

# Defining Effect Methods for Other Models

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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 quaslikelihood (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)

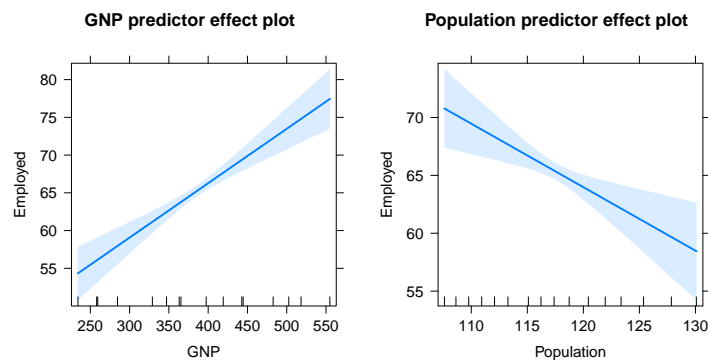
Loading required package: carData

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,
              vcov = mod$varFixed)
  Effect.default(focal.predictors, mod, ..., sources = args)
}
<bytecode: 0x7f9429ba9760>
<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)

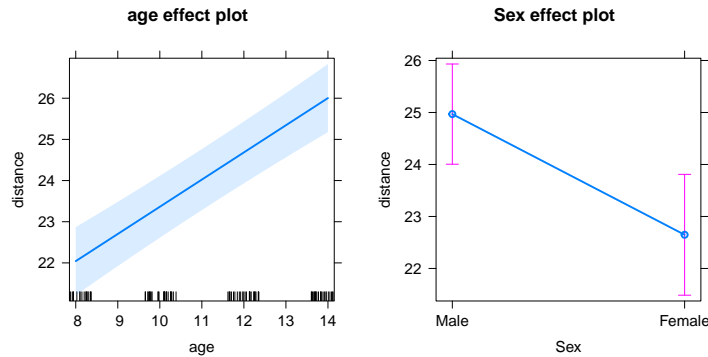
function (focal.predictors, mod, ..., KR = FALSE)
{
  if (KR && !requireNamespace("pbkrtest", quietly = TRUE)) {
    KR <- FALSE
    warning("pbkrtest is not available, KR set to FALSE")
  }
  fam <- family(mod)
  args <- list(call = mod@call, coefficients = lme4::fixef(mod),
              family = fam, vcov = if (fam$family == "gaussian" &&
              fam$link == "identity" && KR) as.matrix(pbkrtest::vcovAdj(mod)) else as.matrix(v
  Effect.default(focal.predictors, mod, ..., sources = args)
}
<bytecode: 0x7f9429848d40>
<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: 0x7f942744aa88>
<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: 0x7f9427383da0>
<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)]
  fam <- binomial(link = mod$link$mean)
  fam$variance <- function(mu) {
    f0 <- function(mu, eta) (1 - mu) * mu/(1 + eta)
    do.call("f0", list(mu, mod$coefficient$precision))
  }
  fam$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: 0x7f94271a5ba8>
<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

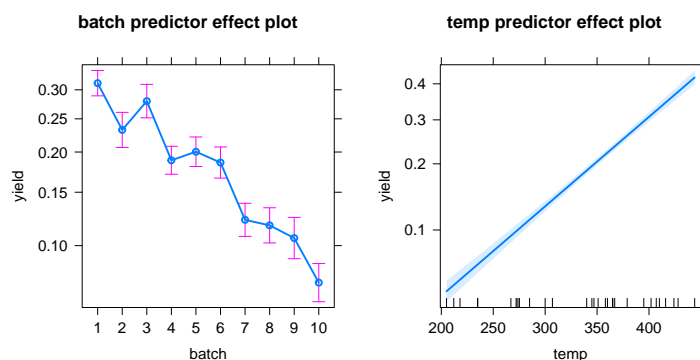
Type of estimator: ML (maximum likelihood)

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: 0x7f9427288740>
<environment: namespace:effects>

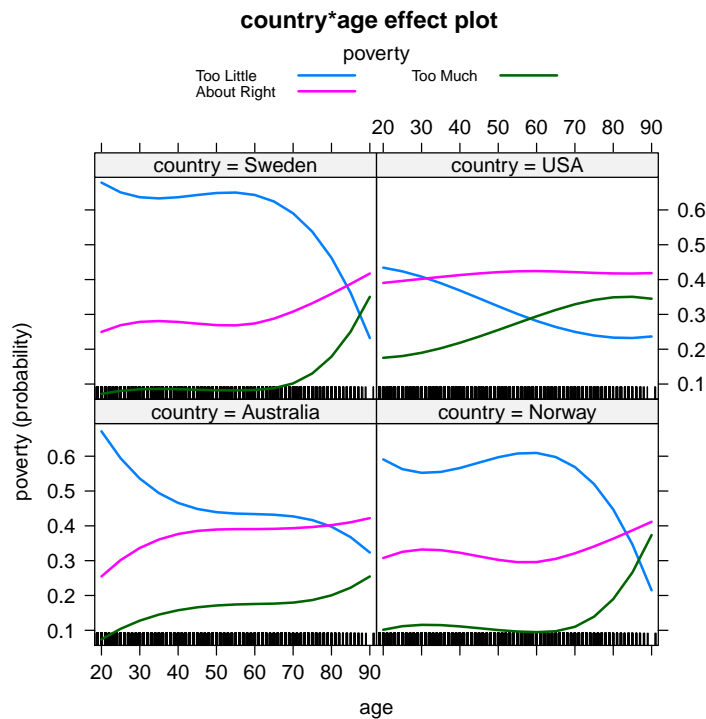
```

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)

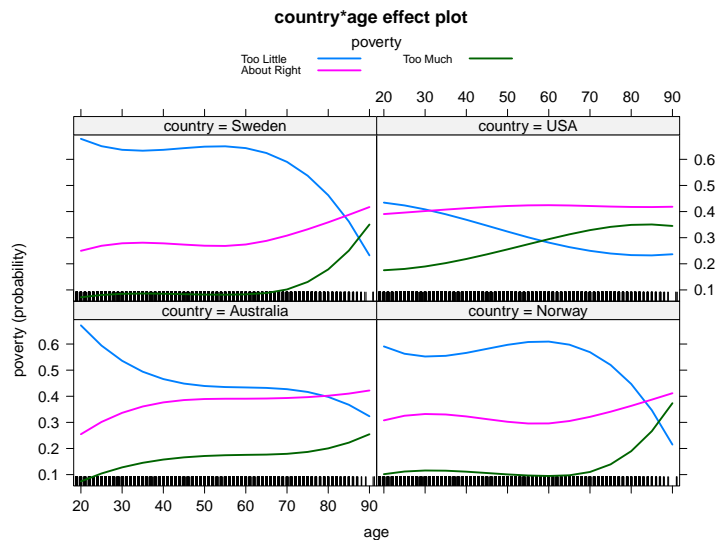
function (focal.predictors, mod, ...)
{
  if (requireNamespace("MASS", quietly = TRUE)) {
    polr <- MASS::polr
  }
  polr.methods <- c("logistic", "probit", "loglog", "cloglog",
    "cauchit")
  method <- mod$link
  if (!(method %in% polr.methods))
    stop("'link' must be a 'method' supported by polr; see help(polr)")
  if (is.null(mod$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: 0x7f94259b74b0>
<environment: namespace:effects>

v2 <- clm2(poverty ~ gender + religion + degree + country*poly(age,3),data=WVS)
plot(efmod2 <- 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: 0x7f94259c4918>
<environment: namespace:effects>

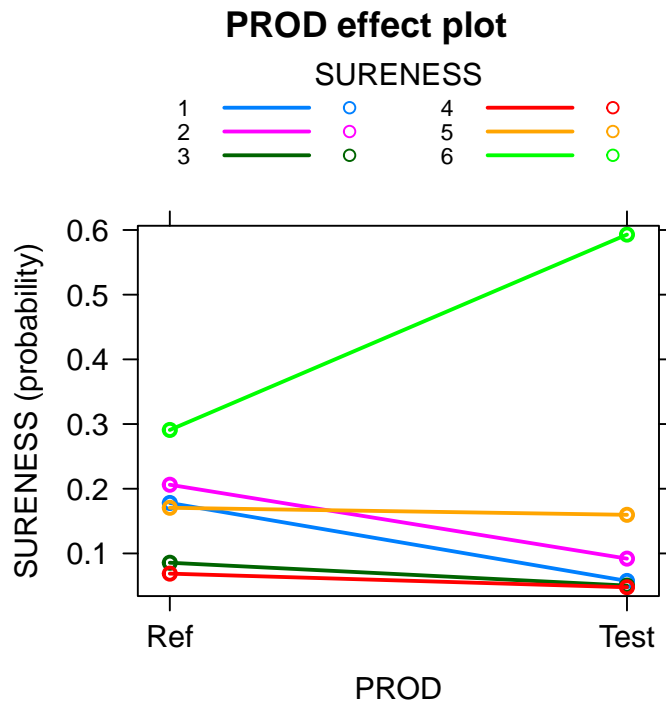
```

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))

```



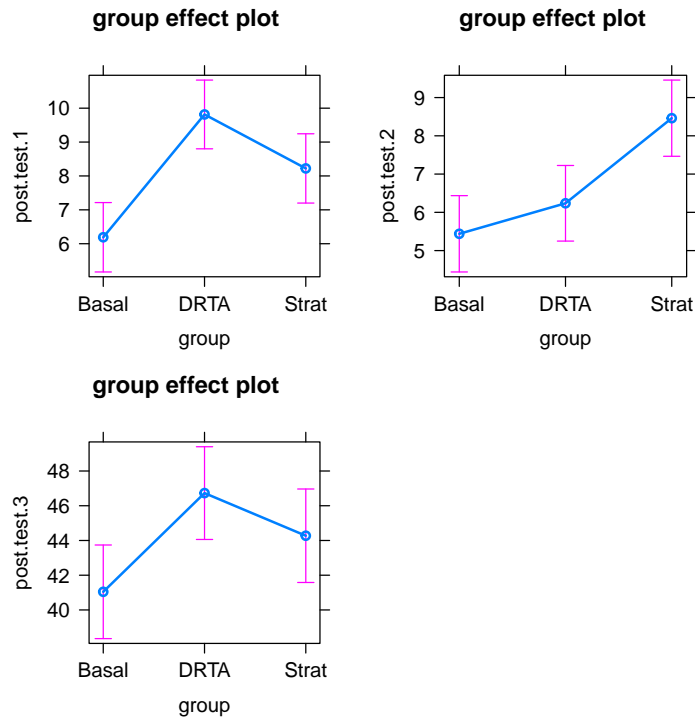
#### 7.4 Others

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

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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.