Defining Effect Methods for Other Models

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August 24, 2018

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 `clm` and `clm2` 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); 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 method of `Effect` for `gls` objects finds the information needed to draw effects plots from `gls` objects:

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

This function simply harvests the needed information into a variable `sources`, and then passes to the result to the default `Effect` method. The three required arguments to the method are: `focal.predictors` and `mod` that match the first two arguments of `Effect.default`, and `...` that matches all other arguments. The list `sources` has up to 6 named elements and is created in the function:

`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 6. The 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.

`call` The `Effect.default` method uses the call to harvest additional arguments that it needs. For `type="glm"`, these arguments are `formula`, `data`, `contrasts`, `subset`, `family`, and `offset`, although only the `formula` argument is required. The default 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 5 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.

`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 6.1 below for an example.

Since the values of all the arguments in `sources` are default values for the `gls` method, there is no need to have written the `Effect.gls` method, as the default method would work.

```
 library(effects)
```

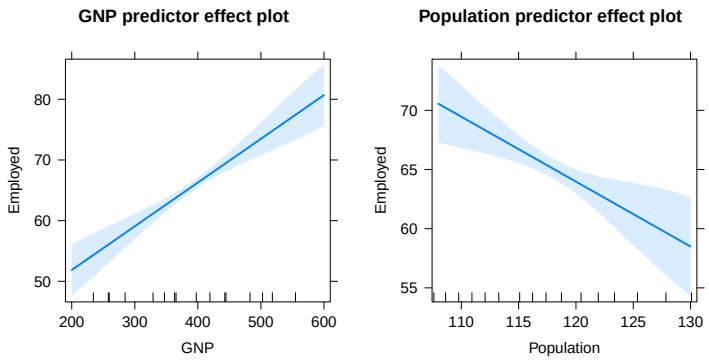
```
Loading required package: carData
```

```
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: 0x7f803aec0320>
<environment: namespace:effects>
```

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

```
 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.

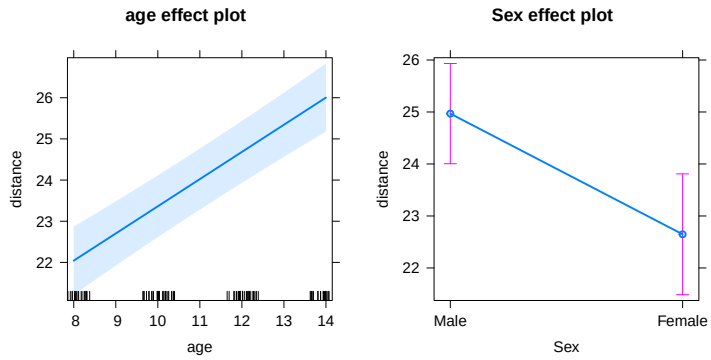
```
 print(Effect.merMod)
```

```
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 == "gaussian" && fam$link == "identity" && KR)
      as.matrix(pbkrtest::vcovAdj(mod)) else as.matrix(vcov(mod)))
  Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f803ffc49b0>
<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 `glimer` 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 0.2312141 0.13569522 0.2798569
2      2 0.08391784 0.3073939 0.04775453 0.1433443
3      3 0.07401714 0.3270802 0.04040242 0.1317591
4      4 0.04842565 0.4251645 0.02163871 0.1048199
```

4 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: 0x7f80422fa1c8>
<environment: namespace:effects>
```

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

5 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: 0x7f803f693270>
<environment: namespace:effects>
```

Beta regression has a response $y \in [0, 1]$, with the connection between the mean μ 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 ϕ estimated by `betareg`.

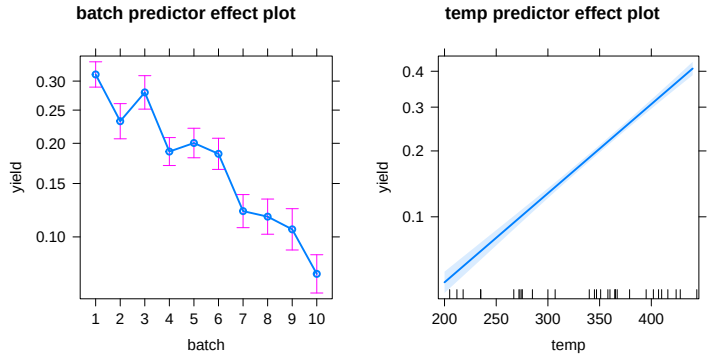
The call to `betareg` does not have a family argument, although it does have a link stored in `mod$link$mean`. For use with `Effect.default`, the method above creates a family from the binomial family generator. It then adjusts this family by changing from binomial variance to the variance for the beta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

```
library(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))
```



6 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.

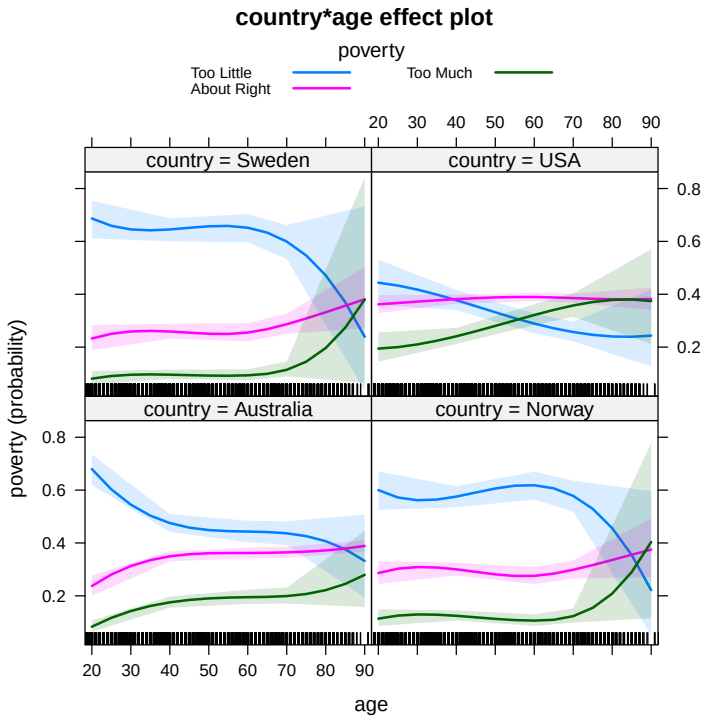
6.1 clm

```
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")
  if(is.null(mod$Hessian)){
    message("\nRe-fitting to get Hessian\n")
    mod <- update(mod, Hess=TRUE)}
  numTheta <- length(mod$Theta)
  numBeta <- length(mod$beta)
  or <- c( (numTheta+1):(numTheta + numBeta), 1:(numTheta))
  args <- list(
    type = "polr",
    coefficients = mod$beta,
    method=method,
    vcov = as.matrix(vcov(mod)[or, or]))
  Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f8027d56498>
<environment: namespace:effects>
```

This method first checks that the `MASS` package is available. Since the `clm` function allows suppressing the computation of the Hessian, the function checks and computes it if needed to get the estimated covariance matrix. 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 `polr` argument `method` is equivalent to the `clm` argument `link`, except that the `clm` link `"logit"` is equivalen to the `polr` method `"logit"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))
```



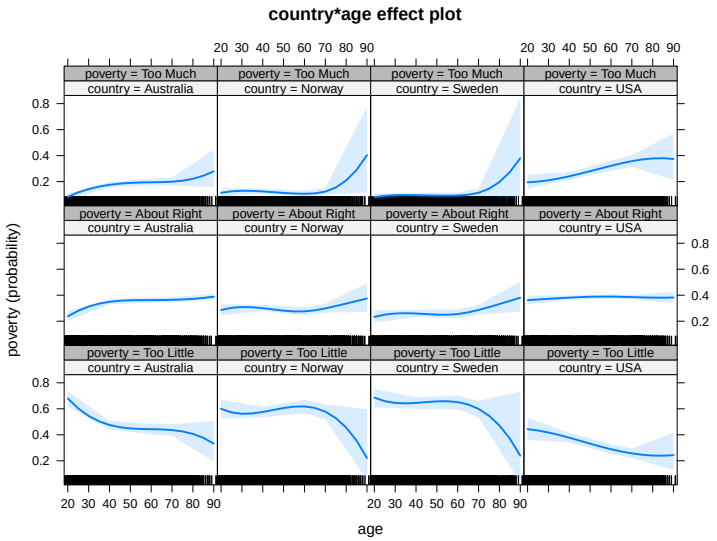
6.2 clm2

Although the fitted madels 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,
    method=method,
    vcov = as.matrix(vcov(mod)[or, or]))
  Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f80469308e8>
<environment: namespace:effects>
```

```
v2 <- clm2(poverty ~ gender + religion + degree + country*poly(age,3),data=WVS)
plot(emod2 <- Effect(c("country", "age"), v2))
```



6.3 clmm

This function allows for random effects in an ordinal model.

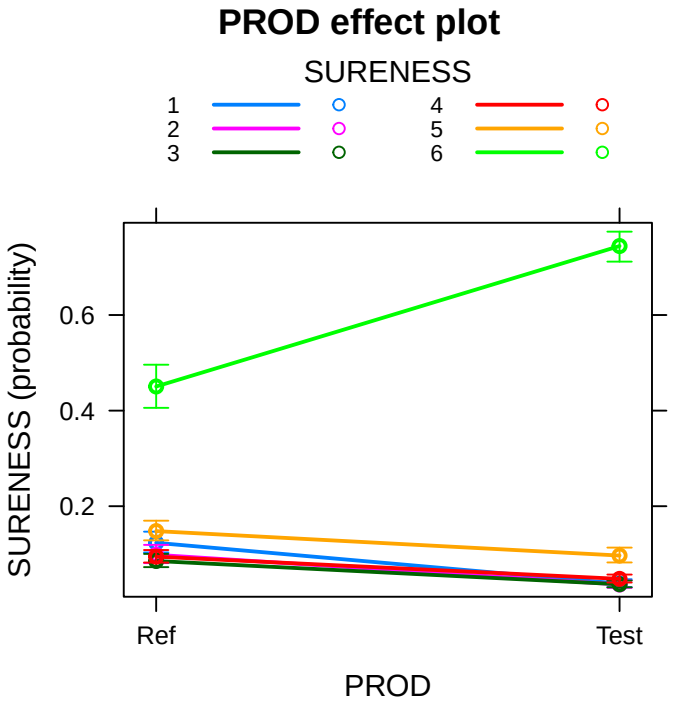
```
print(Effect.clmm)
```

```
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,
    method=method,
    vcov = as.matrix(Vcov))
  Effect.default(focal.predictors, mod, ..., sources=args)
}
<bytecode: 0x7f8027b13930>
<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 coefficents 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))
```



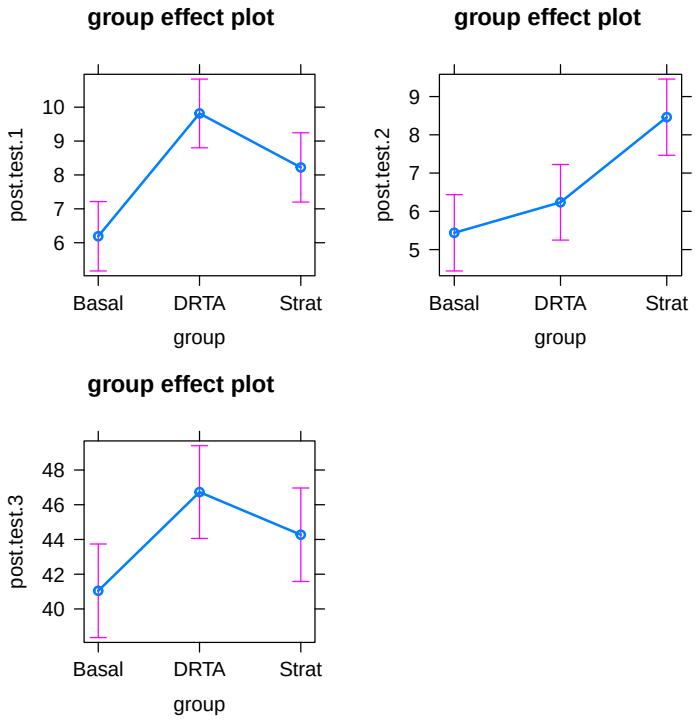
6.4 Others

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 drow 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))
```



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