(\mu)$ . The variance function for the beta is  $\text{var}(y) = \mu(1 - \mu)/(1 + \phi)$ , for a precision parameter  $\phi$  estimated by **betareg**.

The call to **betareg** does not have a family argument, although it does have a link stored in `mod$link$mean`. For use with `Effect.default`, the method above creates a family from the binomial family generator. It then adjusts this family by changing from binomial variance to the variance for the beta distribution. Since the `glm` function expects a variance that is a function of only one parameter, we fix the value of the precision  $\phi$  at its estimator from the **betareg** fit. We need to replace the `initialize` method in the family to one appropriate for  $y \in [0, 1]$ .

```
require(betareg)
```

Loading required package: betareg

```

require(lme4)
data("GasolineYield", package = "betareg")
gy_logit <- betareg(yield ~ batch + temp, data = GasolineYield)
summary(gy_logit)

```

Call:

```
betareg(formula = yield ~ batch + temp, data = GasolineYield)
```



Standardized weighted residuals 2:

Min	1Q	Median	3Q	Max
-2.8750	-0.8149	0.1601	0.8384	2.0483

Coefficients (mean model with logit link):

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	-6.1595710	0.1823247	-33.784	< 2e-16
batch1	1.7277289	0.1012294	17.067	< 2e-16
batch2	1.3225969	0.1179020	11.218	< 2e-16
batch3	1.5723099	0.1161045	13.542	< 2e-16
batch4	1.0597141	0.1023598	10.353	< 2e-16
batch5	1.1337518	0.1035232	10.952	< 2e-16
batch6	1.0401618	0.1060365	9.809	< 2e-16
batch7	0.5436922	0.1091275	4.982	0.000000629
batch8	0.4959007	0.1089257	4.553	0.000005297
batch9	0.3857930	0.1185933	3.253	0.00114
temp	0.0109669	0.0004126	26.577	< 2e-16

Phi coefficients (precision model with identity link):

	Estimate	Std. Error	z value	Pr(> z )
(phi)	440.3	110.0	4.002	0.0000629

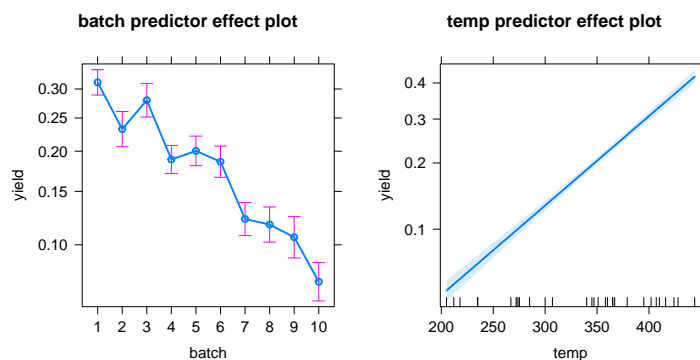
Type of estimator: ML (maximum likelihood)

Log-likelihood: 84.8 on 12 Df

Pseudo R-squared: 0.9617

Number of iterations: 51 (BFGS) + 3 (Fisher scoring)

`plot(predictorEffects(gy_logit))`



## 7 Ordinal Models (ordinal package)

Proportional odds logit and probit regression models fit with the `polr` function in the `MASS` package (Venables and Ripley, 2002) are supported in the `effects`

package. The `ordinal` package, (Christensen, 2015) contains three functions that are very similar to `polr`. The `clm` and `clm2` functions allow more link functions and a number of other generalizations. The `clmm` function allows including random effects.

## 7.1 `clm`

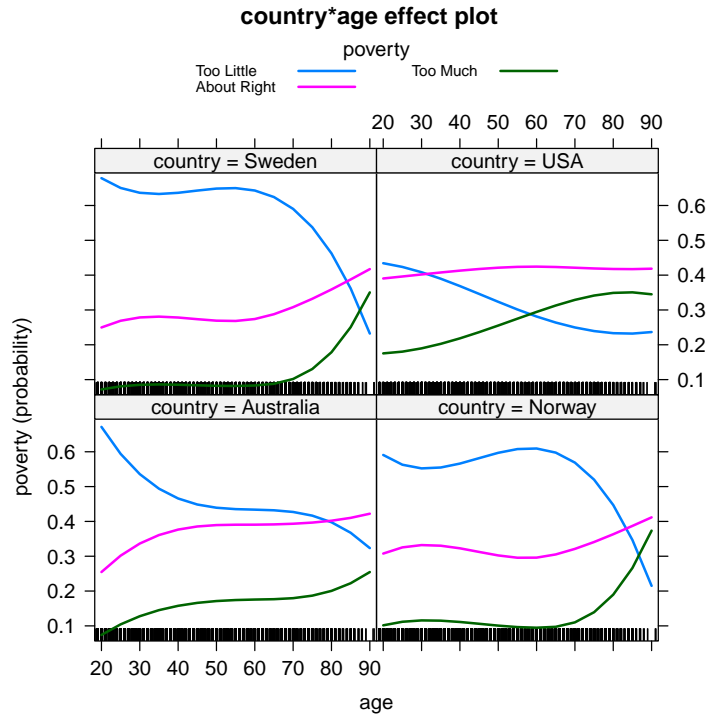
```
print(Effect.clm)

function(focal.predictors, mod, ...){
  if (requireNamespace("MASS", quietly=TRUE)){
    polr <- MASS::polr} else stop("MASS package is required")
  polr.methods <- c("logistic", "probit", "loglog",
                    "cloglog", "cauchit")
  method <- mod$link
  if(method == "logit") method <- "logistic"
  if(!(method %in% polr.methods))
    stop("'link' must be a 'method' supported by polr; see help(polr)")
  if(mod$threshold != "flexible")
    stop("Effects only supports the 'flexible' threshold")
  numTheta <- length(mod$Theta)
  numBeta <- length(mod$beta)
  or <- c( (numTheta+1):(numTheta + numBeta), 1:(numTheta))
  args <- list(
    type = "polr",
    coefficients = mod$beta,
    zeta = mod$alpha,
    method=method,
    vcov = as.matrix(vcov(mod)[or, or]))
  Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f86fa9096d8>
<environment: namespace:effects>
```

This method first checks that the `MASS` package is available. The `clm` function orders the parameters in the order (threshold parameters, linear predictor parameters), so the next few lines identify the elements of `vcov` that are needed by `Effects`. Since the `polr` function does not allow thresholds other than `flexible`, we don't allow them either. The `zeta` argument supplies the estimated thresholds, which are called `zeta` in `polr`, and `Alpha` in `clm`. The `polr` argument `method` is equivalent to the `clm` argument `link`, except that the `clm` link `"logit"` is equivalent to the `polr` method `"logistic"`.

```
require(ordinal)
require(MASS)
mod.wvs1 <- clm(poverty ~ gender + religion + degree + country*poly(age,3),
               data=WVS)
```

```
plot(Effect(c("country", "age"), mod.wvs1),
     lines=list(multiline=TRUE), layout=c(2, 2))
```



## 7.2 clm2

Although the fitted models are similar, syntax for `clm2` is not the same as `clm`, so a separate method is required.

```
print(Effect.clm2)

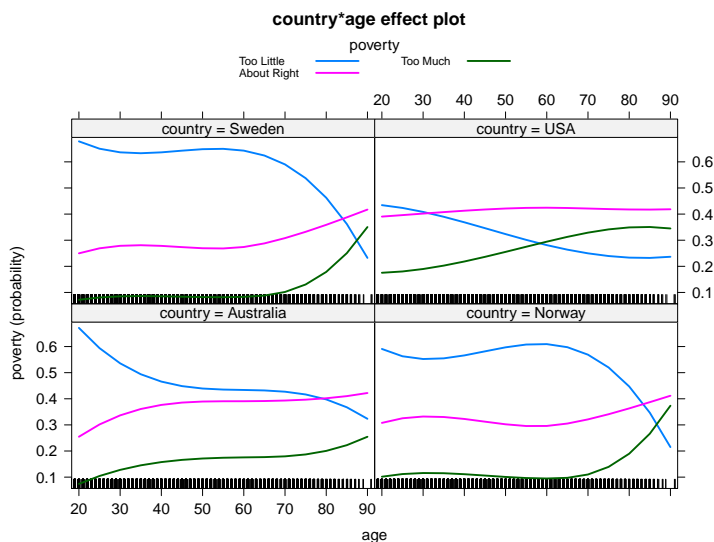
function(focal.predictors, mod, ...){
  if (requireNamespace("MASS", quietly=TRUE)){
    polr <- MASS::polr}
  polr.methods <- c("logistic", "probit", "loglog",
                    "cloglog", "cauchit")
  method <- mod$link
  if(!(method %in% polr.methods))
    stop("'link' must be a 'method' supported by polr; see help(polr)")
  if(is.null(mod$Hessian)){
    message("\nRe-fitting to get Hessian\n")
    mod <- update(mod, Hess=TRUE)}
  if(mod$threshold != "flexible")
```

```

    stop("Effects only supports the flexible threshold")
    numTheta <- length(mod$Theta)
    numBeta <- length(mod$beta)
    or <- c( (numTheta+1):(numTheta + numBeta), 1:(numTheta))
    args <- list(
      type = "polr",
      formula = mod$call$location,
      coefficients = mod$beta,
      zeta = mod$Theta,
      method=method,
      vcov = as.matrix(vcov(mod)[or, or]))
    Effect.default(focal.predictors, mod, ..., sources=args)
  }
  <bytecode: 0x7f870a05bf08>
  <environment: namespace:effects>

v2 <- clm2(poverty ~ gender + religion + degree + country*poly(age,3),data=WVS)
plot(emod2 <- Effect(c("country", "age"), v2),
     lines=list(multiline=TRUE), layout=c(2,2))

```



### 7.3 clmm

This function allows for random effects in an ordinal model.

```

print(Effect.clmm)

function(focal.predictors, mod, ...){
  if (requireNamespace("MASS", quietly=TRUE)){

```

```

    polr <- MASS::polr}
else stop("The MASS package must be installed")
polr.methods <- c("logistic", "probit", "loglog",
                  "cloglog", "cauchit")
method <- mod$link
if(method == "logit") method <- "logistic"
if(!(method %in% polr.methods))
  stop("'link' must be a 'method' supported by polr; see help(polr)")
if(is.null(mod$Hessian)){
  message("\nRe-fitting to get Hessian\n")
  mod <- update(mod, Hess=TRUE)}
if(mod$threshold != "flexible")
  stop("Only threshold='flexible' supported by Effects")
numTheta <- length(mod$Theta)
numBeta <- length(mod$beta)
or <- c( (numTheta+1):(numTheta + numBeta), 1:(numTheta))
Vcov <- as.matrix(vcov(mod)[or, or])
args <- list(
  type = "polr",
  formula = formula(mod),
  coefficients = mod$beta,
  zeta=mod$alpha,
  method=method,
  vcov = as.matrix(Vcov))
Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f870ad85170>
<environment: namespace:effects>

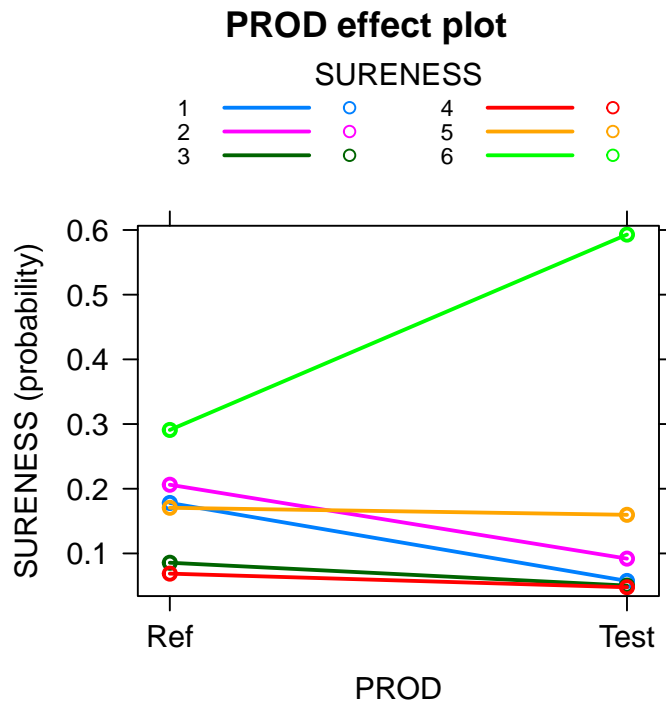
```

The first few lines of the method check for the presence of the MASS package that is needed to use `polr`, makes sure the link used is supported by `polr`, and requires that the argument `threshold` has its default value. The `polr` and `clmm` functions store the fixed effects estimates of regression and threshold coefficients in different orders, so the next few lines rearrange the variance matrix to match the order that `polr` uses.

```

require(ordinal)
require(MASS)
mm1 <- clmm(SURENESS ~ PROD + (1|RESP) + (1|RESP:PROD),
            data = soup, link = "logit", threshold = "flexible")
plot(Effect("PROD", mm1), lines=list(multiline=TRUE))

```



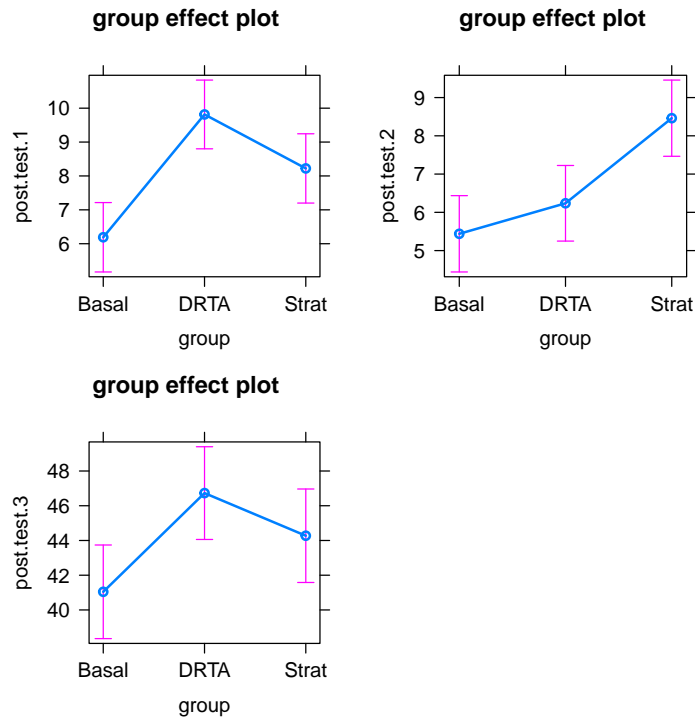
## 7.4 Others

The `poLCA` function in the `poLCA` package (Linzer and Lewis, 2011) fits polytomous variable latent class models, which uses the multinomial effects plots.

The `svyglm` function in the `survey` package (Lumley, 2004, 2016) fits generalized linear models using survey weights.

The `lm` function can also be used to create a multivariate linear model. The `Effect.mlm` function, with slightly different syntax, will draw effects plots for these models, with separate plots of each response.

```
data(Baumann, package="carData")
b1 <- lm(cbind(post.test.1, post.test.2, post.test.3) ~ group +
         pretest.1 + pretest.2, data = Baumann)
plot(Effect("group", b1))
```



## References

- Bates, D., M. Mächler, B. Bolker, and S. Walker (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67(1), 1–48.
- Christensen, R. H. B. (2015). `ordinal`—Regression Models for Ordinal Data. R package version 2015.6-28.
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- Koller, M. (2016). `robustlmm`: An R package for robust estimation of linear mixed-effects models. *Journal of Statistical Software* 75(6), 1–24.
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- Pinheiro, J., D. Bates, S. DebRoy, D. Sarkar, and R Core Team (2016). `nlme`: Linear and Nonlinear Mixed Effects Models. R package version 3.1-127.
- Pinheiro, J., D. Bates, S. DebRoy, D. Sarkar, and R Core Team (2018). *nlme: Linear and Nonlinear Mixed Effects Models*. R package version 3.1-137.
- Venables, W. N. and B. D. Ripley (2002). *Modern Applied Statistics with S* (4th ed.). New York: Springer-Verlag.