

# Package ‘apollo’

January 26, 2022

**Type** Package

**Title** Tools for Choice Model Estimation and Application

**Version** 0.2.7

**Description** Choice models are a widely used technique across numerous scientific disciplines. The Apollo package is a very flexible tool for the estimation and application of choice models in R. Users are able to write their own model functions or use a mix of already available ones. Random heterogeneity, both continuous and discrete and at the level of individuals and choices, can be incorporated for all models. There is support for both standalone models and hybrid model structures. Both classical and Bayesian estimation is available, and multiple discrete continuous models are covered in addition to discrete choice. Multi-threading processing is supported for estimation and a large number of pre and post-estimation routines, including for computing posterior (individual-level) distributions are available.

For examples, a manual, and a support forum, visit

<<http://www.ApolloChoiceModelling.com>>. For more information on choice models see Train, K. (2009) <isbn:978-0-521-74738-7> and Hess, S. & Daly, A.J. (2014) <isbn:978-1-781-00314-5> for an overview of the field.

**License** GPL-2

**URL** <http://www.apolloChoiceModelling.com>

**BugReports** <http://www.apolloChoiceModelling.com/forum/>

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**LazyData** true

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|                        |                                       |
|------------------------|---------------------------------------|
| <code>.onAttach</code> | <i>Prints package startup message</i> |
|------------------------|---------------------------------------|

---

**Description**

This function is only called by R when attaching the package.

**Usage**

```
.onAttach(libname, pkgname)
```

**Arguments**

|                      |                  |
|----------------------|------------------|
| <code>libname</code> | Name of library. |
| <code>pkgname</code> | Name of package. |

**Value**

Nothing

---

|                                   |   |
|-----------------------------------|---|
| <code>apollo_addCovariance</code> | <i>Adds covariance matrix to Apollo model</i> |
|-----------------------------------|---|

---

**Description**

Receives an estimated model object, calculates its Hessian, and classical and robust covariance matrix, and returns the same model object, but with these additional elements.

**Usage**

```
apollo_addCovariance(model, apollo_inputs)
```

**Arguments**

|                            |  |
|----------------------------|--|
| <code>model</code>         | Model object. Estimated model object as returned by function <a href="#">apollo_estimate</a> . |
| <code>apollo_inputs</code> | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |

**Value**

model.

---

|               |                                       |
|---------------|---------------------------------------|
| apollo_attach | <i>Attaches predefined variables.</i> |
|---------------|---------------------------------------|

---

### Description

Attaches parameters and data to allow users to refer to individual variables by name without reference to the object that contains them.

### Usage

```
apollo_attach(apollo_beta, apollo_inputs)
```

### Arguments

`apollo_beta`     Named numeric vector. Names and values for parameters.  
`apollo_inputs`   List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

### Details

This function should be called at the beginning of `apollo_probabilities` to make writing the log-likelihood more user-friendly. If used, then [apollo\\_detach](#) should be called at the end of `apollo_probabilities`, or more conveniently, using `on.exit` after the initial call to `apollo_attach`. `apollo_attach` attaches `apollo_beta`, `database`, `draws`, and the output of `apollo_randCoeff` and `apollo_lcPars`, if they are defined by the user.

### Value

Nothing.

---

|                      |  |
|----------------------|--|
| apollo_avgInterDraws | <i>Averages across inter-individual draws.</i> |
|----------------------|--|

---

### Description

Averages individual-specific likelihood across inter-individual draws.

### Usage

```
apollo_avgInterDraws(P, apollo_inputs, functionality)
```

**Arguments**

|               |   |
|---------------|---|
| P             | List of vectors, matrices or 3-dim arrays. Likelihood of the model components.  |
| apollo_inputs | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .   |
| functionality | Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call <code>apollo_probabilities</code> , though the user can also call <code>apollo_probabilities</code> manually with a given functionality for testing/debugging. Possible values are: <ul style="list-style-type: none"> <li>"components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> <li>"conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.</li> <li>"estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>"gradient": For model estimation, produces analytical gradients of the likelihood, where possible.</li> <li>"output": Prepares output for post-estimation reporting.</li> <li>"prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.</li> <li>"preprocess": Prepares likelihood functions for use in estimation.</li> <li>"raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.</li> <li>"report": Prepares output summarising model and choicest structure.</li> <li>"shares_LL": Produces overall model likelihood with constants only.</li> <li>"validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>"zero_LL": Produces overall model likelihood with all parameters at zero.</li> </ul> |

**Value**

Argument P with (for most functionalities) the original contents averaged over inter-individual draws. Shape depends on argument functionality.

- "components": Returns P without changes.
- "conditionals": Returns P without averaging across draws. Drops all components except "model".
- "estimate": Returns P containing the likelihood of the model averaged across inter-individual draws. Drops all components except "model".
- "gradient": Returns P containing the gradient of the likelihood averaged across inter-individual draws. Drops all components except "model".
- "output": Returns P containing the likelihood of all model components averaged across inter-individual draws.

- "prediction": Returns P containing the probabilities/likelihoods of all alternatives for all model components averaged across inter-individual draws.
- "preprocess": Returns P without changes.
- "raw": Returns P without changes.
- "report": Returns P without changes.
- "shares\_LL": Returns P without changes.
- "validate": Returns P containing the likelihood of the model averaged across inter-individual draws. Drops all components except "model".
- "zero\_LL": Returns P without changes.

---

apollo\_avgIntraDraws *Averages across intra-individual draws.*

---

### Description

Averages observation-specific likelihood across intra-individual draws.

### Usage

```
apollo_avgIntraDraws(P, apollo_inputs, functionality)
```

### Arguments

|               |   |
|---------------|---|
| P             | List of vectors, matrices or 3-dim arrays. Likelihood of the model components.  |
| apollo_inputs | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .   |
| functionality | Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call <code>apollo_probabilities</code> , though the user can also call <code>apollo_probabilities</code> manually with a given functionality for testing/debugging. Possible values are: <ul style="list-style-type: none"> <li>• "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> <li>• "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.</li> <li>• "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>• "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.</li> <li>• "output": Prepares output for post-estimation reporting.</li> <li>• "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.</li> <li>• "preprocess": Prepares likelihood functions for use in estimation.</li> </ul> |

- "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- "report": Prepares output summarising model and choicest structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

### Value

Argument P with (for most functionalities) the original contents averaged over intra-individual draws. Shape depends on argument functionality.

- "components": Returns P without changes.
- "conditionals": Returns P containing the likelihood of the model averaged across intra-individual draws. Drops all components except for "model".
- "estimate": Returns P containing the likelihood of the model averaged across intra-individual draws. Drops all components except "model".
- "gradient": Returns P containing the gradient of the likelihood averaged across intra-individual draws. Drops all components except "model".
- "output": Returns P containing the likelihood of all model components averaged across intra-individual draws.
- "prediction": Returns P containing the probabilities of all alternatives for all model components averaged across intra-individual draws.
- "preprocess": Returns P without changes.
- "raw": Returns P without changes.
- "report": Returns P without changes.
- "validate": Returns P containing the likelihood of the model averaged across intra-individual draws. Drops all components but "model".
- "zero\_LL": Returns P without changes.

---

apollo\_basTest

*Ben-Akiva & Swait test*

---

### Description

Carries out the Ben-Akiva & Swait test for non-nested models and reports the corresponding p-value.

### Usage

```
apollo_basTest(model1, model2)
```



**Arguments**

|        |  |
|--------|--|
| model1 | Either a character variable with the name (and possibly path) of a previously estimated model, or an estimated model in memory, as returned by <a href="#">apollo_estimate</a> . |
| model2 | Either a character variable with the name (and possibly path) of a previously estimated model, or an estimated model in memory, as returned by <a href="#">apollo_estimate</a> . |

**Details**

The two models need to both be discrete choice, and need to have been estimated on the same data.

**Value**

Ben-Akiva & Swait test p-value (invisibly)

---

|                  |                          |
|------------------|--------------------------|
| apollo_bootstrap | <i>Bootstrap a model</i> |
|------------------|--------------------------|

---

**Description**

Samples individuals with replacement from the database, and estimates the model for each sample.

**Usage**

```
apollo_bootstrap(
  apollo_beta,
  apollo_fixed,
  apollo_probabilities,
  apollo_inputs,
  estimate_settings = list(estimationRoutine = "bfgs", maxIterations = 200, writeIter =
    FALSE, hessianRoutine = "none", printLevel = 2L, silent = FALSE, maxLik_settings =
    list()),
  bootstrap_settings = list(nRep = 30, samples = NA, calledByEstimate = FALSE, recycle
    = TRUE)
)
```

**Arguments**

|                      |   |
|----------------------|---|
| apollo_beta          | Named numeric vector. Names and values for parameters.  |
| apollo_fixed         | Character vector. Names (as defined in apollo_beta) of parameters whose value should not change during estimation.  |
| apollo_probabilities | Function. Returns probabilities of the model to be estimated. Must receive three arguments: <ul style="list-style-type: none"> <li>• apollo_beta: Named numeric vector. Names and values of model parameters.</li> <li>• apollo_inputs: List containing options of the model. See <a href="#">apollo_validateInputs</a>.</li> </ul> |

- **functionality**: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".
- apollo\_inputs List grouping most common inputs. Created by function [apollo\\_validateInputs](#).
- estimate\_settings List. Options controlling the estimation process. See [apollo\\_estimate](#). hessianRoutine="none" by default.
- bootstrap\_settings List containing settings for the sampling procedure. User input is required for all settings except those with a default or marked as optional.
- **calledByEstimate**: Logical. TRUE if apollo\_bootstrap is called by [apollo\\_estimate](#). FALSE by default.
  - **nRep**: Numeric scalar. Number of times the model must be estimated with different samples. Default is 30.
  - **recycle**: Logical. If TRUE, the function will look for old output files and append new repetitions to them. If FALSE, output files will be overwritten.
  - **samples**: Numeric matrix or data.frame. Optional argument. Must have as many rows as observations in the database, and as many columns as number of repetitions wanted. Each column represents a re-sample, and each element the number of times that observation must be included in the sample. If this argument is provided, then nRep is ignored. Note that this allows sampling at the observation rather than the individual level, which is not recommended for panel data.
  - **seed**: **DEPRECATED**, apollo\_control\$seed is used since v0.2.5. Numeric scalar (integer). Random number generator seed to generate the bootstrap samples. Only used if samples is NA. Default is 24.

## Details

This function implements a basic block bootstrap. It estimates the model parameters on nRep different samples. Each new sample is constructed by sampling **with replacement** from the original full sample. Each new sample has as many individuals as the original sample, though some of them may be repeated. Sampling is done at the **individual** level, therefore if different individuals have different number of observations, each re-sample does not necessarily have the same number of observations.

If the sampling should be done at the individual level (not recommended for panel data), then the optional bootstrap\_settings\$samples argument should be provided.

For each sample, only the parameters and log-likelihood are estimated. Standard errors are not calculated (they may be added in future versions). The composition of the re-samples is stored in a file, but is stable with the same seed.

This function writes three different files to the working or output directory:

- modelName\_bootstrap\_params.csv: estimated parameters, final log-likelihood, and number of observations for each re-sample
- modelName\_bootstrap\_samples.csv: composition of each re-sample.

- `modelName_bootstrap_vcov.csv`: variance-covariance matrix of the estimated parameters across re-samples.

The first two files are updated throughout the run of this function, while the last one is only written once the function finishes.

When run, this function will look for the first two files above in the working/output directory. If they are found, the function will attempt to pick up re-sampling from where those files left off. This is useful in cases where the original bootstrapping was interrupted, or when additional re-sampling runs are to be performed.

### Value

List with three elements.

- `estimates`: Matrix containing the parameter estimates for each repetition. As many rows as repetitions and as many columns as parameters.
- `LL`: Vector of final log-likelihoods of each repetition.
- `varcov`: Covariance matrix of the estimated parameters across the repetitions.

This function also writes three output files to the working/output directory, with the following names ('x' represents the model name):

- `x_bootstrap_params.csv`: Table containing the parameter estimates, log-likelihood, and number of observations for each repetition.
- `x_bootstrap_samples.csv`: Table containing the description of the sample used in each repetition. Same format than `bootstrap_settings$samples`.
- `x_bootstrap_vcov`: Table containing the covariance matrix of estimated parameters across the repetitions.

---

`apollo_checkArguments` *Checks definitions of Apollo functions*

---

### Description

Checks that the user-defined functions used by Apollo are correctly defined by the user.

### Usage

```
apollo_checkArguments(
  apollo_probabilities = NA,
  apollo_randCoeff = NA,
  apollo_lcPars = NA
)
```

**Arguments**

- apollo\_probabilities  
Function. Likelihood function as defined by the user.
- apollo\_randCoeff  
Function. Used with mixing models. Constructs the random parameters of a mixing model. Receives two arguments:
- **apollo\_beta**: Named numeric vector. Names and values of model parameters.
  - **apollo\_inputs**: The output of this function (apollo\_validateInputs).
- apollo\_lcPars  
Function. Used with latent class models. Constructs a list of parameters for each latent class. Receives two arguments:
- **apollo\_beta**: Named numeric vector. Names and values of model parameters.
  - **apollo\_inputs**: The output of this function (apollo\_validateInputs).

**Details**

It only checks that the functions have the correct definition of inputs. It does not run the functions.

**Value**

Returns (invisibly) TRUE if definitions are correct, and FALSE otherwise.

---

apollo\_choiceAnalysis *Reports market share for subsamples*

---

**Description**

Compares market shares across subsamples in dataset, and conducts statistical tests.

**Usage**

```
apollo_choiceAnalysis(choiceAnalysis_settings, apollo_control, database)
```

**Arguments**

- choiceAnalysis\_settings  
List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.
- **codealternatives**: Named numeric vector. Names of alternatives and their corresponding value in choiceVar. Note that these need not necessarily be the alternatives as defined in the model, but could e.g. relate to cheapest/most expensive.
  - **codeavail**: Named list of numeric vectors or scalars. Availabilities of alternatives, one element per alternative. Names of elements must match those in alternatives. Values can be 0 or 1.

- **codechoiceVar**: Numeric vector. Contains choices for all observations. It will usually be a column from the database. Values are defined in `alternatives`.
- **codeexplanators**: `data.frame`. Variables determining subsamples of the database. Values in each column must describe a group or groups of individuals (e.g. socio-demographics). Most usually a subset of columns from the database.
- **codeprintToScreen**: Logical. TRUE for returning output to screen as well as file. TRUE by default.
- **rows**: Boolean vector. Consideration of which rows to include. Length equal to the number of observations (`nObs`), with entries equal to TRUE for rows to include, and FALSE for rows to exclude. Default is "all", equivalent to `rep(TRUE, nObs)`.

`apollo_control` List. Options controlling the running of the code. See [apollo\\_validateInputs](#).  
`database` `data.frame`. Data used by model.

### Details

Saves the output to a csv file in the `working/output` directory.

### Value

Silently returns a matrix containing the mean value for each explainer for those cases where an alternative is chosen and where it is not chosen, as well as the t-test comparing those means (H0: equivalence). The table is also written to a file called `modelName_choiceAnalysis.csv` and printed to screen.

---

`apollo_classAlloc` *Calculates class allocation probabilities for a Latent Class model*

---

### Description

Calculates class allocation probabilities for a Latent Class model using a Multinomial Logit model and can also perform other operations based on the value of the `functionality` argument.

### Usage

```
apollo_classAlloc(classAlloc_settings)
```

### Arguments

`classAlloc_settings`

List of inputs of the MNL model. It should contain the following.

- **utilities**: Named list of deterministic utilities. Utilities of the classes in class allocation model. Names of elements must match those in `avail`, if provided.

- `avail`: Named list of numeric vectors or scalars. Availabilities of classes, one element per class. Names of elements must match those in classes. Values can be 0 or 1. These can be scalars or vectors (of length equal to rows in the database). A user can also specify `avail=1` to indicate universal availability, or omit the setting completely.
- `rows`: Boolean vector. Consideration of which rows to include. Length equal to the number of observations (`nObs`), with entries equal to `TRUE` for rows to include, and `FALSE` for rows to exclude. Default is `"all"`, equivalent to `rep(TRUE, nObs)`.
- `componentName`: Character. Name given to model component.

### Value

The returned object depends on the value of argument `functionality`, which it fetches from the calling stack (see [apollo\\_validateInputs](#)).

- `"components"`: Same as `"estimate"`.
- `"conditionals"`: Same as `"estimate"`.
- `"estimate"`: List of vector/matrices/arrays with the allocation probabilities for each class.
- `"gradient"`: List containing the likelihood and gradient of the model component.
- `"output"`: Same as `"estimate"`.
- `"prediction"`: Same as `"estimate"`.
- `"preprocess"`: Returns a list with pre-processed inputs, based on `classAlloc_settings`.
- `"raw"`: Same as `"estimate"`.
- `"report"`: Same as `"estimate"`.
- `"shares_LL"`: List with probabilities for each class in an equal shares setting.
- `"validate"`: Same as `"estimate"`, but it also runs a set of tests to validate the function inputs.
- `"zero_LL"`: List with probabilities for each class in an equal shares setting.

---

apollo\_cnl

*Calculates Cross-Nested Logit probabilities*

---

### Description

Calculates the probabilities of a Cross-nested Logit model and can also perform other operations based on the value of the `functionality` argument.

### Usage

```
apollo_cnl(cnl_settings, functionality)
```

**Arguments**

- `cnl_settings` List of inputs of the CNL model. User input is required for all settings except those with a default or marked as optional.
- `alternatives`: Named numeric vector. Names of alternatives and their corresponding value in `choiceVar`.
  - `avail`: Named list of numeric vectors or scalars. Availabilities of alternatives, one element per alternative. Names of elements must match those in `alternatives`. Values can be 0 or 1. These can be scalars or vectors (of length equal to rows in the database). A user can also specify `avail=1` to indicate universal availability, or omit the setting completely.
  - `choiceVar`: Numeric vector. Contains choices for all observations. It will usually be a column from the database. Values are defined in `alternatives`.
  - `cnlNests`: List of numeric scalars or vectors. Lambda parameters for each nest. Elements must be named according to nests. The lambda at the root is fixed to 1, and therefore does not need to be defined.
  - `cnlStructure`: Numeric matrix. One row per nest and one column per alternative. Each element of the matrix is the alpha parameter of that (nest, alternative) pair.
  - `componentName`: Character. Name given to model component.
  - `utilities`: Named list of deterministic utilities. Utilities of the alternatives. Names of elements must match those in `alternatives`.
  - `rows`: Boolean vector. Consideration of which rows to include. Length equal to the number of observations (`nObs`), with entries equal to `TRUE` for rows to include, and `FALSE` for rows to exclude. Default is `"all"`, equivalent to `rep(TRUE, nObs)`.
- `functionality` Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call `apollo_probabilities`, though the user can also call `apollo_probabilities` manually with a given `functionality` for testing/debugging. Possible values are:
- `"components"`: For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.
  - `"conditionals"`: For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
  - `"estimate"`: For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
  - `"gradient"`: For model estimation, produces analytical gradients of the likelihood, where possible.
  - `"output"`: Prepares output for post-estimation reporting.
  - `"prediction"`: For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
  - `"preprocess"`: Prepares likelihood functions for use in estimation.
  - `"raw"`: For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.

- "report": Prepares output summarising model and choiceset structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

## Details

For the model to be consistent with utility maximisation, the estimated value of the lambda parameter of all nests should be between 0 and 1. Lambda parameters are inversely proportional to the correlation between the error terms of alternatives in a nest. If lambda=1, there is no relevant correlation between the unobserved utility of alternatives in that nest. Alpha parameters inside cnlStructure should be between 0 and 1. Using a transformation to ensure this constraint is satisfied is recommended for complex structures (e.g. logistic transformation).

## Value

The returned object depends on the value of argument `functionality` as follows.

- "components": Same as "estimate"
- "conditionals": Same as "estimate"
- "estimate": vector/matrix/array. Returns the probabilities for the chosen alternative for each observation.
- "gradient": Not implemented.
- "output": Same as "estimate" but also writes summary of input data to internal Apollo log.
- "prediction": List of vectors/matrices/arrays. Returns a list with the probabilities for all alternatives, with an extra element for the chosen alternative probability.
- "preprocess": Returns a list with pre-processed inputs, based on `cnl_settings`.
- "raw": Same as "prediction".
- "report": List with tree structure and choice overview.
- "shares\_LL": vector/matrix/array. Returns the probability of the chosen alternative when only constants are estimated.
- "validate": Same as "estimate".
- "zero\_LL": vector/matrix/array. Returns the probability of the chosen alternative when all parameters are zero.



---

apollo\_combineModels *Combines separate model components.*

---

## Description

Combines model components to create likelihood for overall model.

## Usage

```
apollo_combineModels(
  P,
  apollo_inputs,
  functionality,
  components = NULL,
  asList = TRUE
)
```

## Arguments

- |               |  |
|---------------|--|
| P             | List of vectors, matrices or 3-dim arrays. Likelihood of the model components.   |
| apollo_inputs | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |
| functionality | Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call <a href="#">apollo_probabilities</a> , though the user can also call <a href="#">apollo_probabilities</a> manually with a given functionality for testing/debugging. Possible values are: <ul style="list-style-type: none"> <li>• "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> <li>• "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.</li> <li>• "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>• "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.</li> <li>• "output": Prepares output for post-estimation reporting.</li> <li>• "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.</li> <li>• "preprocess": Prepares likelihood functions for use in estimation.</li> <li>• "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.</li> <li>• "report": Prepares output summarising model and choiceset structure.</li> <li>• "shares_LL": Produces overall model likelihood with constants only.</li> </ul> |

|            |  |
|------------|--|
|            | <ul style="list-style-type: none"> <li>• "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>• "zero_LL": Produces overall model likelihood with all parameters at zero.</li> </ul> |
| components | Character vector. Optional argument. Names of elements in P that should be multiplied to construct the whole model likelihood. If a single element is provided, it is interpreted as a regular expression. Default is to include all components in P.  |
| asList     | Logical. Only used if functionality is "conditionals", "estimate", "validate", "zero_LL" or "output". If TRUE, it will return a list as described in the 'Value' section. If FALSE, it will only return a vector/matrix/3-dim array of the product of likelihoods inside P. Default is TRUE.         |

### Details

This function should be called inside `apollo_probabilities` after all model components have been produced.

It should be called before `apollo_avgInterDraws`, `apollo_avgIntraDraws`, `apollo_panelProd` and `apollo_prepareProb`, whichever apply, except where these functions are called inside any latent class components of the overall model.

### Value

Argument P with (for most functionalities) an extra element called "model", which is the product of all the other elements. Shape depends on argument functionality.

- "components": Returns P without changes.
- "conditionals": Returns P with an extra component called "model", which is the product of all other elements of P.
- "estimate": Returns P with an extra component called "model", which is the product of all other elements of P.
- "gradient": Returns P containing the gradient of the likelihood after applying the product rule across model components.
- "output": Returns P with an extra component called "model", which is the product of all other elements of P.
- "prediction": Returns P without changes.
- "preprocess": Returns P without changes.
- "raw": Returns P without changes.
- "shares\_LL": Returns P with an extra component called "model", which is the product of all other elements of P.
- "validate": Returns P with an extra component called "model", which is the product of all other elements of P.
- "zero\_LL": Returns P with an extra component called "model", which is the product of all other elements of P.

---

apollo\_combineResults *Write model results to file*

---

## Description

Writes results from various models to a single csv file.

## Usage

```
apollo_combineResults(combineResults_settings = NULL)
```

## Arguments

combineResults\_settings

List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.

- `modelName`s: Character vector. Optional names of models to combine. Omit or use an empty vector to combine results from all models in the working/output directory.
- `printClassical`: Boolean. TRUE for printing classical standard errors. FALSE by default.
- `printPVal`: Boolean. TRUE for printing p-values. FALSE by default.
- `printT1`: Boolean. If TRUE, t-test for  $H_0: \text{apollo\_beta}=1$  are printed. FALSE by default.
- `estimateDigits`: Numeric scalar. Number of decimal places to print for estimates. Default is 4.
- `tDigits`: Numeric scalar. Number of decimal places to print for t-ratios values. Default is 2.
- `pDigits`: Numeric scalar. Number of decimal places to print for p-values. Default is 2.
- `sortByDate`: Boolean. If TRUE, models are ordered by date. Default is TRUE.

## Value

Nothing, but writes a file called 'model\_comparison\_[date].csv' in the working/output directory.

---

apollo\_compareInputs *Compares the content of apollo\_inputs to their counterparts in the global environment*

---

### Description

Compares the content of apollo\_inputs to their counterparts in the global environment

### Usage

```
apollo_compareInputs(apollo_inputs)
```

### Arguments

apollo\_inputs List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

### Value

Logical. TRUE if the content of apollo\_inputs is the same than the one in the global environment, FALSE otherwise.

---

apollo\_conditionals *Calculates conditionals*

---

### Description

Calculates posterior expected values (conditionals) of continuously distributed random coefficients, as well as their standard deviations.

### Usage

```
apollo_conditionals(model, apollo_probabilities, apollo_inputs)
```

### Arguments

model Model object. Estimated model object as returned by function [apollo\\_estimate](#).

apollo\_probabilities

Function. Returns probabilities of the model to be estimated. Must receive three arguments:

- apollo\_beta: Named numeric vector. Names and values of model parameters.
- apollo\_inputs: List containing options of the model. See [apollo\\_validateInputs](#).
- functionality: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".

apollo\_inputs List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

**Details**

This functions is only meant for use with continuous distributions

**Value**

List of matrices. Each matrix has dimensions nIndiv x 3. One matrix per random component. Each row of each matrix contains the indivID of an individual, and the posterior mean and s.d. of this random component for this individual

---

|                    |                                       |
|--------------------|---------------------------------------|
| apollo_deltaMethod | <i>Delta method for Apollo models</i> |
|--------------------|---------------------------------------|

---

**Description**

Applies the Delta method to calculate the standard errors of transformations of parameters.

**Usage**

```
apollo_deltaMethod(model, deltaMethod_settings)
```

**Arguments**

- |                      |  |
|----------------------|--|
| model                | Model object. Estimated model object as returned by function <a href="#">apollo_estimate</a> .   |
| deltaMethod_settings | List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional. <ul style="list-style-type: none"> <li>• expression: Character vector. A character vector with a single or multiple arbitrary functions of the estimated parameters, as text. For example: <code>c(VTT="b1/b2*60")</code>. Each expression can only contain model parameters (estimated or fixed), numeric values, and operands. At least one of the parameters used needs to not have been fixed in estimation. Variables in the database cannot be included. If the user does not provide a name for an expression, then the expression itself is used in the output. If this setting is provided, then <code>operation</code>, <code>parName1</code>, <code>parName2</code>, <code>multPar1</code> and <code>multPar2</code> are ignored.</li> <li>• varcov: Character. Type of variance-covariance matrix to use in calculations. It can take values "classical", "robust" and "bootstrap". Default is "robust".</li> <li>• operation: Character. Function to calculate the delta method for. See details. Not used if expression is provided.</li> <li>• parName1: Character. Name of the first parameter if operation is used. See details. Not used if expression is provided.</li> <li>• parName2: Character. Name of the second parameter if operation is used. See details. Not used if expression is provided.. Optional depending on operation.</li> </ul> |

- multPar1: Numeric scalar. An optional value to scale parName1. Not used if expression is provided.
- multPar2: Numeric scalar. An optional value to scale parName2. Not used if expression is provided.

## Details

apollo\_deltaMethod can be used in two ways. The first and recommended way is to provide an element called expression inside its argument deltaMethod\_settings. expression should contain the expression or expressions for which the standard error is/are to be calculated, as text. For example, to calculate the ratio between parameters b1 and b2, expression=c(vtt="b1/b2") should be used.

The second method is to provide the name of a specific operation inside deltaMethod\_settings. The following five operations are supported.

- sum: Calculates the s.e. of parName1 + parName2
- diff: Calculates the s.e. of parName1 - parName2 and parName2 - parName1
- prod: Calculates the s.e. of parName1\*parName2
- ratio: Calculates the s.e. of parName1/parName2 and parName2/parName1
- exp: Calculates the s.e. of exp(parName1)
- logistic: If only parName1 is provided, it calculates the s.e. of  $\exp(\text{parName1}) / (1 + \exp(\text{parName1}))$  and  $1 / (1 + \exp(\text{parName1}))$ . If parName1 and parName2 are provided, it calculates  $\exp(\text{par}_i) / (1 + \exp(\text{parName1})) + e$  for  $i=1, 2, \text{ and } 3$  ( $\text{par}_3 = 1$ ).
- lognormal: Calculates the mean and s.d. of a lognormal distribution based on the mean (parName1) and s.d. (parName2) of the underlying normal.

By default, apollo\_deltaMethod uses the robust covariance matrix. However, the user can change this through the varcov setting.

## Value

Matrix containing value, s.e. and t-ratio resulting from the requested expression or operation. This is also printed to screen.

---

|               |  |
|---------------|--|
| apollo_detach | <i>Detaches parameters and the database.</i> |
|---------------|--|

---

## Description

Detaches variables attached by [apollo\\_attach](#).

## Usage

```
apollo_detach(apollo_beta = NA, apollo_inputs = NA)
```

**Arguments**

- apollo\_beta      Named numeric vector. Names and values for parameters.
- apollo\_inputs    List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

**Details**

This function detaches the variables attached by [apollo\\_attach](#). It should be called at the end of `apollo_probabilities`, only if [apollo\\_attach](#) was called at the beginning. This can also be achieved by adding the line `on.exit(apollo_detach(apollo_beta, apollo_inputs))` right after calling [apollo\\_attach](#). This function can also be called without any arguments, i.e. `apollo_detach()`.

**Value**

Nothing.

---

|            |                                    |
|------------|------------------------------------|
| apollo_dft | <i>Calculate DFT probabilities</i> |
|------------|------------------------------------|

---

**Description**

Calculate probabilities of a Decision Field Theory (DFT) model and can also perform other operations based on the value of the `functionality` argument.

**Usage**

```
apollo_dft(dft_settings, functionality)
```

**Arguments**

- `dft_settings`      List of settings for the DFT model. It should contain the following elements.
- **alternatives**: Named numeric vector. Names of alternatives and their corresponding value in `choiceVar`.
  - **avail**: Named list of numeric vectors or scalars. Availabilities of alternatives, one element per alternative. Names of elements must match those in `alternatives`. Values can be 0 or 1. These can be scalars or vectors (of length equal to rows in the database). A user can also specify `avail=1` to indicate universal availability, or omit the setting completely.
  - **altStart**: A named list with as many elements as alternatives. Each element can be a scalar or vector containing the starting preference value for the alternative.
  - **attrScalings**: A named list with as many elements as attributes, or fewer. Each element is a factor that scale the attribute, and can be a scalar, a vector or a matrix/array. They do not need to add up to one for each observation. `attrWeights` and `attrScalings` are incompatible, and they should not be both defined for an attribute. Default is 1 for all attributes.

- **attrValues:** A named list with as many elements as alternatives. Each element is itself a named list of vectors of the alternative attributes for each observation (usually a column from the database). All alternatives must have the same attributes (can be set to zero if not relevant).
- **attrWeights:** A named list with as many elements as attributes, or fewer. Each element is the weight of the attribute, and can be a scalar, a vector with as many elements as observations, or a matrix/array if random. They should add up to one for each observation and draw (if present), and will be re-scaled if they do not. `attrWeights` and `attrScalings` are incompatible, and they should not be both defined for an attribute. Default is 1 for all attributes.
- `choiceVar:` Numeric vector. Contains choices for all observations. It will usually be a column from the database. Values are defined in `alternatives`.
- `componentName:` Character. Name given to model component.
- **procPars:** A list containing the four DFT 'process parameters'
  - **error\_sd:** Numeric scalar or vector. The standard deviation of the the error term in each timestep.
  - **timesteps:** Numeric scalar or vector. Number of timesteps to consider. Should be an integer bigger than 0.
  - **phi1:** Numeric scalar or vector. Sensitivity.
  - **phi2:** Numeric scalar or vector. Process parameter.
- `rows:` Boolean vector. Consideration of which rows to include. Length equal to the number of observations (`nObs`), with entries equal to TRUE for rows to include, and FALSE for rows to exclude. Default is "all", equivalent to `rep(TRUE, nObs)`.

functionality Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call `apollo_probabilities`, though the user can also call `apollo_probabilities` manually with a given functionality for testing/debugging. Possible values are:

- "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.
- "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
- "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.
- "output": Prepares output for post-estimation reporting.
- "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- "preprocess": Prepares likelihood functions for use in estimation.
- "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.



- "report": Prepares output summarising model and choiceset structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

## Value

The returned object depends on the value of argument `functionality` as follows.

- "components": Same as "estimate"
- "conditionals": Same as "estimate"
- "estimate": vector/matrix/array. Returns the probabilities for the chosen alternative for each observation.
- "gradient": Not implemented.
- "output": Same as "estimate" but also writes summary of input data to internal Apollo log.
- "prediction": List of vectors/matrices/arrays. Returns a list with the probabilities for all alternatives, with an extra element for the chosen alternative probability.
- "preprocess": Returns a list with pre-processed inputs, based on `dft_settings`.
- "raw": Same as "prediction"
- "report": Choice overview.
- "shares\_LL": Not implemented. Returns a vector of NA with as many elements as observations.
- "validate": Same as "estimate"
- "zero\_LL": vector/matrix/array. Returns the probability of the chosen alternative when all parameters are zero.

## References

Hancock, T.; Hess, S. and Choudhury, C. (2018) Decision field theory: Improvements to current methodology and comparisons with standard choice modelling techniques. *Transportation Research* 107B, 18 - 40. Hancock, T.; Hess, S. and Choudhury, C. (Submitted) An accumulation of preference: two alternative dynamic models for understanding transport choices. Roe, R.; Busemeyer, J. and Townsend, J. (2001) Multialternative decision field theory: A dynamic connectionist model of decision making. *Psychological Review* 108, 370

---

apollo\_diagnostics      *Pre-process input for common models return*

---

### Description

Pre-process input for common models return

### Usage

```
apollo_diagnostics(inputs, modelType, apollo_inputs, data = TRUE, param = TRUE)
```

### Arguments

|               |   |
|---------------|---|
| inputs        | List of settings  |
| modelType     | Character. Type of model, e.g. "mnl", "nl", "cnl", etc.   |
| apollo_inputs | List of main inputs to the model estimation process. See <a href="#">apollo_validateInputs</a> .                                      |
| data          | Boolean. TRUE for printing report related to dependent and independent variables. FALSE for not printing it. Default is TRUE.         |
| param         | Boolean. TRUE for printing report related to estimated parameters (e.g. model structure). FALSE for not printing it. Default is TRUE. |

### Value

(invisibly) TRUE if no error happend during execution.

---

apollo\_drugChoiceData      *Simulated dataset of medication choice.*

---

### Description

A simulated dataset containing 10,000 stated medication choices among four alternatives.

### Usage

```
apollo_drugChoiceData
```

### Format

A data.frame with 10,000 rows and 33 variables:

**ID** Numeric. Identification number of the individual.

**task** Numeric. Index of choice situations for each individual, going from 1 to 10.

**best** Numeric. Index of alternative selected as best option.

**second\_pref** Numeric. Index of alternative selected as second-best option.

**third\_pref** Numeric. Index of alternative selected as third-best option.

**worst** Numeric. Index of alternative selected as worst option.

**brand\_1** Character. Brand for alternative 1.

**country\_1** Character. Country of origin for alternative 1.

**char\_1** Character. Characteristics of alternative 1 (standard, fast acting, or double strength).

**side\_effects\_1** Numeric. Chance of suffering negative side effects with alternative 1.

**price\_1** Numeric. Cost of alternative 1 in Pounds sterling (GBP).

**brand\_2** Character. Brand for alternative 2.

**country\_2** Character. Country of origin for alternative 2.

**char\_2** Character. Characteristics of alternative 2 (standard, fast acting, or double strength).

**side\_effects\_2** Numeric. Chance of suffering negative side effects with alternative 2.

**price\_2** Numeric. Cost of alternative 2 in Pounds sterling (GBP).

**brand\_3** Character. Brand for alternative 3.

**country\_3** Character. Country of origin for alternative 3.

**char\_3** Character. Characteristics of alternative 3 (standard, fast acting, or double strength).

**side\_effects\_3** Numeric. Chance of suffering negative side effects with alternative 3.

**price\_3** Numeric. Cost of alternative 3 in Pounds sterling (GBP).

**brand\_4** Character. Brand for alternative 4.

**country\_4** Character. Country of origin for alternative 4.

**char\_4** Character. Characteristics of alternative 4 (standard, fast acting, or double strength).

**side\_effects\_4** Numeric. Chance of suffering negative side effects with alternative 4.

**price\_4** Numeric. Cost of alternative 4 in Pounds sterling (GBP).

**regular\_user** Numeric. 1 if the respondent is a regular user of headache medicine, 0 otherwise.

**university\_educated** Numeric. 1 if the respondent holds a university degree, 0 otherwise.

**over\_50** Numeric. 1 if the respondent is 50 years old or older, 0 otherwise.

**attitude\_quality** Numeric. Level of agreement from 1 (strongly disagree) to 5 (strongly agree) with the phrase 'I am concerned about the quality of drugs developed by unknown companies'.

**attitude\_ingredients** Numeric. Level of agreement from 1 (strongly disagree) to 5 (strongly agree) with the phrase 'I believe that ingredients are the same no matter what brand'.

**attitude\_patent** Numeric. Level of agreement from 1 (strongly disagree) to 5 (strongly agree) with the phrase 'The original patent holders have valuable experience with their medicines'.

**attitude\_dominance** Numeric. Level of agreement from 1 (strongly disagree) to 5 (strongly agree) with the phrase 'I believe the dominance of big pharmaceutical companies is unhelpful'.

## Details

This dataset is to be used for discrete choice modelling. Data comes from 1,000 individuals, each with ten stated choice (SC) scenarios involving a choice among headache medication. There are 10,000 choices in total. Data is simulated. Each observation contains attributes of the alternatives, characteristics of the respondent, and their answers to four attitudinal questions. All four alternatives are always available for all individuals. Alternatives 1 and 2 are branded, while alternatives 3 and 4 are generic. Respondents provide a full ranking of alternatives for each choice task (i.e. observation).

**Source**

<http://www.apollochoicemodelling.com/>

---

|             |  |
|-------------|--|
| apollo_dVdB | <i>Calculates gradients of utility functions</i> |
|-------------|--|

---

**Description**

Calculates gradients (derivatives) of utility functions.

**Usage**

```
apollo_dVdB(apollo_beta, apollo_inputs, V)
```

**Arguments**

|               |   |
|---------------|---|
| apollo_beta   | Named numeric vector of parameters.   |
| apollo_inputs | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> . |
| V             | List of functions   |

**Value**

Named list. Each element is itself a list of functions: the partial derivatives of the elements of V.

---

|           |  |
|-----------|--|
| apollo_el | <i>Calculates Exploded Logit probabilities</i> |
|-----------|--|

---

**Description**

Calculates the probabilities of an Exploded Logit model and can also perform other operations based on the value of the functionality argument.

**Usage**

```
apollo_el(el_settings, functionality)
```

## Arguments

- `el_settings` List of inputs of the Exploded Logit model. It should contain the following.
- `alternatives`: Named numeric vector. Names of alternatives and their corresponding value in `choiceVar`.
  - `avail`: Named list of numeric vectors or scalars. Availabilities of alternatives, one element per alternative. Names of elements must match those in `alternatives`. Values can be 0 or 1. These can be scalars or vectors (of length equal to rows in the database). A user can also specify `avail=1` to indicate universal availability, or omit the setting completely.
  - `choiceVars`: List of numeric vectors. Contain choices for each position of the ranking. The list must be ordered with the best choice first, second best second, etc. It will usually be a list of columns from the database. Use value -1 if a stage does not apply for a given observations (e.g. when some individuals have shorter rankings).
  - `componentName`: Character. Name given to model component.
  - `utilities`: Named list of deterministic utilities. Utilities of the alternatives. Names of elements must match those in `alternatives`.
  - `rows`: Boolean vector. Consideration of which rows to include. Length equal to the number of observations (`nObs`), with entries equal to `TRUE` for rows to include, and `FALSE` for rows to exclude. Default is `"all"`, equivalent to `rep(TRUE, nObs)`.
  - `scales`: List of vectors. Scale factors of each Logit model. At least one element should be normalized to 1. If omitted, `scale=1` for all positions is assumed.
- `functionality` Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call `apollo_probabilities`, though the user can also call `apollo_probabilities` manually with a given `functionality` for testing/debugging. Possible values are:
- `"components"`: For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.
  - `"conditionals"`: For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
  - `"estimate"`: For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
  - `"gradient"`: For model estimation, produces analytical gradients of the likelihood, where possible.
  - `"output"`: Prepares output for post-estimation reporting.
  - `"prediction"`: For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
  - `"preprocess"`: Prepares likelihood functions for use in estimation.
  - `"raw"`: For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.

- "report": Prepares output summarising model and choiceset structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

## Details

The function calculates the probability of a ranking as a product of Multinomial Logit models with gradually reducing availability, where scale differences can be allowed for.

## Value

The returned object depends on the value of argument `functionality` as follows.

- "components": Same as "estimate"
- "conditionals": Same as "estimate"
- "estimate": vector/matrix/array. Returns the probabilities for the chosen alternative for each observation.
- "gradient": List containing the likelihood and gradient of the model component.
- "output": Same as "estimate" but also writes summary of input data to internal Apollo log.
- "prediction": Not applicable (NA).
- "preprocess": Returns a list with pre-processed inputs, based on `el_settings`.
- "raw": Same as "estimate"
- "report": Choice overview across stages.
- "shares\_LL": Not implemented. Returns a vector of NA with as many elements as observations.
- "validate": Same as "estimate"
- "zero\_LL": vector/matrix/array. Returns the probability of the chosen alternative when all parameters are zero.

---

apollo\_estimate

*Estimates model*

---

## Description

Estimates a model using the likelihood function defined by `apollo_probabilities`.

**Usage**

```
apollo_estimate(
  apollo_beta,
  apollo_fixed,
  apollo_probabilities,
  apollo_inputs,
  estimate_settings = NA
)
```

**Arguments**

- apollo\_beta** Named numeric vector. Names and values for parameters.
- apollo\_fixed** Character vector. Names (as defined in `apollo_beta`) of parameters whose value should not change during estimation.
- apollo\_probabilities** Function. Returns probabilities of the model to be estimated. Must receive three arguments:
- `apollo_beta`: Named numeric vector. Names and values of model parameters.
  - `apollo_inputs`: List containing options of the model. See [apollo\\_validateInputs](#).
  - `functionality`: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".
- apollo\_inputs** List grouping most common inputs. Created by function [apollo\\_validateInputs](#).
- estimate\_settings** List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.
- `bootstrapSE`: Numeric. Number of bootstrap samples to calculate standard errors. Default is 0, meaning no bootstrap s.e. will be calculated. Number must zero or a positive integer. Only used if `apollo_control$HB` is FALSE.
  - `bootstrapSeed`: Numeric scalar (integer). Random number generator seed to generate the bootstrap samples. Only used if `bootstrapSE` > 0. Default is 24.
  - `constraints`: Character vector. Linear constraints on parameters to estimate. For example `c('b1>0', 'b1 + 2*b2>1')`. Only >, < and = can be used. Inequalities cannot be mixed with equality constraints, e.g. `c(b1-b2=0, b2>0)` will fail. All parameter names must be on the left side. Fixed parameters cannot go into constraints. Alternatively, constraints can be defined as in [maxLik](#). Constraints can only be used with maximum likelihood estimation and the BFGS routine in particular.
  - `estimationRoutine`: Character. Estimation method. Can take values "bfgs", "bhhh", or "nr". Used only if `apollo_control$HB` is FALSE. Default is "bfgs".
  - `hessianRoutine`: Character. Name of routine used to calculate the Hessian of the log-likelihood function after estimation. Valid values are "analytic" (default), "numDeriv" (to use the numeric routine in package `numDeriv`),

"maxLik" (to use the numeric routine in package maxLik), and "none" to avoid estimating the Hessian and the covariance matrix. Only used if `apollo_control$HB=FALSE`.

- `maxIterations`: Numeric. Maximum number of iterations of the estimation routine before stopping. Used only if `apollo_control$HB` is FALSE. Default is 200.
- `maxLik_settings`: List. Additional settings for maxLik. See argument `control` in [maxBFGS](#), [maxBHHH](#) and [maxNM](#) for more details. Only used for maximum likelihood estimation.
- `numDeriv_settings`: List. Additional arguments to the Richardson method used by numDeriv to calculate the Hessian. See argument `method.args` in [grad](#) for more details.
- `printLevel`: Higher values render more verbous outputs. Can take values 0, 1, 2 or 3. Ignored if `apollo_control$HB` is TRUE. Default is 3.
- `scaleAfterConvergence`: Logical. Used to increase numerical precision of convergence. If TRUE, parameters are scaled to 1 after convergence, and the estimation is repeated from this new starting values. Results are reported scaled back, so it is a transparent process for the user. Default is TRUE.
- `scaleHessian`: Logical. If TRUE, parameters are scaled to 1 for Hessian estimation. Default is TRUE.
- `scaling`: Named vector. Names of elements should match those in `apollo_beta`. Optional scaling for parameters. If provided, for each parameter  $i$ ,  $(\text{apollo\_beta}[i]/\text{scaling}[i])$  is optimised, but  $\text{scaling}[i]*(\text{apollo\_beta}[i]/\text{scaling}[i])$  is used during estimation. For example, if parameter  $b_3=10$ , while  $b_1$  and  $b_2$  are close to 1, then setting `scaling = c(b3=10)` can help estimation, specially the calculation of the Hessian. Reports will still be based on the non-scaled parameters.
- `silent`: Logical. If TRUE, no information is printed to the console during estimation. Default is FALSE.
- `writeIter`: Logical. Writes value of the parameters in each iteration to a csv file. Works only if `estimation_routine="bfgs"`. Default is TRUE.

## Details

This is the main function of the Apollo package. The estimation process begins by running a number of checks on the `apollo_probabilities` function provided by the user. If all checks are passed, estimation begins. There is no limit to estimation time other than reaching the maximum number of iterations. If Bayesian estimation is used, estimation will finish once the predefined number of iterations are completed. By default, this functions writes the estimated parameter values in each iteration to a file in the `working/output` directory. Writing can be turned off by setting `estimate_settings$writeIter` to FALSE. By default, **final results are not written into a file nor printed to the console**, so users must make sure to call function [apollo\\_modelOutput](#) and/or [apollo\\_saveOutput](#) afterwards. Users are strongly encouraged to visit <http://www.ApolloChoiceModelling.com> to download examples on how to use the Apollo package. The webpage also provides a detailed manual for the package, as well as a user-group to get further help.



**Value**

model object

---

|                   |  |
|-------------------|--|
| apollo_estimateHB | <i>Estimates model using Bayesian estimation</i> |
|-------------------|--|

---

**Description**

Estimates a model using Bayesian estimation on the likelihood function defined by `apollo_probabilities`.

**Usage**

```
apollo_estimateHB(
  apollo_beta,
  apollo_fixed,
  apollo_probabilities,
  apollo_inputs,
  estimate_settings = NA
)
```

**Arguments**

`apollo_beta` Named numeric vector. Names and values for parameters.

`apollo_fixed` Character vector. Names (as defined in `apollo_beta`) of parameters whose value should not change during estimation.

`apollo_probabilities` Function. Returns probabilities of the model to be estimated. Must receive three arguments:

- `apollo_beta`: Named numeric vector. Names and values of model parameters.
- `apollo_inputs`: List containing options of the model. See [apollo\\_validateInputs](#).
- `functionality`: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".

`apollo_inputs` List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

`estimate_settings` List. Options controlling the estimation process, as used for in [apollo\\_estimate](#).

**Details**

This is a sub function of [apollo\\_estimate](#) which is called when using Bayesian estimation.

**Value**

model object

---

apollo\_expandLoop      *Expands loops in a function or expression*

---

### Description

Expands loops replacing the index by its value. It also evaluates paste and paste0, and removes get.

### Usage

```
apollo_expandLoop(f, apollo_inputs)
```

### Arguments

f                      function (usually apollo\_probabilities) inside which the name of the components are inserted.

apollo\_inputs      List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

### Details

For example, the expression  $\text{for}(j \text{ in } 1:3) \text{V}[\text{paste0}('alt', j)] = b1 * \text{get}(\text{paste0}('x', j)) + b2 * X[, j]$

would be expanded into:

$$\text{V}[\text{alt1}] = b1 * x1 + b2 * X[, 1] \quad \text{V}[\text{alt2}] = b1 * x2 + b2 * X[, 2] \quad \text{V}[\text{alt3}] = b1 * x3 + b2 * X[, 3]$$

### Value

A function or an expression (same type as input f)

---

apollo\_firstRow      *Keeps only the first row for each individual*

---

### Description

Given a multi-row input, keeps only the first row for each individual.

### Usage

```
apollo_firstRow(P, apollo_inputs)
```

### Arguments

P                      List of vectors, matrices or 3-dim arrays. Likelihood of the model components (or other object).

apollo\_inputs      List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

**Details**

This is a function to keep only the first row of an object per individual. It can handle multiple types of components, including scalars, vectors and three-dimensional arrays (cubes). The argument database MUST contain a column called 'apollo\_sequence', which is created by [apollo\\_validateData](#).

**Value**

If P is a list, then it returns a list where each element has only the first row of each individual. If P is a single element, then it returns a single element with only the first row of each individual. The size of the element is changed only in the first dimension. If input is a scalar, then it returns a vector with the element repeated as many times as individuals in database. If the element is a vector, its length will be changed to the number of individuals. If the element is a matrix, then its first dimension will be changed to the number of individuals, while keeping the size of the second dimension. If the element is a cube, then only the first dimension's length is changed, preserving the others.

---

|                 |   |
|-----------------|---|
| apollo_fitsTest | <i>Compares log-likelihood of model across categories</i> |
|-----------------|---|

---

**Description**

Given the estimates of a model, it compares the log-likelihood at the observation level across categories of observations.

**Usage**

```
apollo_fitsTest(model, apollo_probabilities, apollo_inputs, fitsTest_settings)
```

**Arguments**

- |                      |  |
|----------------------|--|
| model                | Model object. Estimated model object as returned by function <a href="#">apollo_estimate</a> .   |
| apollo_probabilities | Function. Returns probabilities of the model to be estimated. Must receive three arguments: <ul style="list-style-type: none"> <li>• <code>apollo_beta</code>: Named numeric vector. Names and values of model parameters.</li> <li>• <code>apollo_inputs</code>: List containing options of the model. See <a href="#">apollo_validateInputs</a>.</li> <li>• <code>functionality</code>: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares_LL", "validate" or "zero_LL".</li> </ul> |
| apollo_inputs        | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |
| fitsTest_settings    | List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional. <ul style="list-style-type: none"> <li>• <b>subsamples</b>: Named list of boolean vectors. Each element of the list defines whether a given observation belongs to a given subsample (e.g. by sociodemographics).</li> </ul>   |

**Details**

Prints a table comparing the average log-likelihood at the observation level for each category.

**Value**

Matrix with average log-likelihood at observation level per category (invisibly).

---

|             |  |
|-------------|--|
| apollo_fmnl | <i>Calculates Fractional Multinomial Logit probabilities</i> |
|-------------|--|

---

**Description**

Calculates the probabilities of a Fractional Multinomial Logit model and can also perform other operations based on the value of the functionality argument.

**Usage**

```
apollo_fmnl(fmnl_settings, functionality)
```

**Arguments**

- |               |  |
|---------------|--|
| fmnl_settings | <p>List of inputs of the FMNL model. It should contain the following.</p> <ul style="list-style-type: none"> <li>• alternatives: Character vector. Names of alternatives, elements must match the names in list 'utilities'.</li> <li>• avail: Named list of numeric vectors or scalars. Availabilities of alternatives, one element per alternative. Names of elements must match those in alternatives. Values can be 0 or 1. These can be scalars or vectors (of length equal to rows in the database). A user can also specify avail=1 to indicate universal availability, or omit the setting completely.</li> <li>• choiceShares: Named list of numeric vectors. Share allocated to each alternative. One element per alternative, as long as the number of observations or a scalar. Names must match those in alternatives.</li> <li>• componentName: Character. Name given to model component.</li> <li>• rows: Boolean vector. Consideration of which rows to include. Length equal to the number of observations (nObs), with entries equal to TRUE for rows to include, and FALSE for rows to exclude. Default is "all", equivalent to rep(TRUE, nObs).</li> <li>• utilities: Named list of deterministic utilities. Utilities of the alternatives. Names of elements must match those in alternatives.</li> </ul> |
| functionality | <p>Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call apollo_probabilities, though the user can also call apollo_probabilities manually with a given functionality for testing/debugging. Possible values are:</p> <ul style="list-style-type: none"> <li>• "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> </ul>  |

- "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
- "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.
- "output": Prepares output for post-estimation reporting.
- "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- "preprocess": Prepares likelihood functions for use in estimation.
- "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- "report": Prepares output summarising model and choicest structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

## Value

The returned object depends on the value of argument `functionality` as follows.

- "components": Same as "estimate"
- "conditionals": Same as "estimate"
- "estimate": vector/matrix/array. Returns the probabilities for the chosen alternative for each observation.
- "gradient": List containing the likelihood and gradient of the model component.
- "output": Same as "estimate" but also writes summary of input data to internal Apollo log.
- "prediction": List of vectors/matrices/arrays. Returns a list with the probabilities for all alternatives, with an extra element for the probability of the chosen alternative.
- "preprocess": Returns a list with pre-processed inputs, based on `mfnl_settings`.
- "raw": Same as "prediction"
- "report": Overview of dependent variable
- "shares\_LL": vector/matrix/array. Returns the probability of the chosen alternative when only constants are estimated.
- "validate": Same as "estimate", but it also runs a set of tests to validate the function inputs.
- "zero\_LL": vector/matrix/array. Returns the probability of the chosen alternative when all parameters are zero.

---

apollo\_initialise      *Prepares environment*

---

**Description**

Prepares environment (the global environment if called by the user) for model definition and estimation.

**Usage**

```
apollo_initialise()
```

**Details**

This function detaches variables and makes sure that output is directed to console. It does not delete variables from the working environment.

**Value**

Nothing.

---

apollo\_insertComponentName  
*Adds componentName2 to model calls*

---

**Description**

Adds componentName2 to model calls

**Usage**

```
apollo_insertComponentName(e)
```

**Arguments**

e                      An expression or a function. It will usually be apollo\_probabilities.

**Value**

The original argument 'e' but modified to incorporate a new setting called 'componentName2' to every call to apollo\_<model> (e.g. apollo\_mnl, apollo\_nl, etc.).

---

|                   |  |
|-------------------|--|
| apollo_insertFunc | <i>Modifies function to make it compatible with analytic gradients</i> |
|-------------------|--|

---

## Description

Takes a likelihood function and inserts function () before key elements to allow for analytic gradient calculation

## Usage

```
apollo_insertFunc(f, like = TRUE, randCoeff = FALSE, lcPars = FALSE)
```

## Arguments

|           |  |
|-----------|--|
| f         | Function. Expressions inside it will be turned into functions. Usually apollo_probabilities or apollo_randCoeff. |
| like      | Logical. Must be TRUE if f is apollo_probabilities. FALSE otherwise.   |
| randCoeff | Logical. Must be TRUE if f is apollo_randCoeff. FALSE otherwise.   |
| lcPars    | Logical. Must be TRUE if f is apollo_lcPars. FALSE otherwise.  |

## Details

It modifies the definition of the following models.

- apollo\_mnl: Turns all elements inside mnl\_settings\$V into functions.
- apollo\_ol: Turns ol\_settings\$V and all elements inside ol\_settings\$tau into functions.
- apollo\_op: Turns op\_settings\$V and all elements inside op\_settings\$tau into functions.
- apollo\_normalDensity: Turns normalDensity\_settings\$xNormal, normalDensity\_settings\$mu and normalDensity\_settings\$sigma into functions.

It can only track a maximum of 3 levels of depth in definitions. For example: `V<-list()  
V[["A"]]<-b1*x1A + b2*x2A V[["B"]]<-b1*x1B + b2*x2B mnl_settings1<-list(alternatives=c("A","B"),V  
= V,choiceVar= Y,avail = 1,componentName="MNL1") P[["MNL1"]]<-apollo_mnl(mnl_settings1,functionality)`  
But it may not be able to deal with the following: `VA<-b1*x1A + b2*x2A V<-list() V[["A"]]  
<-VA V[["B"]]<-b1*x1B + b2*x2B mnl_settings1<-list(alternatives=c("A","B"),V = V,choiceVar=  
Y,avail = 1,componentName="MNL1") P[["MNL1"]]<-apollo_mnl(mnl_settings1,functionality)`  
But that might be enough given how apollo\_dVdB works.

## Value

Function f but with relevant expressions turned into function definitions.

---

apollo\_insertRows      *Inserts rows*

---

### Description

Given a numeric object (scalar, vector, matrix or 3-dim array) inserts rows in the specified places.

### Usage

```
apollo_insertRows(v, r, val)
```

### Arguments

|     |  |
|-----|--|
| v   | Numeric scalar, vector, matrix or 3-dim array.   |
| r   | Boolean vector. TRUE for inserting a row from utilities, FALSE to insert a new row with value val. |
| val | Numeric scalar. Value that will fill new rows.   |

### Details

In general, r should be longer than the number of rows in utilities, and sum(r)=nrow(v). If not, then a new object with as many rows as r will be returned. Old rows will be taken from utilities from the top down.

### Value

The same argument utilities but with the rows where r==FALSE removed.

---

apollo\_insertScaling      *Scales variables inside a function*

---

### Description

It changes the syntax of the function by replacing variable names for their scaled form, e.g.  $x \rightarrow x * \text{apollo\_inputs}\$\text{apollo\_scale}[["x"]]$ . In assignments, it only scales the right side of the assignment.

### Usage

```
apollo_insertScaling(e, sca)
```

### Arguments

|     |  |
|-----|--|
| e   | Function, expression, call or symbol to alter.   |
| sca | Named numeric vector with the scales. The names in these vectors determine which variables should be scaled. |



**Value**

A function, expression, call or symbol with the corresponding variables scaled.

---

|                 |                             |
|-----------------|-----------------------------|
| apollo_keepRows | <i>Keeps only some rows</i> |
|-----------------|-----------------------------|

---

**Description**

Given a numeric object (scalar, vector, matrix or 3-dim array) keeps only the specified rows.

**Usage**

```
apollo_keepRows(v, r)
```

**Arguments**

|   |  |
|---|--|
| v | Numeric scalar, vector, matrix or 3-dim array.   |
| r | Boolean vector. As many elements as rows in utilities. TRUE for keeping the row. FALSE to drop it. |

**Value**

The same argument utilities but with the rows where r==FALSE removed.

---

|           |  |
|-----------|--|
| apollo_lc | <i>Calculates the likelihood of a latent class model</i> |
|-----------|--|

---

**Description**

Given within class probabilities, and class allocation probabilities, calculates the probabilities of an Exploded Logit model and can also perform other operations based on the value of the functionality argument.

**Usage**

```
apollo_lc(lc_settings, apollo_inputs, functionality)
```

## Arguments

- |               |   |
|---------------|---|
| lc_settings   | <p>List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.</p> <ul style="list-style-type: none"> <li>• <b>inClassProb</b>: List of probabilities. Conditional likelihood for each class. One element per class, in the same order as classProb.</li> <li>• <b>classProb</b>: List of probabilities. Allocation probability for each class. One element per class, in the same order as inClassProb.</li> <li>• <b>componentName</b>: Character. Name given to model component (optional).</li> </ul>   |
| apollo_inputs | <p>List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a>.</p>   |
| functionality | <p>Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call <a href="#">apollo_probabilities</a>, though the user can also call <a href="#">apollo_probabilities</a> manually with a given functionality for testing/debugging. Possible values are:</p> <ul style="list-style-type: none"> <li>• "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> <li>• "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.</li> <li>• "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>• "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.</li> <li>• "output": Prepares output for post-estimation reporting.</li> <li>• "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.</li> <li>• "preprocess": Prepares likelihood functions for use in estimation.</li> <li>• "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.</li> <li>• "report": Prepares output summarising model and choicest structure.</li> <li>• "shares_LL": Produces overall model likelihood with constants only.</li> <li>• "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>• "zero_LL": Produces overall model likelihood with all parameters at zero.</li> </ul> |

## Value

The returned object depends on the value of argument `functionality` as follows.

- "components": Returns nothing.
- "conditionals": Same as "estimate"
- "estimate": vector/matrix/array. Returns the probabilities for the chosen alternative for each observation.

- "gradient": List containing the likelihood and gradient of the model component.
- "output": Same as "estimate" but also writes summary of input data to internal Apollo log.
- "prediction": List of vectors/matrices/arrays. Returns a list with the probabilities for all models components, for each class.
- "preprocess": Returns a list with pre-processed inputs, based on lc\_settings.
- "raw": Same as "prediction"
- "report": Class allocation overview.
- "shares\_LL": Same as "estimate"
- "validate": Same as "estimate", but also runs a set of tests on the given arguments.
- "zero\_LL": Same as "estimate"

---

apollo\_lcConditionals *Calculates conditionals of a latent class model.*

---

### Description

Calculates posterior expected values (conditionals) of class allocation probabilities for each individual.

### Usage

```
apollo_lcConditionals(model, apollo_probabilities, apollo_inputs)
```

### Arguments

- |                      |   |
|----------------------|---|
| model                | Model object. Estimated model object as returned by function <a href="#">apollo_estimate</a> .  |
| apollo_probabilities | Function. Returns probabilities of the model to be estimated. Must receive three arguments: <ul style="list-style-type: none"> <li>• apollo_beta: Named numeric vector. Names and values of model parameters.</li> <li>• apollo_inputs: List containing options of the model. See <a href="#">apollo_validateInputs</a>.</li> <li>• functionality: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares_LL", "validate" or "zero_LL".</li> </ul> |
| apollo_inputs        | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .   |

### Details

This function can only be used with latent class models without continuous heterogeneity.

### Value

A matrix with the posterior class allocation probabilities for each individual.

---

|             |                                       |
|-------------|---------------------------------------|
| apollo_lcEM | <i>Uses EM for latent class model</i> |
|-------------|---------------------------------------|

---

### Description

Uses the EM algorithm for estimating a latent class model.

### Usage

```
apollo_lcEM(
  apollo_beta,
  apollo_fixed,
  apollo_probabilities,
  apollo_inputs,
  lcEM_settings = NA,
  estimate_settings = NA
)
```

### Arguments

- |                      |  |
|----------------------|--|
| apollo_beta          | Named numeric vector. Names and values for parameters.   |
| apollo_fixed         | Character vector. Names (as defined in <code>apollo_beta</code> ) of parameters whose value should not change during estimation.   |
| apollo_probabilities | Function. Returns probabilities of the model to be estimated. Must receive three arguments: <ul style="list-style-type: none"> <li>• <code>apollo_beta</code>: Named numeric vector. Names and values of model parameters.</li> <li>• <code>apollo_inputs</code>: List containing options of the model. See <a href="#">apollo_validateInputs</a>.</li> <li>• <code>functionality</code>: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares_LL", "validate" or "zero_LL".</li> </ul>   |
| apollo_inputs        | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |
| lcEM_settings        | List. Options controlling the EM process. <ul style="list-style-type: none"> <li>• <b>EMmaxIterations</b>: Numeric. Maximum number of iterations of the EM algorithm before stopping. Default is 100.</li> <li>• <b>postEM</b>: Numeric scalar. Determines the tasks performed by this function after the EM algorithm has converged. Can take values 0, 1 or 2 only. If value is 0, only the EM algorithm will be performed, and the results will be a model object without a covariance matrix (i.e. estimates only). If value is 1, after the EM algorithm, the covariance matrix of the model will be calculated as well, and the result will be a model object with a covariance matrix. If value is 2, after the EM algorithm, the estimated parameter values will be used as starting value for a maximum likelihood estimation process, which will render a model object with a covariance matrix. Performing</li> </ul> |

maximum likelihood estimation after the EM algorithm is useful, as there may be room for further improvement. Default is 2.

- **silent**: Boolean. If TRUE, no information is printed to the console during estimation. Default is FALSE.
- **stoppingCriterion**: Numeric. Convergence criterion. The EM process will stop when improvements in the log-likelihood fall below this value. Default is  $10^{-5}$ .

estimate\_settings

List. Options controlling the estimation process within each EM iteration. See [apollo\\_estimate](#) for details.

## Details

This function uses the EM algorithm for estimating a Latent Class model. It is only suitable for models without continuous mixing. All parameters need to vary across classes and need to be included in the `apollo_lcPars` function which is used by `apollo_lcEM`.

## Value

model object

---

apollo\_lcUnconditionals

*Returns unconditionals for a latent class model model*

---

## Description

Returns values for random parameters and class allocation probabilities in a latent class model model.

## Usage

```
apollo_lcUnconditionals(model, apollo_probabilities, apollo_inputs)
```

## Arguments

`model` Model object. Estimated model object as returned by function [apollo\\_estimate](#).

`apollo_probabilities`

Function. Returns probabilities of the model to be estimated. Must receive three arguments:

- `apollo_beta`: Named numeric vector. Names and values of model parameters.
- `apollo_inputs`: List containing options of the model. See [apollo\\_validateInputs](#).
- `functionality`: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".

`apollo_inputs` List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

**Value**

List of object, one per random component and one for the class allocation probabilities.

---

|               |  |
|---------------|--|
| apollo_llCalc | <i>Calculates log-likelihood of all model components</i> |
|---------------|--|

---

**Description**

Calculates the log-likelihood of each model component as well as the whole model.

**Usage**

```
apollo_llCalc(apollo_beta, apollo_probabilities, apollo_inputs, silent = FALSE)
```

**Arguments**

|                      |   |
|----------------------|---|
| apollo_beta          | Named numeric vector. Names and values for parameters.  |
| apollo_probabilities | Function. Returns probabilities of the model to be estimated. Must receive three arguments: <ul style="list-style-type: none"> <li>• apollo_beta: Named numeric vector. Names and values of model parameters.</li> <li>• apollo_inputs: List containing options of the model. See <a href="#">apollo_validateInputs</a>.</li> <li>• functionality: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares_LL", "validate" or "zero_LL".</li> </ul> |
| apollo_inputs        | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .   |
| silent               | Boolean. If TRUE, no information is printed to the console by the function. Default is FALSE.   |

**Details**

This function calls `apollo_probabilities` with `functionality="output"`. It then reorders the list of likelihoods so that "model" goes first.

**Value**

A list of vectors. Each vector corresponds to the log-likelihood of the whole model (first element) or a model component.

---

|                  |                              |
|------------------|------------------------------|
| apollo_loadModel | <i>Loads model from file</i> |
|------------------|------------------------------|

---

**Description**

Loads a previously estimated model object from a file.

**Usage**

```
apollo_loadModel(modelName)
```

**Arguments**

|           |                                       |
|-----------|---------------------------------------|
| modelName | Character. Name of the model to load. |
|-----------|---------------------------------------|

**Details**

This function looks for a file named `modelName_model.rds` in the working or output directory, loads the object contained in it, and returns it.

**Value**

A model object.

---

|               |                              |
|---------------|------------------------------|
| apollo_lrTest | <i>Likelihood ratio test</i> |
|---------------|------------------------------|

---

**Description**

Calculates the likelihood ratio test value between two models and reports the corresponding p-value.

**Usage**

```
apollo_lrTest(model1, model2)
```

**Arguments**

|        |  |
|--------|--|
| model1 | Either a character variable with the name of a previously estimated model, or an estimated model in memory, as returned by <a href="#">apollo_estimate</a> . |
| model2 | Either a character variable with the name of a previously estimated model, or an estimated model in memory, as returned by <a href="#">apollo_estimate</a> . |

**Details**

The two models need to have been estimated on the same data, and one model needs to be nested within the other model.

**Value**

LR-test p-value (invisibly)

---

apollo\_makeCluster      *Creates cluster for estimation.*

---

**Description**

Splits data, creates cluster and loads different pieces of the database on each worker.

**Usage**

```
apollo_makeCluster(
  apollo_probabilities,
  apollo_inputs,
  silent = FALSE,
  cleanMemory = FALSE
)
```

**Arguments**

`apollo_probabilities`      Function. Returns probabilities of the model to be estimated. Must receive three arguments:

- `apollo_beta`: Named numeric vector. Names and values of model parameters.
- `apollo_inputs`: List containing options of the model. See [apollo\\_validateInputs](#).
- `functionality`: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".

`apollo_inputs`      List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

`silent`      Boolean. If TRUE, no messages are printed to the terminal. FALSE by default. It overrides `apollo_inputs$silent`.

`cleanMemory`      Boolean. If TRUE, it saves `apollo_inputs` to disc, and removes database and draws from the `apollo_inputs` in `.GlobalEnv` and the parent environment.

**Details**

Internal use only. Called by `apollo_estimate` before estimation. Using multiple cores greatly increases memory consumption.

**Value**

Cluster (i.e. an object of class `cluster` from package `parallel`)



---

|                  |   |
|------------------|---|
| apollo_makeDraws | <i>Creates draws for models with mixing</i> |
|------------------|---|

---

### Description

Creates a list containing all draws necessary to estimate a model with mixing.

### Usage

```
apollo_makeDraws(apollo_inputs, silent = FALSE)
```

### Arguments

|               |  |
|---------------|--|
| apollo_inputs | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .    |
| silent        | Boolean. If true, then no information is printed to console or default output. FALSE by default. |

### Details

Internal use only. Called by `apollo_validateInputs`. This function creates a list whose elements are the sets of draws requested by the user for use in a model with mixing. If the model does not include mixing, then it is not necessary to run this function. The number of draws has a massive impact on memory usage and estimation time. Memory usage and number of computations scale geometrically as  $N \times \text{interNDraws} \times \text{intraNDraws}$  (where  $N$  is the number of observations). Special care should be taken when using both inter and intra-individual draws, as memory usage can easily reach the GB order of magnitude. Also, keep in mind that using several threads (i.e. multicore) at least doubles the memory usage. This function returns a list, with each element representing a random component of the mixing model. The dimensions of the array depend on the type of draws used.

1. If only inter-individual draws are used, then draws are stored as 2-dimensional arrays (i.e. matrices).
2. If intra-individual draws are used, then draws are stored as 3-dimensional arrays.
3. The first dimension of the arrays (rows) correspond with the observations in the database.
4. The second dimension of the arrays (columns) correspond to the number of inter-individual draws.
5. The third dimension of the arrays correspond to the number of intra-individual draws.

### Value

List. Each element is an array of draws representing a random component of the mixing model.

---

apollo\_makeGrad      *Creates gradient function.*

---

### Description

Creates gradient function from the likelihood function `apollo_probabilities` provided by the user. Returns NULL if the creation of gradient function fails.

### Usage

```
apollo_makeGrad(
  apollo_beta,
  apollo_fixed,
  apollo_logLike,
  validateGrad = FALSE
)
```

### Arguments

|                             |  |
|-----------------------------|--|
| <code>apollo_beta</code>    | Named numeric vector. Names and values for parameters.   |
| <code>apollo_fixed</code>   | Character vector. Names (as defined in <code>apollo_beta</code> ) of parameters whose value should not change during estimation.   |
| <code>apollo_logLike</code> | Function to calculate the log-likelihood of the model, as created by <a href="#">apollo_makeLogLike</a> . If provided, the value of the analytical gradient will be compared to the value of the numerical gradient as calculated using <code>apollo_logLike</code> and the <code>numDeriv</code> package. If the difference between the two is bigger than 1 that the analytical gradient is wrong and NULL will be returned. |
| <code>validateGrad</code>   | Logical. If TRUE, it compares the value of the analytical gradient evaluated at <code>apollo_beta</code> against the numeric gradient (using <code>numDeriv</code> ) at the same value. If the difference is bigger than 1 return NULL.  |

### Details

Internal use only. Called by `apollo_estimate` before estimation. The returned function can be single-threaded or multi-threaded based on the model options.

### Value

`apollo_gradient` function. It receives the following arguments

- `b` Numeric vector of `_variable_` parameters (i.e. must not include fixed parameters).
- `countIter` Not used. Included only to mirror inputs of `apollo_logLike`.
- `getNIter` Not used. Included only to mirror inputs of `apollo_logLike`.
- `sumLL` Not used. Included only to mirror inputs of `apollo_logLike`.
- `writeIter` Not used. Included only to mirror inputs of `apollo_logLike`.

If the creation of the gradient function fails, then it returns NULL.

---

apollo\_makeLogLike      *Creates log-likelihood function.*

---

## Description

Creates log-likelihood function from the likelihood function `apollo_probabilities` provided by the user.

## Usage

```
apollo_makeLogLike(
  apollo_beta,
  apollo_fixed,
  apollo_probabilities,
  apollo_inputs,
  apollo_estSet = list(estimationRoutine = "BFGS"),
  cleanMemory = FALSE
)
```

## Arguments

|                                   |  |
|-----------------------------------|--|
| <code>apollo_beta</code>          | Named numeric vector. Names and values for parameters.   |
| <code>apollo_fixed</code>         | Character vector. Names (as defined in <code>apollo_beta</code> ) of parameters whose value should not change during estimation.   |
| <code>apollo_probabilities</code> | Function. Returns probabilities of the model to be estimated. Must receive three arguments: <ul style="list-style-type: none"> <li>• <code>apollo_beta</code>: Named numeric vector. Names and values of model parameters.</li> <li>• <code>apollo_inputs</code>: List containing options of the model. See <a href="#">apollo_validateInputs</a>.</li> <li>• <code>functionality</code>: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares_LL", "validate" or "zero_LL".</li> </ul> |
| <code>apollo_inputs</code>        | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |
| <code>apollo_estSet</code>        | List of estimation options. It must contain at least one element called <code>estimationRoutine</code> defining the estimation algorithm. See <a href="#">apollo_estimate</a> .  |
| <code>cleanMemory</code>          | Logical. If TRUE, then <code>apollo_inputs\$draws</code> and <code>apollo_inputs\$database</code> are erased throughout the calling stack. Used to reduce memory usage in case of multithreading and a large database or number of draws.  |

## Details

Internal use only. Called by `apollo_estimate` before estimation. The returned function can be single-threaded or multi-threaded based on the model options.

**Value**

apollo\_logLike function.

---

|              |                                     |
|--------------|-------------------------------------|
| apollo_mdcev | <i>Calculates MDCEV likelihoods</i> |
|--------------|-------------------------------------|

---

**Description**

Calculates the likelihoods of a Multiple Discrete Continuous Extreme Value (MDCEV) model and can also perform other operations based on the value of the functionality argument.

**Usage**

```
apollo_mdcev(mdcev_settings, functionality)
```

**Arguments**

- mdcev\_settings List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.
- alpha: Named list. Alpha parameters for each alternative, including for any outside good. As many elements as alternatives.
  - alternatives: Character vector. Names of alternatives, elements must match the names in list 'utilities'.
  - avail: Named list of numeric vectors or scalars. Availabilities of alternatives, one element per alternative. Names of elements must match those in alternatives. Values can be 0 or 1. These can be scalars or vectors (of length equal to rows in the database). A user can also specify avail=1 to indicate universal availability, or omit the setting completely.
  - budget: Numeric vector. Budget for each observation.
  - componentName: Character. Name given to model component.
  - continuousChoice: Named list of numeric vectors. Amount of consumption of each alternative. One element per alternative, as long as the number of observations or a scalar. Names must match those in alternatives.
  - cost: Named list of numeric vectors. Price of each alternative. One element per alternative, each one as long as the number of observations or a scalar. Names must match those in alternatives.
  - gamma: Named list. Gamma parameters for each alternative, excluding any outside good. As many elements as inside good alternatives.
  - nRep: Numeric scalar. Number of simulations of the whole dataset used for forecasting. The forecast is the average of these simulations. Default is 100.
  - outside: Character. Optional name of the outside good.
  - rawPrediction: Logical scalar. TRUE for prediction to be returned at the draw level (a 3-dim array). FALSE for prediction to be returned averaged across draws. Default is FALSE.

- `rows`: Boolean vector. Consideration of which rows to include. Length equal to the number of observations (`nObs`), with entries equal to `TRUE` for rows to include, and `FALSE` for rows to exclude. Default is `"all"`, equivalent to `rep(TRUE, nObs)`.
- `sigma`: Numeric scalar. Scale parameter of the model extreme value type I error.
- `utilities`: Named list. Utilities of the alternatives. Names of elements must match those in argument `'alternatives'`.

`functionality` Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call `apollo_probabilities`, though the user can also call `apollo_probabilities` manually with a given `functionality` for testing/debugging. Possible values are:

- `"components"`: For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.
- `"conditionals"`: For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
- `"estimate"`: For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- `"gradient"`: For model estimation, produces analytical gradients of the likelihood, where possible.
- `"output"`: Prepares output for post-estimation reporting.
- `"prediction"`: For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- `"preprocess"`: Prepares likelihood functions for use in estimation.
- `"raw"`: For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- `"report"`: Prepares output summarising model and choiceset structure.
- `"shares_LL"`: Produces overall model likelihood with constants only.
- `"validate"`: Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- `"zero_LL"`: Produces overall model likelihood with all parameters at zero.

## Value

The returned object depends on the value of argument `functionality` as follows.

- `"components"`: Same as `"estimate"`
- `"conditionals"`: Same as `"estimate"`
- `"estimate"`: vector/matrix/array. Returns the probabilities for the observed consumption for each observation.
- `"gradient"`: Not implemented

- "output": Same as "estimate" but also writes summary of input data to internal Apollo log.
- "prediction": A matrix with one row per observation, and columns indicating means and s.d. of continuous and discrete predicted consumptions.
- "preprocess": Returns a list with pre-processed inputs, based on mdcev\_settings.
- "raw": Same as "estimate"
- "report": Dependent variable overview.
- "shares\_LL": Not implemented. Returns a vector of NA with as many elements as observations.
- "validate": Same as "estimate", but it also runs a set of tests to validate the function inputs.
- "zero\_LL": Not implemented. Returns a vector of NA with as many elements as observations.

---

 apollo\_mdcev2

*Calculates MDCEV likelihoods*


---

### Description

Calculates the likelihoods of a Multiple Discrete Continuous Extreme Value (MDCEV) model and can also perform other operations based on the value of the `functionality` argument.

### Usage

```
apollo_mdcev2(mdcev_settings, functionality)
```

### Arguments

- `mdcev_settings` List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.
- `alpha`: Named list. Alpha parameters for each alternative, including for any outside good. As many elements as alternatives.
  - `alternatives`: Character vector. Names of alternatives, elements must match the names in list 'utilities'.
  - `avail`: Named list of numeric vectors or scalars. Availabilities of alternatives, one element per alternative. Names of elements must match those in alternatives. Values can be 0 or 1. These can be scalars or vectors (of length equal to rows in the database). A user can also specify `avail=1` to indicate universal availability, or omit the setting completely.
  - `budget`: Numeric vector. Budget for each observation.
  - `componentName`: Character. Name given to model component.
  - `continuousChoice`: Named list of numeric vectors. Amount of consumption of each alternative. One element per alternative, as long as the number of observations or a scalar. Names must match those in alternatives.
  - `cost`: Named list of numeric vectors. Price of each alternative. One element per alternative, each one as long as the number of observations or a scalar. Names must match those in alternatives.

- `gamma`: Named list. Gamma parameters for each alternative, excluding any outside good. As many elements as inside good alternatives.
- `nRep`: Numeric scalar. Number of simulations of the whole dataset used for forecasting. The forecast is the average of these simulations. Default is 100.
- `outside`: Character. Optional name of the outside good.
- `rawPrediction`: Logical scalar. TRUE for prediction to be returned at the draw level (a 3-dim array). FALSE for prediction to be returned averaged across draws. Default is FALSE.
- `rows`: Boolean vector. Consideration of which rows to include. Length equal to the number of observations (`nObs`), with entries equal to TRUE for rows to include, and FALSE for rows to exclude. Default is "all", equivalent to `rep(TRUE, nObs)`.
- `sigma`: Numeric scalar. Scale parameter of the model extreme value type I error.
- `utilities`: Named list. Utilities of the alternatives. Names of elements must match those in argument 'alternatives'.

`functionality` Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call `apollo_probabilities`, though the user can also call `apollo_probabilities` manually with a given functionality for testing/debugging. Possible values are:

- `"components"`: For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.
- `"conditionals"`: For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
- `"estimate"`: For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- `"gradient"`: For model estimation, produces analytical gradients of the likelihood, where possible.
- `"output"`: Prepares output for post-estimation reporting.
- `"prediction"`: For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- `"preprocess"`: Prepares likelihood functions for use in estimation.
- `"raw"`: For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- `"report"`: Prepares output summarising model and choiceset structure.
- `"shares_LL"`: Produces overall model likelihood with constants only.
- `"validate"`: Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- `"zero_LL"`: Produces overall model likelihood with all parameters at zero.

**Value**

The returned object depends on the value of argument `functionality` as follows.

- `"components"`: Same as `"estimate"`
- `"conditionals"`: Same as `"estimate"`
- `"estimate"`: vector/matrix/array. Returns the probabilities for the observed consumption for each observation.
- `"gradient"`: Not implemented
- `"output"`: Same as `"estimate"` but also writes summary of input data to internal Apollo log.
- `"prediction"`: A matrix with one row per observation, and columns indicating means and s.d. of continuous and discrete predicted consumptions.
- `"preprocess"`: Returns a list with pre-processed inputs, based on `mdcev_settings`.
- `"raw"`: Same as `"estimate"`
- `"report"`: Dependent variable overview.
- `"shares_LL"`: Not implemented. Returns a vector of NA with as many elements as observations.
- `"validate"`: Same as `"estimate"`, but it also runs a set of tests to validate the function inputs.
- `"zero_LL"`: Not implemented. Returns a vector of NA with as many elements as observations.

---

apollo\_mdcnev

*Calculates MDCNEV likelihoods*

---

**Description**

Calculates the likelihoods of a Multiple Discrete Continuous Nested Extreme Value (MDCNEV) model with an outside good and can also perform other operations based on the value of the `functionality` argument.

**Usage**

```
apollo_mdcnev(mdcnev_settings, functionality)
```

**Arguments**

`mdcnev_settings`

List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.

- `alpha`: Named list. Alpha parameters for each alternative, including for the outside good. As many elements as alternatives.
- `avail`: Named list of numeric vectors or scalars. Availabilities of alternatives, one element per alternative. Names of elements must match those in alternatives. Values can be 0 or 1. These can be scalars or vectors (of length equal to rows in the database). A user can also specify `avail=1` to indicate universal availability, or omit the setting completely.



- **alternatives:** Character vector. Names of alternatives, elements must match the names in list 'utilities'.
- **budget:** Numeric vector. Budget for each observation.
- **componentName:** Character. Name given to model component.
- **continuousChoice:** Named list of numeric vectors. Amount of consumption of each alternative. One element per alternative, as long as the number of observations or a scalar. Names must match those in alternatives.
- **cost:** Named list of numeric vectors. Price of each alternative. One element per alternative, each one as long as the number of observations or a scalar. Names must match those in alternatives.
- **gamma:** Named list. Gamma parameters for each alternative, including for the outside good. As many elements as alternatives.
- **mdcnevNests:** Named list. Lambda parameters for each nest. Elements must be named with the nest name. The lambda at the root is fixed to 1, and therefore must not be defined. The value of the estimated mdcnevNests parameters should be between 0 and 1 to ensure consistency with random utility maximization.
- **mdcnevStructure:** Numeric matrix. One row per nest and one column per alternative. Each element of the matrix is 1 if an alternative belongs to the corresponding nest.
- **outside:** Character. Alternative name for the outside good. Default is "outside"
- **rows:** Boolean vector. Consideration of which rows to include. Length equal to the number of observations (nObs), with entries equal to TRUE for rows to include, and FALSE for rows to exclude. Default is "all", equivalent to rep(TRUE, nObs).
- **utilities:** Named list. Utilities of the alternatives. Names of elements must match those in argument 'alternatives'.

**functionality** Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call `apollo_probabilities`, though the user can also call `apollo_probabilities` manually with a given functionality for testing/debugging. Possible values are:

- "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.
- "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
- "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.
- "output": Prepares output for post-estimation reporting.
- "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- "preprocess": Prepares likelihood functions for use in estimation.

- "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- "report": Prepares output summarising model and choicest structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

### Value

The returned object depends on the value of argument `functionality` as follows.

- "components": Same as "estimate"
- "conditionals": Same as "estimate"
- "estimate": vector/matrix/array. Returns the probabilities for the observed consumption for each observation.
- "gradient": Not implemented
- "output": Same as "estimate" but also writes summary of input data to internal Apollo log.
- "prediction": A matrix with one row per observation, and columns indicating means and s.d. of continuous and discrete predicted consumptions.
- "preprocess": Returns a list with pre-processed inputs, based on `mdcnev_settings`.
- "raw": Same as "estimate"
- "report": Dependent variable overview.
- "shares\_LL": Not implemented. Returns a vector of NA with as many elements as observations.
- "validate": Same as "estimate", but it also runs a set of tests to validate the function inputs.
- "zero\_LL": Not implemented. Returns a vector of NA with as many elements as observations.

---

apollo\_mixEM

*Uses EM for models with continuous random coefficients*

---

### Description

Uses the EM algorithm for estimating a model with continuous random coefficients.

### Usage

```
apollo_mixEM(
  apollo_beta,
  apollo_fixed,
  apollo_probabilities,
  apollo_inputs,
  mixEM_settings = NA,
  estimate_settings = NA
)
```

**Arguments**

- apollo\_beta** Named numeric vector. Names and values for parameters. These need to be provided in the following order. With  $K$  random parameters,  $K$  means for the underlying Normals, followed by the elements of the lower triangle of the Cholesky matrix, by row.
- apollo\_fixed** Character vector. Names (as defined in `apollo_beta`) of parameters whose value should not change during estimation.
- apollo\_probabilities** Function. Returns probabilities of the model to be estimated. Must receive three arguments:
- **apollo\_beta**: Named numeric vector. Names and values of model parameters.
  - **apollo\_inputs**: List containing options of the model. See [apollo\\_validateInputs](#).
  - **functionality**: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".
- apollo\_inputs** List grouping most common inputs. Created by function [apollo\\_validateInputs](#).
- mixEM\_settings** List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.
- **EMmaxIterations**: Numeric. Maximum number of iterations of the EM algorithm before stopping. Default is 100.
  - **postEM**: Numeric scalar. Determines the tasks performed by this function after the EM algorithm has converged. Can take values 0, 1 or 2 only. If value is 0, only the EM algorithm will be performed, and the results will be a model object without a covariance matrix (i.e. estimates only). If value is 1, after the EM algorithm, the covariance matrix of the model will be calculated as well, and the result will be a model object with a covariance matrix. If value is 2, after the EM algorithm, the estimated parameter values will be used as starting value for a maximum likelihood estimation process, which will render a model object with a covariance matrix. Performing maximum likelihood estimation after the EM algorithm is useful, as there may be room for further improvement. Default is 2.
  - **silent**: Boolean. If TRUE, no information is printed to the console during estimation. Default is FALSE.
  - **stoppingCriterion**: Numeric. Convergence criterion. The EM process will stop when improvements in the log-likelihood fall below this value. Default is  $10^{-5}$ .
  - **transforms**: List. Optional argument, with one entry per parameter, showing the inverse transform to return from beta to the underlying Normal. E.g. if the first parameter is specified as negative lognormal inside `apollo_randCoeff`, then the entry in transforms should be `transforms[[1]]=function(x) log(-x)`
- estimate\_settings** List. Options controlling the estimation process within each EM iteration. See [apollo\\_estimate](#) for details.

**Details**

This function uses the EM algorithm for estimating a model with continuous random coefficients. It is only suitable for models where all parameters are random, with a full covariance matrix. All random parameters need to be based on underlying Normals with a full covariance matrix, but any transform thereof can be used.

**Value**

model object

---

apollo\_mlhs

*Generate random draws using MLHS algorithm*

---

**Description**

Generate random draws using the Modified Latin Hypercube Sampling algorithm.

**Usage**

apollo\_mlhs(N, d, i)

**Arguments**

|   |  |
|---|--|
| N | Numeric. The number of draws to generate in each dimension |
| d | Numeric. The number of dimensions to generate draws in     |
| i | Numeric. The number of individuals to generate draws for   |

**Details**

Internal use only. Algorithm described in Hess, S., Train, K., and Polak, J. (2006) Transportation Research Part B, 40, 147 - 163.

**Value**

A (N\*i) x d matrix with random draws

---

|            |   |
|------------|---|
| apollo_mnl | <i>Calculates Multinomial Logit probabilities</i> |
|------------|---|

---

**Description**

Calculates the probabilities of a Multinomial Logit model and can also perform other operations based on the value of the functionality argument.

**Usage**

```
apollo_mnl(mnl_settings, functionality)
```

**Arguments**

- |               |  |
|---------------|--|
| mnl_settings  | <p>List of inputs of the MNL model. It should contain the following.</p> <ul style="list-style-type: none"> <li>• alternatives: Named numeric vector. Names of alternatives and their corresponding value in choiceVar.</li> <li>• avail: Named list of numeric vectors or scalars. Availabilities of alternatives, one element per alternative. Names of elements must match those in alternatives. Values can be 0 or 1. These can be scalars or vectors (of length equal to rows in the database). A user can also specify avail=1 to indicate universal availability, or omit the setting completely.</li> <li>• choiceVar: Numeric vector. Contains choices for all observations. It will usually be a column from the database. Values are defined in alternatives.</li> <li>• utilities: Named list of deterministic utilities. Utilities of the alternatives. Names of elements must match those in alternatives.</li> <li>• rows: Boolean vector. Consideration of which rows to include. Length equal to the number of observations (nObs), with entries equal to TRUE for rows to include, and FALSE for rows to exclude. Default is "all", equivalent to rep(TRUE, nObs).</li> <li>• componentName: Character. Name given to model component.</li> </ul> |
| functionality | <p>Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call apollo_probabilities, though the user can also call apollo_probabilities manually with a given functionality for testing/debugging. Possible values are:</p> <ul style="list-style-type: none"> <li>• "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> <li>• "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.</li> <li>• "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>• "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.</li> <li>• "output": Prepares output for post-estimation reporting.</li> </ul>   |

- "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- "preprocess": Prepares likelihood functions for use in estimation.
- "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- "report": Prepares output summarising model and choiceset structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

## Value

The returned object depends on the value of argument `functionality` as follows.

- "components": Same as "estimate"
- "conditionals": Same as "estimate"
- "estimate": vector/matrix/array. Returns the probabilities for the chosen alternative for each observation.
- "gradient": List containing the likelihood and gradient of the model component.
- "output": Same as "estimate" but also writes summary of input data to internal Apollo log.
- "prediction": List of vectors/matrices/arrays. Returns a list with the probabilities for all alternatives, with an extra element for the probability of the chosen alternative.
- "preprocess": Returns a list with pre-processed inputs, based on `mnl_settings`.
- "validate": Same as "estimate", but it also runs a set of tests to validate the function inputs.
- "raw": Same as "prediction"
- "report": Choice overview
- "shares\_LL": vector/matrix/array. Returns the probability of the chosen alternative when only constants are estimated.
- "validate": Same as "estimate"
- "zero\_LL": vector/matrix/array. Returns the probability of the chosen alternative when all parameters are zero.

---

apollo\_modeChoiceData *Simulated dataset of mode choice.*

---

### Description

A simulated dataset containing 8,000 mode choices among four alternatives.

### Usage

apollo\_modeChoiceData

### Format

A data.frame with 8,000 rows and 25 variables:

**ID** Numeric. Identification number of the individual.

**RP** Numeric. 1 if the row corresponds to a revealed preference (RP) observation. 0 otherwise.

**RP\_journey** Numeric. Consecutive ID of RP observations.

**SP** Numeric. 1 if the row corresponds to a stated preference (SP) observation. 0 otherwise.

**SP\_task** Numeric. Consecutive ID of SP choice tasks.

**access\_air** Numeric. Access time (in minutes) of mode air.

**access\_bus** Numeric. Access time (in minutes) of mode bus.

**access\_rail** Numeric. Access time (in minutes) of mode rail.

**av\_air** Numeric. 1 if the mode air (plane) is available. 0 otherwise.

**av\_bus** Numeric. 1 if the mode bus is available. 0 otherwise.

**av\_car** Numeric. 1 if the mode car is available. 0 otherwise.

**av\_rail** Numeric. 1 if the mode rail (train) is available. 0 otherwise.

**business** Numeric. Purpose of the trip. 1 for business, 0 for other.

**choice** Numeric. Choice indicator, 1=car, 2=bus, 3=air, 4=rail.

**cost\_air** Numeric. Cost (in GBP) of mode air.

**cost\_bus** Numeric. Cost (in GBP) of mode bus.

**cost\_car** Numeric. Cost (in GBP) of mode car.

**cost\_rail** Numeric. Cost (in GBP) of mode rail.

**female** Numeric. Sex of individual. 1 for female, 0 for male.

**income** Numeric. Income (in GBP per annum) of the individual.

**service\_air** Numeric. Additional services for the air alternative. 1 for no-frills, 2 for wifi, 3 for food. This is not used in the RP data, where it is set to 0.

**service\_rail** Numeric. Additional services for the rail alternative. 1 for no-frills, 2 for wifi, 3 for food. This is not used in the RP data, where it is set to 0.

**time\_air** Numeric. Travel time (in minutes) of mode air.

**time\_bus** Numeric. Travel time (in minutes) of mode bus.

**time\_car** Numeric. Travel time (in minutes) of mode car.

**time\_rail** Numeric. Travel time (in minutes) of mode rail.

## Details

This dataset is to be used for discrete choice modelling. Data comes from 500 individuals, each with two revealed preferences (RP) observation, and 14 stated (SC) observations. There are 8,000 choices in total. Data is simulated. Each observation contains attributes for the alternatives, availability of alternatives, and characteristics of the individuals.

## Source

<http://www.apollochoicemodelling.com/>

---

|                    |   |
|--------------------|---|
| apollo_modelOutput | <i>Prints estimation results to console</i> |
|--------------------|---|

---

## Description

Prints estimation results to console. Amount of information presented can be adjusted through arguments.

## Usage

```
apollo_modelOutput(model, modelOutput_settings = NA)
```

## Arguments

|                      |  |
|----------------------|--|
| model                | Model object. Estimated model object as returned by function <a href="#">apollo_estimate</a> .   |
| modelOutput_settings | List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional. <ul style="list-style-type: none"> <li>• <code>printChange</code>: Logical. TRUE for printing difference between starting values and estimates. FALSE by default.</li> <li>• <code>printClassical</code>: Logical. TRUE for printing classical standard errors. TRUE by default.</li> <li>• <code>printCorr</code>: Logical. TRUE for printing parameters correlation matrix. If <code>printClassical=TRUE</code>, both classical and robust matrices are printed. FALSE by default.</li> <li>• <code>printCovar</code>: Logical. TRUE for printing parameters covariance matrix. If <code>printClassical=TRUE</code>, both classical and robust matrices are printed. FALSE by default.</li> <li>• <code>printDataReport</code>: Logical. TRUE for printing summary of choices in database and other diagnostics. FALSE by default.</li> <li>• <code>printFixed</code>: Logical. TRUE for printing fixed parameters among estimated parameter. TRUE by default.</li> <li>• <code>printFunctions</code>: Logical. TRUE for printing <code>apollo_control</code>, <code>apollo_randCoeff</code> (when available), <code>apollo_lcPars</code> (when available) and <code>apollo_probabilities</code>. FALSE by default.</li> </ul> |



- `printModelStructure`: Logical. TRUE for printing model structure. TRUE by default.
- `printOutliers`: Logical or Scalar. TRUE for printing 20 individuals with worst average fit across observations. FALSE by default. If Scalar is given, this replaces the default of 20.
- `printPVal`: Logical or Scalar. TRUE or 1 for printing p-values for one-sided test, 2 for printing p-values for two-sided test, FALSE for not printing p-values. FALSE by default.
- `printT1`: Logical. If TRUE, t-test for  $H_0: \text{apollo\_beta}=1$  are printed. FALSE by default.

### Details

Prints to screen the output of a model previously estimated by `apollo_estimate()`

### Value

A matrix of coefficients, s.d. and t-tests (invisible)

---

|           |  |
|-----------|--|
| apollo_nl | <i>Calculates Nested Logit probabilities</i> |
|-----------|--|

---

### Description

Calculates the probabilities of a Nested Logit model and can also perform other operations based on the value of the `functionality` argument.

### Usage

```
apollo_nl(nl_settings, functionality)
```

### Arguments

- `nl_settings` List of inputs of the NL model. It should contain the following.
- `alternatives`: Named numeric vector. Names of alternatives and their corresponding value in `choiceVar`.
  - `avail`: Named list of numeric vectors or scalars. Availabilities of alternatives, one element per alternative. Names of elements must match those in `alternatives`. Values can be 0 or 1. These can be scalars or vectors (of length equal to rows in the database). A user can also specify `avail=1` to indicate universal availability, or omit the setting completely.
  - `choiceVar`: Numeric vector. Contains choices for all observations. It will usually be a column from the database. Values are defined in `alternatives`.
  - `componentName`: Character. Name given to model component.
  - `nlNests`: List of numeric scalars or vectors. Lambda parameters for each nest. Elements must be named with the nest name. The lambda at the root is automatically fixed to 1 if not provided by the user.

- `n1Structure`: Named list of character vectors. As many elements as nests, it must include the "root". Each element contains the names of the nests or alternatives that belong to it. Element names must match those in `n1Nests`.
- `utilities`: Named list of deterministic utilities. Utilities of the alternatives. Names of elements must match those in `alternatives`.
- `rows`: Boolean vector. Consideration of which rows to include. Length equal to the number of observations (`nObs`), with entries equal to `TRUE` for rows to include, and `FALSE` for rows to exclude. Default is "all", equivalent to `rep(TRUE, nObs)`.

`functionality` Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call `apollo_probabilities`, though the user can also call `apollo_probabilities` manually with a given `functionality` for testing/debugging. Possible values are:

- "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.
- "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
- "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.
- "output": Prepares output for post-estimation reporting.
- "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- "preprocess": Prepares likelihood functions for use in estimation.
- "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- "report": Prepares output summarising model and choiceset structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

## Details

In this implementation of the Nested Logit model, each nest must have a lambda parameter associated to it. For the model to be consistent with utility maximisation, the estimated value of the Lambda parameter of all nests should be between 0 and 1. Lambda parameters are inversely proportional to the correlation between the error terms of alternatives in a nest. If `lambda=1`, then there is no relevant correlation between the unobserved utility of alternatives in that nest. The tree must contain an upper nest called "root". The lambda parameter of the root is automatically set to 1 if not specified in `n1Nests`, but can be changed by the user if desired (though not advised).

**Value**

The returned object depends on the value of argument `functionality` as follows.

- `"components"`: Same as `"estimate"`
- `"conditionals"`: Same as `"estimate"`
- `"estimate"`: vector/matrix/array. Returns the probabilities for the chosen alternative for each observation.
- `"gradient"`: Not implemented.
- `"output"`: Same as `"estimate"` but also writes summary of input data to internal Apollo log.
- `"prediction"`: List of vectors/matrices/arrays. Returns a list with the probabilities for all alternatives, with an extra element for the probability of the chosen alternative.
- `"preprocess"`: Returns a list with pre-processed inputs, based on `n1_settings`.
- `"raw"`: Same as `"prediction"`
- `"report"`: List with tree structure and choice overview.
- `"shares_LL"`: vector/matrix/array. Returns the probability of the chosen alternative when only constants are estimated.
- `"validate"`: Same as `"estimate"`, but it also runs a set of tests to validate the function inputs.
- `"zero_LL"`: vector/matrix/array. Returns the probability of the chosen alternative when all parameters are zero.

---

`apollo_normalDensity` *Calculates density for a Normal distribution*

---

**Description**

Calculates density for a Normal distribution at a specific value with a specified mean and standard deviation and can also perform other operations based on the value of the `functionality` argument.

**Usage**

```
apollo_normalDensity(normalDensity_settings, functionality)
```

**Arguments**

`normalDensity_settings`

List of arguments to the functions. It must contain the following.

- `componentName`: Character. Name given to model component.
- `mu`: Numeric scalar. Intercept of the linear model.
- `outcomeNormal`: Numeric vector. Dependent variable.
- `rows`: Boolean vector. Consideration of which rows to include. Length equal to the number of observations (`nObs`), with entries equal to `TRUE` for rows to include, and `FALSE` for rows to exclude. Default is `"all"`, equivalent to `rep(TRUE, nObs)`.

- `sigma`: Numeric scalar. Variance of error component of linear model to be estimated.
  - `xNormal`: Numeric vector. Single explanatory variable.
- functionality Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call `apollo_probabilities`, though the user can also call `apollo_probabilities` manually with a given functionality for testing/debugging. Possible values are:
- `"components"`: For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.
  - `"conditionals"`: For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
  - `"estimate"`: For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
  - `"gradient"`: For model estimation, produces analytical gradients of the likelihood, where possible.
  - `"output"`: Prepares output for post-estimation reporting.
  - `"prediction"`: For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
  - `"preprocess"`: Prepares likelihood functions for use in estimation.
  - `"raw"`: For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
  - `"report"`: Prepares output summarising model and choiceset structure.
  - `"shares_LL"`: Produces overall model likelihood with constants only.
  - `"validate"`: Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
  - `"zero_LL"`: Produces overall model likelihood with all parameters at zero.

### Details

This function calculates the probability of the linear model outcome  $\text{outcomeNormal} = \mu + \text{xNormal} + \text{epsilon}$ , where  $\text{epsilon}$  is a random error distributed  $\text{Normal}(0, \text{sigma})$ . If using this function in the context of an Integrated Choice and Latent Variable (ICLV) model with continuous indicators, then `outcomeNormal` would be the value of the indicator, `xNormal` would be the value of the latent variable (possibly multiplied by a parameter to measure its correlation with the indicator, e.g.  $\text{xNormal} = \text{lambda} * \text{LV}$ ), and  $\mu$  would be an additional parameter to be estimated (the mean of the indicator, which should be fixed to zero if the indicator is centered around its mean beforehand).

### Value

The returned object depends on the value of argument `functionality` as follows.

- `"components"`: Same as `"estimate"`
- `"conditionals"`: Same as `"estimate"`

- "estimate": vector/matrix/array. Returns the likelihood for each observation.
- "gradient": Not implemented
- "output": Same as "estimate" but also writes summary of input data to internal Apollo log.
- "prediction": Not implemented. Returns NA.
- "preprocess": Returns a list with pre-processed inputs, based on normalDensity\_settings.
- "raw": Same as "estimate"
- "report": Dependent variable overview.
- "shares\_LL": Not implemented. Returns a vector of NA with as many elements as observations.
- "validate": Same as "estimate", but it also runs a set of tests to validate the function inputs.
- "zero\_LL": Not implemented. Returns a vector of NA with as many elements as observations.

---

 apollo\_ol

*Calculates Ordered Logit probabilities*


---

### Description

Calculates the probabilities of an Ordered Logit model and can also perform other operations based on the value of the functionality argument.

### Usage

```
apollo_ol(ol_settings, functionality)
```

### Arguments

- |             |  |
|-------------|--|
| ol_settings | <p>List of settings for the OL model. It should include the following.</p> <ul style="list-style-type: none"> <li>• coding: Numeric or character vector. Optional argument. Defines the order of the levels in outcomeOrdered. The first value is associated with the lowest level of outcomeOrdered, and the last one with the highest value. If not provided, is assumed to be 1:(length(tau) + 1).</li> <li>• componentName: Character. Name given to model component.</li> <li>• outcomeOrdered: Numeric vector. Dependent variable. The coding of this variable is assumed to be from 1 to the maximum number of different levels. For example, if the ordered response has three possible values: "never", "sometimes" and "always", then it is assumed that outcomeOrdered contains "1" for "never", "2" for "sometimes", and 3 for "always". If another coding is used, then it should be specified using the coding argument.</li> <li>• rows: Boolean vector. TRUE if a row must be considered in the calculations, FALSE if it must be excluded. It must have length equal to the length of argument outcomeOrdered. Default value is "all", meaning all rows are considered in the calculation.</li> </ul> |
|-------------|--|

- `tau`: List of numeric vectors/matrices/3-dim arrays. Thresholds. As many as number of different levels in the dependent variable - 1. Extreme thresholds are fixed at `-inf` and `+inf`. Mixing is allowed in thresholds. Can also be a matrix with as many rows as observations and as many columns as thresholds.
- `utilities`: Numeric vector/matrix/3-sim array. A single explanatory variable (usually a latent variable). Must have the same number of rows as `outcomeOrdered`.

`functionality` Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call `apollo_probabilities`, though the user can also call `apollo_probabilities` manually with a given `functionality` for testing/debugging. Possible values are:

- `"components"`: For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.
- `"conditionals"`: For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
- `"estimate"`: For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- `"gradient"`: For model estimation, produces analytical gradients of the likelihood, where possible.
- `"output"`: Prepares output for post-estimation reporting.
- `"prediction"`: For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- `"preprocess"`: Prepares likelihood functions for use in estimation.
- `"raw"`: For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- `"report"`: Prepares output summarising model and choicest structure.
- `"shares_LL"`: Produces overall model likelihood with constants only.
- `"validate"`: Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- `"zero_LL"`: Produces overall model likelihood with all parameters at zero.

### Details

This function estimates an Ordered Logit model of the type:  $y^* = V + \text{epsilon}$  `outcomeOrdered = 1` if  $-\text{Inf} < y^* < \text{tau}[1]$  `2` if  $\text{tau}[1] < y^* < \text{tau}[2]$  ... `maxLvl` if  $\text{tau}[\text{length}(\text{tau})] < y^* < +\text{Inf}$  Where `epsilon` is distributed standard logistic, and the values `1, 2, ..., maxLvl` can be replaced by `coding[1], coding[2], ..., coding[maxLvl]`. The behaviour of the function changes depending on the value of the `functionality` argument.

### Value

The returned object depends on the value of argument `functionality` as follows.

- "components": Same as "estimate"
- "conditionals": Same as "estimate"
- "estimate": vector/matrix/array. Returns the probabilities for the chosen alternative for each observation.
- "gradient": List containing the likelihood and gradient of the model component.
- "output": Same as "estimate" but also writes summary of input data to internal Apollo log.
- "prediction": List of vectors/matrices/arrays. Returns a list with the probabilities for all possible levels, with an extra element for the probability of the chosen alternative.
- "preprocess": Returns a list with pre-processed inputs, based on `ol_settings`.
- "raw": Same as "prediction"
- "report": Dependent variable overview.
- "shares\_LL": Not implemented. Returns a vector of NA with as many elements as observations.
- "validate": Same as "estimate", but it also runs a set of tests to validate the function inputs.
- "zero\_LL": Not implemented. Returns a vector of NA with as many elements as observations.

---

 apollo\_op

*Calculates Ordered Probit probabilities*


---

### Description

Calculates the probabilities of an Ordered Probit model and can also perform other operations based on the value of the `functionality` argument.

### Usage

```
apollo_op(op_settings, functionality)
```

### Arguments

- |                          |   |
|--------------------------|---|
| <code>op_settings</code> | <p>List of settings for the OP model. It should include the following.</p> <ul style="list-style-type: none"> <li>• <code>coding</code>: Numeric or character vector. Optional argument. Defines the order of the levels in <code>outcomeOrdered</code>. The first value is associated with the lowest level of <code>outcomeOrdered</code>, and the last one with the highest value. If not provided, is assumed to be <code>1:(length(tau) + 1)</code>.</li> <li>• <code>componentName</code>: Character. Name given to model component.</li> <li>• <code>outcomeOrdered</code>: Numeric vector. Dependent variable. The coding of this variable is assumed to be from 1 to the maximum number of different levels. For example, if the ordered response has three possible values: "never", "sometimes" and "always", then it is assumed that <code>outcomeOrdered</code> contains "1" for "never", "2" for "sometimes", and 3 for "always". If another coding is used, then it should be specified using the <code>coding</code> argument.</li> </ul> |
|--------------------------|---|

- **rows**: Boolean vector. TRUE if a row must be considered in the calculations, FALSE if it must be excluded. It must have length equal to the length of argument `outcomeOrdered`. Default value is "all", meaning all rows are considered in the calculation.
- **tau**: List of numeric vectors/matrices/3-dim arrays. Thresholds. As many as number of different levels in the dependent variable - 1. Extreme thresholds are fixed at -inf and +inf. Mixing is allowed in thresholds. Can also be a matrix with as many rows as observations and as many columns as thresholds.
- **utilities**: Numeric vector/matrix/3-sim array. A single explanatory variable (usually a latent variable). Must have the same number of rows as `outcomeOrdered`.

**functionality** Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call `apollo_probabilities`, though the user can also call `apollo_probabilities` manually with a given functionality for testing/debugging. Possible values are:

- "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.
- "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
- "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.
- "output": Prepares output for post-estimation reporting.
- "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- "preprocess": Prepares likelihood functions for use in estimation.
- "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- "report": Prepares output summarising model and choiceset structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

## Details

This function estimates an ordered probit model of the type:

$$y^* = V + \epsilon y = 1 \text{ if } -\infty < y^* < \tau_1, 2 \text{ if } \tau_1 < y^* < \tau_2, \dots, \max(y) \text{ if } \tau_{\max(y)-1} < y^* < \infty$$

Where  $\epsilon$  is distributed standard normal, and the values 1, 2, ...,  $\max(y)$  can be replaced by `coding[1]`, `coding[2]`, ..., `coding[ $\max(y)$ ]`. The behaviour of the function changes depending on the value of the functionality argument.



**Value**

The returned object depends on the value of argument `functionality` as follows.

- `"components"`: Same as `"estimate"`
- `"conditionals"`: Same as `"estimate"`
- `"estimate"`: vector/matrix/array. Returns the probabilities for the chosen alternative for each observation.
- `"gradient"`: List containing the likelihood and gradient of the model component.
- `"output"`: Same as `"estimate"` but also writes summary of input data to internal Apollo log.
- `"prediction"`: List of vectors/matrices/arrays. Returns a list with the probabilities for all possible levels, with an extra element for the probability of the chosen alternative.
- `"preprocess"`: Returns a list with pre-processed inputs, based on `op_settings`.
- `"raw"`: Same as `"prediction"`
- `"report"`: Dependent variable overview.
- `"shares_LL"`: Not implemented. Returns a vector of NA with as many elements as observations.
- `"validate"`: Same as `"estimate"`, but it also runs a set of tests to validate the function inputs.
- `"zero_LL"`: Not implemented. Returns a vector of NA with as many elements as observations.

---

|                    |                                     |
|--------------------|-------------------------------------|
| apollo_outOfSample | <i>Cross-validation of fit (LL)</i> |
|--------------------|-------------------------------------|

---

**Description**

Randomly generates estimation and validation samples, estimates the model on the first and calculates the likelihood for the second, then repeats.

**Usage**

```
apollo_outOfSample(
  apollo_beta,
  apollo_fixed,
  apollo_probabilities,
  apollo_inputs,
  estimate_settings = list(estimationRoutine = "bfgs", maxIterations = 200, writeIter =
    FALSE, hessianRoutine = "none", printLevel = 3L, silent = TRUE),
  outOfSample_settings = list(nRep = 10, validationSize = 0.1, samples = NA)
)
```

## Arguments

- apollo\_beta** Named numeric vector. Names and values for parameters.
- apollo\_fixed** Character vector. Names (as defined in `apollo_beta`) of parameters whose value should not change during estimation.
- apollo\_probabilities** Function. Returns probabilities of the model to be estimated. Must receive three arguments:
  - **apollo\_beta**: Named numeric vector. Names and values of model parameters.
  - **apollo\_inputs**: List containing options of the model. See [apollo\\_validateInputs](#).
  - **functionality**: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".
- apollo\_inputs** List grouping most common inputs. Created by function [apollo\\_validateInputs](#).
- estimate\_settings** List. Options controlling the estimation process. See [apollo\\_estimate](#).
- outOfSample\_settings** List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.

**nRep** Numeric scalar. Number of times a different pair of estimation and validation sets are to be extracted from the full database. Default is 30.

**samples** Numeric matrix or data.frame. Optional argument. Must have as many rows as observations in the database, and as many columns as number of repetitions wanted. Each column represents a re-sample, and each element must be a 0 if the observation should be assigned to the estimation sample, or 1 if the observation should be assigned to the prediction sample. If this argument is provided, then `nRep` and `validationSize` are ignored. Note that this allows sampling at the observation rather than the individual level.

**validationSize** Numeric scalar. Size of the validation sample. Can be a percentage of the sample (0-1) or the number of individuals in the validation sample (>1). Default is 0.1.

## Details

A common way to test for overfitting of a model is to measure its fit on a sample not used during estimation that is, measuring its out-of-sample fit. A simple way to do this is splitting the complete available dataset in two parts: an estimation sample, and a validation sample. The model of interest is estimated using only the estimation sample, and then those estimated parameters are used to measure the fit of the model (e.g. the log-likelihood of the model) on the validation sample. Doing this with only one validation sample, however, may lead to biased results, as a particular validation sample need not be representative of the population. One way to minimise this issue is to randomly draw several pairs of estimation and validation samples from the complete dataset, and apply the procedure to each pair.

The splitting of the database into estimation and validation samples is done at the individual level, not at the observation level. If the sampling wants to be done at the individual level (not recommended on panel data), then the optional `outOfSample_settings$samples` argument should be provided.

This function writes two different files to the working/output directory:

- `modelName_outOfSample_params.csv`: Records the estimated parameters, final log-likelihood, and number of observations on each repetition.
- `modelName_outOfSample_samples.csv`: Records the sample composition of each repetition.

The first two files are updated throughout the run of this function, while the last one is only written once the function finishes.

When run, this function will look for the two files above in the working/output directory. If they are found, the function will attempt to pick up re-sampling from where those files left off. This is useful in cases where the original bootstrapping was interrupted, or when additional re-sampling wants to be performed.

### Value

A matrix with the average log-likelihood per observation for both the estimation and validation samples, for each repetition. Two additional files with further details are written to the working/output directory.

---

|                               |   |
|-------------------------------|---|
| <code>apollo_panelProd</code> | <i>Calculates product across observations from same individual.</i> |
|-------------------------------|---|

---

### Description

Multiplies likelihood of observations from the same individual, or adds the log of them.

### Usage

```
apollo_panelProd(P, apollo_inputs, functionality)
```

### Arguments

- |                            |  |
|----------------------------|--|
| <code>P</code>             | List of vectors, matrices or 3-dim arrays. Likelihood of the model components.   |
| <code>apollo_inputs</code> | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |
| <code>functionality</code> | Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call <code>apollo_probabilities</code> , though the user can also call <code>apollo_probabilities</code> manually with a given functionality for testing/debugging. Possible values are: <ul style="list-style-type: none"> <li>• "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> <li>• "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.</li> <li>• "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> </ul> |

- "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.
- "output": Prepares output for post-estimation reporting.
- "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- "preprocess": Prepares likelihood functions for use in estimation.
- "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- "report": Prepares output summarising model and choicest structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

### Details

This function should be called inside `apollo_probabilities` only if the data has a panel structure. It should be called after `apollo_avgIntraDraws` if intra-individual draws are used.

### Value

Argument `P` with (for most functionalities) the original contents after multiplying across observations at the individual level. Shape depends on argument functionality.

- "components": Returns `P` without changes.
- "conditionals": Returns `P` without averaging across draws. Drops all components except "model".
- "estimate": Returns `P` containing the likelihood of the model after multiplying observations at the individual level. Drops all components except "model".
- "gradient": Returns `P` containing the gradient of the likelihood after applying the product rule across observations for the same individual.
- "output": Returns `P` containing the likelihood of the model after multiplying observations at the individual level.
- "prediction": Returns `P` containing the probabilities/likelihoods of all alternatives for all model components averaged across inter-individual draws.
- "preprocess": Returns `P` without changes.
- "raw": Returns `P` without changes.
- "report": Returns `P` without changes.
- "shares\_LL": Returns `P` containing the likelihood of the model after multiplying observations at the individual level.
- "validate": Returns `P` containing the likelihood of the model averaged across inter-individual draws. Drops all components except "model".
- "zero\_LL": Returns `P` containing the likelihood of the model after multiplying observations at the individual level.

---

|                   |  |
|-------------------|--|
| apollo_prediction | <i>Predicts using an estimated model</i> |
|-------------------|--|

---

## Description

Calculates `apollo_probabilities` with `functionality="prediction"`.

## Usage

```
apollo_prediction(
  model,
  apollo_probabilities,
  apollo_inputs,
  prediction_settings = list(),
  modelComponent = NA
)
```

## Arguments

`model` Model object. Estimated model object as returned by function [apollo\\_estimate](#).

`apollo_probabilities`

Function. Returns probabilities of the model to be estimated. Must receive three arguments:

- `apollo_beta`: Named numeric vector. Names and values of model parameters.
- `apollo_inputs`: List containing options of the model. See [apollo\\_validateInputs](#).
- `functionality`: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".

`apollo_inputs` List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

`prediction_settings`

List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.

- `modelComponent`: Character. Name of component of `apollo_probabilities` output to calculate predictions for. Default is to predict for all components.
- `nRep`: Scalar integer. Only used for models that require simulation for prediction (e.g. MDCEV). Number of draws used to calculate prediction. Default is 100.
- `runs`: Numeric. Number of runs to use for computing confidence intervals of predictions.
- `silent`: Boolean. If TRUE, this function won't print any output to screen.
- `summary`: Boolean. If TRUE, a summary of the prediction is printed to screen. TRUE by default.

`modelComponent` **Deprecated**. Same as `modelComponent` inside `prediction_settings`.

**Details**

Structure of predictions are simplified before returning, e.g. list of vectors are turned into a matrix.

**Value**

A list containing predictions for component `modelComponent` of the model described in `apollo_probabilities`. The particular shape of the prediction will depend on the model component.

---

|                                 |                                   |
|---------------------------------|-----------------------------------|
| <code>apollo_prepareProb</code> | <i>Checks likelihood function</i> |
|---------------------------------|-----------------------------------|

---

**Description**

Checks that the likelihood function for the mode is in the appropriate format to be returned.

**Usage**

```
apollo_prepareProb(P, apollo_inputs, functionality)
```

**Arguments**

- |                            |  |
|----------------------------|--|
| <code>P</code>             | List of vectors, matrices or 3-dim arrays. Likelihood of the model components.   |
| <code>apollo_inputs</code> | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |
| <code>functionality</code> | Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call <code>apollo_probabilities</code> , though the user can also call <code>apollo_probabilities</code> manually with a given functionality for testing/debugging. Possible values are: <ul style="list-style-type: none"> <li>• "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> <li>• "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.</li> <li>• "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>• "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.</li> <li>• "output": Prepares output for post-estimation reporting.</li> <li>• "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.</li> <li>• "preprocess": Prepares likelihood functions for use in estimation.</li> <li>• "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.</li> <li>• "report": Prepares output summarising model and choicest structure.</li> </ul> |

- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

### Details

This function should be called inside `apollo_probabilities`, near the end of it, just before `return(P)`. This function only performs checks on the shape of `P`, but does not change its values.

### Value

Argument `P` with (for most functionalities) the original contents. Output depends on argument functionality.

- "components": Returns `P` without changes.
- "conditionals": Returns only the "model" component of argument `P`.
- "estimate": Returns only the "model" component of argument `P`.
- "gradient": Returns only the "model" component of argument `P`.
- "output": Returns argument `P` without any changes to its content, but gives names to unnamed elements.
- "prediction": Returns argument `P` without any changes.
- "preprocess": Returns argument `P` without any changes to its content, but gives names to elements corresponding to `componentNames`.
- "raw": Returns argument `P` without any changes.
- "report": Returns `P` without changes.
- "shares\_LL": Returns argument `P` without any changes to its content, but gives names to unnamed elements.
- "validate": Returns argument `P` without any changes.
- "zero\_LL": Returns argument `P` without any changes to its content, but gives names to unnamed elements.

---

|                                |   |
|--------------------------------|---|
| <code>apollo_preprocess</code> | <i>Pre-process input for multiple models return</i> |
|--------------------------------|---|

---

### Description

Pre-process input for multiple models return

### Usage

```
apollo_preprocess(inputs, modelType, functionality, apollo_inputs)
```

**Arguments**

|               |  |
|---------------|--|
| inputs        | List of settings   |
| modelType     | Character. Type of model, e.g. "mnl", "nl", "cnl", etc.  |
| functionality | <p>Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call <code>apollo_probabilities</code>, though the user can also call <code>apollo_probabilities</code> manually with a given functionality for testing/debugging. Possible values are:</p> <ul style="list-style-type: none"> <li>• "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> <li>• "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.</li> <li>• "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>• "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.</li> <li>• "output": Prepares output for post-estimation reporting.</li> <li>• "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.</li> <li>• "preprocess": Prepares likelihood functions for use in estimation.</li> <li>• "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.</li> <li>• "report": Prepares output summarising model and choiceset structure.</li> <li>• "shares_LL": Produces overall model likelihood with constants only.</li> <li>• "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>• "zero_LL": Produces overall model likelihood with all parameters at zero.</li> </ul> |
| apollo_inputs | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |

**Value**

The returned object is a pre-processed version of the model settings. This is independent of functionality, but the function is only called during preprocessing.

---

|              |                                   |
|--------------|-----------------------------------|
| apollo_print | <i>Prints message to terminal</i> |
|--------------|-----------------------------------|

---

**Description**

Prints message to terminal if `apollo_inputs$silent` is FALSE



**Usage**

```
apollo_print(txt, nSignifD = 4, widthLim = 11, highlight = FALSE)
```

**Arguments**

|           |  |
|-----------|--|
| txt       | Character, what to print.  |
| nSignifD  | Optional numeric integer. Minimum number of significant digits when printing numeric matrices. Default is 4.         |
| widthLim  | Optional numeric integer. Minimum width (in characters) of each column when printing numeric matrices. Default is 11 |
| highlight | Optional logical. If TRUE, the message will be highlighted and will pause execution for 5 seconds.                   |

**Value**

Nothing

---

|                 |                                   |
|-----------------|-----------------------------------|
| apollo_readBeta | <i>Reads parameters from file</i> |
|-----------------|-----------------------------------|

---

**Description**

Reads in parameters from a previously estimated model and copies the values to the given `apollo_beta` vector, only for those parameters whose name matches.

**Usage**

```
apollo_readBeta(
  apollo_beta,
  apollo_fixed,
  inputModelName,
  overwriteFixed = FALSE
)
```

**Arguments**

|                |  |
|----------------|--|
| apollo_beta    | Named numeric vector. Names and values for parameters.   |
| apollo_fixed   | Character vector. Names (as defined in <code>apollo_beta</code> ) of parameters whose value should not change during estimation. |
| inputModelName | Character. <code>modelName</code> for model from which results are used as starting values.                                      |
| overwriteFixed | Boolean. TRUE if starting values for fixed parameters should also be updated from input file.                                    |

**Details**

This function will update the values of the parameters in its argument `apollo_beta` with the matching values in the file `(inputModelName)_estimates.csv`. If there is no match for a given parameter in `apollo_beta`, its value will not be updated.

**Value**

Named numeric vector. Names and updated starting values for parameters.

---

|                                |   |
|--------------------------------|---|
| <code>apollo_saveOutput</code> | <i>Saves estimation results to files.</i> |
|--------------------------------|---|

---

**Description**

Writes files in the working/output directory with the estimation results.

**Usage**

```
apollo_saveOutput(model, saveOutput_settings = NA)
```

**Arguments**

- |                                  |   |
|----------------------------------|---|
| <code>model</code>               | Model object. Estimated model object as returned by function <a href="#">apollo_estimate</a> .  |
| <code>saveOutput_settings</code> | <p>List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.</p> <ul style="list-style-type: none"> <li>• <code>printChange</code>: Boolean. TRUE for printing difference between starting values and estimates. TRUE by default.</li> <li>• <code>printClassical</code>: Boolean. TRUE for printing classical standard errors. TRUE by default.</li> <li>• <code>printCorr</code>: Boolean. TRUE for printing parameters correlation matrix. If <code>printClassical=TRUE</code>, both classical and robust matrices are printed. TRUE by default.</li> <li>• <code>printCovar</code>: Boolean. TRUE for printing parameters covariance matrix. If <code>printClassical=TRUE</code>, both classical and robust matrices are printed. TRUE by default.</li> <li>• <code>printDataReport</code>: Boolean. TRUE for printing summary of choices in database and other diagnostics. FALSE by default.</li> <li>• <code>printFunctions</code>: Boolean. TRUE for printing <code>apollo_control</code>, <code>apollo_randCoeff</code> (when available), <code>apollo_lcPars</code> (when available) and <code>apollo_probabilities</code>. TRUE by default.</li> <li>• <code>printOutliers</code>: Boolean or Scalar. TRUE for printing 20 individuals with worst average fit across observations. FALSE by default. If Scalar is given, this replaces the default of 20.</li> <li>• <code>printModelStructure</code>: Boolean. TRUE for printing model structure. TRUE by default.</li> </ul> |

- `printPVal`: Boolean or Scalar. TRUE or 1 for printing p-values for one-sided test, 2 for printing p-values for two-sided test, FALSE for not printing p-values. FALSE by default.
- `printT1`: Boolean. If TRUE, t-test for  $H_0: \text{apollo\_beta}=1$  are printed. FALSE by default.
- `saveEst`: Boolean. TRUE for saving estimated parameters and standard errors to a CSV file. TRUE by default.
- `saveCorr`: Boolean. TRUE for saving estimated correlation matrix to a CSV file. FALSE by default.
- `saveCov`: Boolean. TRUE for saving estimated correlation matrix to a CSV file. FALSE by default.
- `saveModelObject`: Boolean. TRUE to save the R model object to a file (use `apollo_loadModel` to load it to memory). TRUE by default.
- `writeF12`: Boolean. TRUE for writing results into an F12 file (ALOGIT format). FALSE by default.

## Details

Estimation results are saved different files in the working/output directory:

- `(modelName)_corr.csv` CSV file with the estimated classical correlation matrix. Only when bayesian estimation was not used.
- `(modelName)_covar.csv` CSV file with the estimated classical covariance matrix. Only when bayesian estimation was not used.
- `(modelName)_estimates.csv` CSV file with the estimated parameter values, their standars errors, and t-ratios.
- `(modelName).F12` F12 file with model results. Compatible with ALOGIT.
- `(modelName)_output.txt` Text file with the output produced by function `apollo_modelOutput`.
- `(modelName)_robcorr.csv` CSV file with the estimated robust correlation matrix. Only when bayesian estimation was not used.
- `(modelName)_robcovar.csv` CSV file with the estimated robust covariance matrix. Only when bayesian estimation was not used.

## Value

nothing

---

|                                 |   |
|---------------------------------|---|
| <code>apollo_searchStart</code> | <i>Searches for better starting values.</i> |
|---------------------------------|---|

---

## Description

Given a set of starting values and a range for them, searches for points with a better likelihood and steeper gradients.

**Usage**

```
apollo_searchStart(
  apollo_beta,
  apollo_fixed,
  apollo_probabilities,
  apollo_inputs,
  searchStart_settings = NA
)
```

**Arguments**

- apollo\_beta** Named numeric vector. Names and values for parameters.
- apollo\_fixed** Character vector. Names (as defined in `apollo_beta`) of parameters whose value should not change during estimation.
- apollo\_probabilities** Function. Returns probabilities of the model to be estimated. Must receive three arguments:
- `apollo_beta`: Named numeric vector. Names and values of model parameters.
  - `apollo_inputs`: List containing options of the model. See [apollo\\_validateInputs](#).
  - `functionality`: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".
- apollo\_inputs** List grouping most common inputs. Created by function [apollo\\_validateInputs](#).
- searchStart\_settings** List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.
- `apolloBetaMax`: Vector. Maximum possible value of parameters when generating candidates. Ignored if `smartStart` is TRUE. Default is `apollo_beta + 0.1`.
  - `apolloBetaMin`: Vector. Minimum possible value of parameters when generating candidates. Ignored if `smartStart` is TRUE. Default is `apollo_beta - 0.1`.
  - `bfgsIter`: Numeric scalar. Number of BFGS iterations to perform at each stage to each remaining candidate. Default is 20.
  - `dTest`: Numeric scalar. Tolerance for test 1. A candidate is discarded if its distance in parameter space to a better one is smaller than `dTest`. Default is 1.
  - `gTest`: Numeric scalar. Tolerance for test 2. A candidate is discarded if the norm of its gradient is smaller than `gTest` AND its LL is further than `llTest` from a better candidate. Default is  $10^{-3}$ .
  - `llTest`: Numeric scalar. Tolerance for test 2. A candidate is discarded if the norm of its gradient is smaller than `gTest` AND its LL is further than `llTest` from a better candidate. Default is 3.

- **maxStages**: Numeric scalar. Maximum number of search stages. The algorithm will stop when there is only one candidate left, or if it reaches this number of stages. Default is 5.
- **nCandidates**: Numeric scalar. Number of candidate sets of parameters to be used at the start. Should be an integer bigger than 1. Default is 100.
- **smartStart**: Boolean. If TRUE, candidates are randomly generated with more chances in the directions the Hessian indicates improvement of the LL function. Default is FALSE.

### Details

This function implements a simplified version of the algorithm proposed by Bierlaire, M., Themans, M. & Zufferey, N. (2010), A Heuristic for Nonlinear Global Optimization, *INFORMS Journal on Computing*, 22(1), pp.59-70. The main difference lies in it implementing only two out of three tests on the candidates described by the authors. The implemented algorithm has the following steps.

1. Randomly draw `nCandidates` candidates from an interval given by the user.
2. Label all candidates with a valid log-likelihood (LL) as active.
3. Apply `bfgsIter` iterations of the BFGS algorithm to each active candidate.
4. Apply the following tests to each active candidate:
  - (a) Has the BFGS search converged?
  - (b) Are the candidate parameters after BFGS closer than `dTest` from any other candidate with higher LL?
  - (c) Is the LL of the candidate after BFGS further than `distLL` from a candidate with better LL, and its gradient smaller than `gTest`?
5. Mark any candidates for which at least one test results in yes as inactive.
6. Go back to step 3, unless only one candidate is active, or the maximum number of iterations (`maxStages`) has been reached.

This function will write a CSV file to the `working/output` directory summarising progress. This file is called `modelName_searchStart.csv`.

### Value

named vector of model parameters. These are the best values found.

---

|                             |   |
|-----------------------------|---|
| <code>apollo_setRows</code> | <i>Sets specified rows to a given value</i> |
|-----------------------------|---|

---

### Description

Given a numeric object (scalar, vector, matrix or 3-dim array) sets a subset of rows to a given value.

### Usage

```
apollo_setRows(v, r, val)
```

**Arguments**

|     |  |
|-----|--|
| v   | Numeric scalar, vector, matrix or 3-dim array. Rows of this object will be replaced by val and                 |
| r   | Boolean vector. As many elements as rows in utilities. TRUE for replacing that row, FALSE for not changing it. |
| val | Numeric scalar. Value to which the specified rows must be set to.  |

**Value**

The same argument utilities but with the rows where r==TRUE set to val.

---

|                   |   |
|-------------------|---|
| apollo_sharesTest | <i>Compares predicted and observed shares</i> |
|-------------------|---|

---

**Description**

Comparing the shares predicted by the model with the shares observed in the data, and conducts statistical tests.

**Usage**

```
apollo_sharesTest(
  model,
  apollo_probabilities,
  apollo_inputs,
  sharesTest_settings
)
```

**Arguments**

|                      |  |
|----------------------|--|
| model                | Model object. Estimated model object as returned by function <a href="#">apollo_estimate</a> .   |
| apollo_probabilities | Function. Returns probabilities of the model to be estimated. Must receive three arguments: <ul style="list-style-type: none"> <li>• <code>apollo_beta</code>: Named numeric vector. Names and values of model parameters.</li> <li>• <code>apollo_inputs</code>: List containing options of the model. See <a href="#">apollo_validateInputs</a>.</li> <li>• <code>functionality</code>: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares_LL", "validate" or "zero_LL".</li> </ul> |
| apollo_inputs        | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |
| sharesTest_settings  | List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.  |

- **alternatives:** Named numeric vector. Names of alternatives and their corresponding value in choiceVar.
- **choiceVar:** Numeric vector. Contains choices for all observations. It will usually be a column from the database. Values are defined in alternatives.
- **modelComponent:** Name of model component. Set to model by default.
- **newAlts:** Optional list describing the new alternatives to be used by apollo\_sharesTest. This should have as many elements as new alternatives, with each entry being a matrix of 0-1 entries, with one row per observation, and one column per alternative used in the model.
- **newAltsOnly:** Boolean. If TRUE, results will only be printed for the 'new' alternatives defined in newAlts, not the original alternatives used in the model. Set to FALSE by default.
- **subsamples:** Named list of boolean vectors. Each element of the list defines whether a given observation belongs to a given subsample (e.g. by sociodemographics).

### Details

This is an auxiliary function to help guide the definition of utility functions in a choice model. By comparing the predicted and observed shares of alternatives for different categories of the data, it is possible to identify what additional explanatory variables could improve the fit of the model.

### Value

Nothing

---

|             |   |
|-------------|---|
| apollo_sink | <i>Starts or stops writing output to a text file.</i> |
|-------------|---|

---

### Description

Starts or stops writing the output shown in the console to a file named "modelName\_additional\_output.txt".

### Usage

```
apollo_sink(apollo_inputs = NULL)
```

### Arguments

**apollo\_inputs** List grouping most common inputs. Created by function [apollo\\_validateInputs](#). If not provided, it will be looked for in the global environment.

### Details

After the first time this function is called, all output shown in the console will also be written to a text file called "modelName\_additional\_output.txt", where "modelName" is the modelName set inside apollo\_control. The second time this function is called, it stops writing the console output to the file. The user should always call this function an even number of times to close the output file and prevents data loss.

**Value**

Nothing.

---

|                  |  |
|------------------|--|
| apollo_speedTest | <i>Measures evaluation time of a model</i> |
|------------------|--|

---

**Description**

Measures the evaluation time of a model for different number of cores and draws.

**Usage**

```
apollo_speedTest(
  apollo_beta,
  apollo_fixed,
  apollo_probabilities,
  apollo_inputs,
  speedTest_settings = NA
)
```

**Arguments**

- apollo\_beta** Named numeric vector. Names and values for parameters.
- apollo\_fixed** Character vector. Names (as defined in `apollo_beta`) of parameters whose value should not change during estimation.
- apollo\_probabilities** Function. Returns probabilities of the model to be estimated. Must receive three arguments:
- `apollo_beta`: Named numeric vector. Names and values of model parameters.
  - `apollo_inputs`: List containing options of the model. See [apollo\\_validateInputs](#).
  - `functionality`: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".
- apollo\_inputs** List grouping most common inputs. Created by function [apollo\\_validateInputs](#).
- speedTest\_settings** List. Contains settings for this function. User input is required for all settings except those with a default or marked as optional.
- `nCoresTry`: Numeric vector. Number of threads to try. Default is from 1 to the detected number of cores.
  - `nDrawsTry`: Numeric vector. Number of inter and intra-person draws to try. Default value is `c(50, 100, 200)`.
  - `nRep`: Numeric scalar. Number of times the likelihood is evaluated for each combination of threads and draws. Default is 10.



**Details**

This function evaluates the function `apollo_probabilities` several times using different number of threads (a.k.a. processor cores), and draws (if the model uses mixing). It then plots the estimation time for each combination. Estimation time grows at least linearly with number of draws, while time savings decrease with the number of threads. This function can help decide what number of draws and cores to use for estimation, though a high number of draws is always recommended. If the computer will be used for additional activities during estimation, no more than (machine number of cores - 1) should be used. Using more threads than cores available in the machine will lead to reduce dperformance. The use of additional cores come at the expense of additional memory usage. If R uses more memory than the physical RAM available, then significant slow-downs in processing time can be expected. This function can help avoiding such pitfalls.

**Value**

A matrix with the average time per evaluation for each number of threads and draws combination. A graph is also plotted.

---

`apollo_swissRouteChoiceData`  
*Dataset of route choice.*

---

**Description**

A Stated Preference dataset containing 3,492 route choices among two alternatives.

**Usage**

```
apollo_swissRouteChoiceData
```

**Format**

A data frame with 3,492 rows and 16 variables:

- ID** Numeric. Identification number of the individual.
- choice** Numeric. Choice indicator, 1 for alternative 1, and 2 for alternative 2.
- tt1** Numeric. Travel time (in minutes) for alternative 1.
- tc1** Numeric. Travel cost (in CHF) for alternative 1.
- hw1** Numeric. Headway time (in minutes) for alternative 1.
- ch1** Numeric. Number of interchanges for alternative 1.
- tt2** Numeric. Travel time (in minutes) for alternative 2.
- tc2** Numeric. Travel cost (in CHF) for alternative 2.
- hw2** Numeric. Headway time (in minutes) for alternative 2.
- ch2** Numeric. Number of interchanges for alternative 2.
- hh\_inc\_abs** Numeric. Household income (in CHF per annum).

**car\_availability** Numeric. 1 if respondent has a car available, 0 otherwise.

**commute** Numeric. 1 if the purpose of the trip is commuting. 0 otherwise.

**shopping** Numeric. 1 if the purpose of the trip is shopping. 0 otherwise.

**business** Numeric. 1 if the purpose of the trip is business. 0 otherwise.

**leisure** Numeric. 1 if the purpose of the trip is leisure. 0 otherwise.

### Details

This dataset is to be used for discrete choice modelling. Data comes from 388 individuals who participated in a Stated Choice (SC) survey, providing a total of 3,492 observations. Each choice scenario includes two alternatives described in terms of travel time, cost, headway and interchanges. Additional information on respondents is available. This dataset comes from the following publication. Vrtic, M. & Axhausen, K.W. (2003), The impact of tilting trains in Switzerland: A route choice model of regional and long distance public transport trips. 82nd annual meeting of the transportation research board, Washington, DC.

### Source

<http://www.apollochoicemodelling.com/>

---

apollo\_timeUseData      *Dataset of time use.*

---

### Description

A Revealed Preference dataset containing 2,826 full-day observations.

### Usage

apollo\_timeUseData

### Format

An object of class `data.frame` with 2826 rows and 20 columns.

### Details

This dataset is to be used for Multiple Discrete Continuous (MDC) modelling. Data comes from 447 individuals who provided activity diaries for a total of 2,826 days. Each observation summarizes the amount of time spent in each of twelve different activities. The dataset also includes characteristics of the participants. This dataset comes from the following publication. Calastri, C., Crastes dit Sourd, R. and Hess, S. (2020) We want it all: experiences from a survey seeking to capture social network structures, lifetime events and short-term travel and activity planning. *Transportation*, 47(1), pp. 175-201.

**individ** Numeric. Identification number of the individual.

**day** Numeric. Index of the day for each observation (day 1 was excluded).

**date** Numeric. Date in format yyyyymmdd.

**budget** Numeric. Total amount of time registered during the day (in minutes).

**t\_a01** Numeric. Time spent dropping-of or picking up other people (in minutes).

**t\_a02** Numeric. Time spent working (in minutes).

**t\_a03** Numeric. Time spent on educational activities (in minutes).

**t\_a04** Numeric. Time spent shopping (in minutes).

**t\_a05** Numeric. Time spent on private business (in minutes).

**t\_a06** Numeric. Time spent getting petrol (in minutes).

**t\_a07** Numeric. Time spent on social or leisure activities (in minutes).

**t\_a08** Numeric. Time spent on vacation or long (inter-city) travel (in minutes).

**t\_a09** Numeric. Time spent doing exercise (in minutes).

**t\_a10** Numeric. Time spent at home (in minutes).

**t\_a11** Numeric. Time spent travelling (everyday travelling) (in minutes).

**t\_a12** Numeric. Non-allocated time (in minutes).

**female** Numeric. 1 if respondent is female. 0 otherwise.

**age** Numeric. Age of respondent (in years, approximate).

**occ\_full\_time** Numeric. 1 if the respondent works full time.

**weekend** Numeric. 1 if the current date is a weekend.

### Source

<http://www.apollochoicemodelling.com/>

---

apollo\_unconditionals *Returns draws for continuously distributed random parameters in mixture model*

---

### Description

Returns draws (unconditionals) for random parameters in model, including interactions with deterministic covariates.

### Usage

```
apollo_unconditionals(model, apollo_probabilities, apollo_inputs)
```

**Arguments**

|                      |  |
|----------------------|--|
| model                | Model object. Estimated model object as returned by function <a href="#">apollo_estimate</a> .   |
| apollo_probabilities | Function. Returns probabilities of the model to be estimated. Must receive three arguments: <ul style="list-style-type: none"> <li>• <code>apollo_beta</code>: Named numeric vector. Names and values of model parameters.</li> <li>• <code>apollo_inputs</code>: List containing options of the model. See <a href="#">apollo_validateInputs</a>.</li> <li>• <code>functionality</code>: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares_LL", "validate" or "zero_LL".</li> </ul> |
| apollo_inputs        | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |

**Details**

This functions is only meant for use with continuous distributions

**Value**

List of object, one per random coefficient. With inter-individual draws only, this will be a matrix, with one row per individual, and one column per draw. With intra-individual draws, this will be a three-dimensional array, with one row per observation, inter-individual draws in the second dimension, and intra-individual draws in the third dimension.

---

|                 |   |
|-----------------|---|
| apollo_validate | <i>Pre-process input for common models return</i> |
|-----------------|---|

---

**Description**

Pre-process input for common models return

**Usage**

```
apollo_validate(inputs, modelType, functionality, apollo_inputs)
```

**Arguments**

|               |   |
|---------------|---|
| inputs        | List of settings  |
| modelType     | Character. Type of model, e.g. "mnl", "nl", "cml", etc.   |
| functionality | Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call <code>apollo_probabilities</code> , though the user can also call <code>apollo_probabilities</code> manually with a given functionality for testing/debugging. Possible values are: <ul style="list-style-type: none"> <li>• "components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> </ul> |

- "conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.
- "estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "gradient": For model estimation, produces analytical gradients of the likelihood, where possible.
- "output": Prepares output for post-estimation reporting.
- "prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.
- "preprocess": Prepares likelihood functions for use in estimation.
- "raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.
- "report": Prepares output summarising model and choicest structure.
- "shares\_LL": Produces overall model likelihood with constants only.
- "validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.
- "zero\_LL": Produces overall model likelihood with all parameters at zero.

apollo\_inputs List of main inputs to the model estimation process. See [apollo\\_validateInputs](#).

## Value

The returned object depends on the value of argument operation

---

apollo\_validateControl

*Validates apollo\_control*

---

## Description

Validates the options controlling the running of the code `apollo_control` and sets default values for the omitted ones.

## Usage

```
apollo_validateControl(database, apollo_control, silent = FALSE)
```

## Arguments

database data.frame. Data used by model.

apollo\_control List. Options controlling the running of the code. User input is required for all settings except those with a default or marked as optional.

- calculateLLC: Boolean. TRUE if user wants to calculate LL at constants (if applicable). - TRUE by default.
- HB: Boolean. TRUE if using RSGHB for Bayesian estimation of model.
- indivID: Character. Name of column in the database with each decision maker's ID.
- mixing: Boolean. TRUE for models that include random parameters.
- modelDescr: Character. Description of the model. Used in output files.
- modelName: Character. Name of the model. Used when saving the output to files.
- nCores: Numeric>0. Number of cores to use in calculations of the model likelihood.
- noDiagnostics: Boolean. TRUE if user does not wish model diagnostics to be printed - FALSE by default.
- noValidation: Boolean. TRUE if user does not wish model input to be validated before estimation - FALSE by default.
- outputDirectory: Character. Optional directory for outputs if different from working director - empty by default
- panelData: Boolean. TRUE if there are multiple observations (i.e. rows) for each decision maker - Automatically set based on indivID by default.
- seed: Numeric. Seed for random number generation.
- weights: Character. Name of column in database containing weights for estimation.
- workInLogs: Boolean. TRUE for increased numeric precision in models with panel data - FALSE by default.

silent            Boolean. If TRUE, no messages are printed to screen.

### Details

This function should be run before running apollo\_validateData.

### Value

Validated version of apollo\_control, with additional element called panelData set to TRUE for repeated choice data.

---

apollo\_validateData    *Validates data*

---

### Description

Checks consistency of the database with apollo\_control, sorts it by indivID, and adds an internal ID variable (apollo\_sequence)

### Usage

```
apollo_validateData(database, apollo_control, silent)
```

**Arguments**

|                |  |
|----------------|--|
| database       | data.frame. Data used by model.  |
| apollo_control | List. Options controlling the running of the code. See <a href="#">apollo_validateInputs</a> . |
| silent         | Boolean. TRUE to keep the function from printing to the console. Default is FALSE.             |

**Details**

This function should be called after calling [apollo\\_validateControl](#). Observations are sorted only if `apollo_control$panelData=TRUE`.

**Value**

Data.frame. Validated version of database.

---

apollo\_validateHBControl

*Validates the apollo\_HB list of parameters*

---

**Description**

Validates the apollo\_HB list of parameters and sets default values for the omitted ones.

**Usage**

```
apollo_validateHBControl(
  apollo_HB,
  apollo_beta,
  apollo_fixed,
  apollo_control,
  silent = FALSE
)
```

**Arguments**

|           |   |
|-----------|---|
| apollo_HB | List. Contains options for Bayesian estimation. See <code>?RSGHB::doHB</code> for details. Parameters <code>modelName</code> , <code>gVarNamesFixed</code> , <code>gVarNamesNormal</code> , <code>gDIST</code> , <code>svN</code> and <code>FC</code> are automatically set based on the other arguments of this function. Other settings to include are the following. <ul style="list-style-type: none"> <li><code>constraintNorm</code>: Character vector. Constraints for <i>random</i> coefficients in bayesian estimation. Constraints can be written as "b1&gt;b2", "b1&lt;b2", "b1&gt;0", or "b1&lt;0".</li> <li><code>fixedA</code>: Named numeric vector. Contains the names and fixed mean values of random parameters. For example, <code>c(b1=0)</code> fixes the mean of b1 to zero.</li> <li><code>fixedD</code>: Named numeric vector. Contains the names and fixed variance of random parameters. For example, <code>c(b1=1)</code> fixes the variance of b1 to zero.</li> </ul> |
|-----------|---|

- gNCREP: Numeric. Number of burn-in iterations to use prior to convergence (default=10<sup>5</sup>).
- gNEREP: Numeric. Number of iterations to keep for averaging after convergence has been reached (default=10<sup>5</sup>).
- gINFOSKIP: Numeric. Number of iterations between printing/plotting information about the iteration process (default=250).
- hbDist: *Mandatory* setting. A named character vector determining the distribution of each parameter to be estimated. Possible values are as follows.
  - "CN+": Positive censored normal.
  - "CN-": Negative censored normal.
  - "JSB": Johnson SB.
  - "LN+": Positive log-normal.
  - "LN-": Negative log-normal.
  - "N": Normal.
  - "NR": Fixed (as in non-random) parameter.

|                |  |
|----------------|--|
| apollo_beta    | Named numeric vector. Names and values for parameters.   |
| apollo_fixed   | Character vector. Names (as defined in apollo_beta) of parameters whose value should not change during estimation. value is constant throughout estimation). |
| apollo_control | List. Options controlling the running of the code. See <a href="#">apollo_validateInputs</a> .   |
| silent         | Boolean. TRUE to keep the function from printing to the console. Default is FALSE.   |

### Details

This function is only necessary when using bayesian estimation.

### Value

Validated apollo\_HB

---

apollo\_validateInputs *Prepares input for apollo\_estimate*

---

### Description

Searches the user work space (.GlobalEnv) for all necessary input to run apollo\_estimate, and packs it in a single list.



**Usage**

```
apollo_validateInputs(
  apollo_beta = NA,
  apollo_fixed = NA,
  database = NA,
  apollo_control = NA,
  apollo_HB = NA,
  apollo_draws = NA,
  apollo_randCoeff = NA,
  apollo_lcPars = NA,
  recycle = FALSE,
  silent = FALSE
)
```

**Arguments**

- |                |   |
|----------------|---|
| apollo_beta    | Named numeric vector. Names and values for parameters.  |
| apollo_fixed   | Character vector. Names (as defined in apollo_beta) of parameters whose value should not change during estimation.  |
| database       | data.frame. Data used by model.   |
| apollo_control | List. Options controlling the running of the code. User input is required for all settings except those with a default or marked as optional. <ul style="list-style-type: none"> <li>• calculateLLC: Boolean. TRUE if user wants to calculate LL at constants (if applicable). - TRUE by default.</li> <li>• HB: Boolean. TRUE if using RSGHB for Bayesian estimation of model.</li> <li>• indivID: Character. Name of column in the database with each decision maker's ID.</li> <li>• mixing: Boolean. TRUE for models that include random parameters.</li> <li>• modelDescr: Character. Description of the model. Used in output files.</li> <li>• modelName: Character. Name of the model. Used when saving the output to files.</li> <li>• nCores: Numeric&gt;0. Number of cores to use in calculations of the model likelihood.</li> <li>• noDiagnostics: Boolean. TRUE if user does not wish model diagnostics to be printed - FALSE by default.</li> <li>• noValidation: Boolean. TRUE if user does not wish model input to be validated before estimation - FALSE by default.</li> <li>• outputDirectory: Character. Optional directory for outputs if different from working director - empty by default</li> <li>• panelData: Boolean. TRUE if there are multiple observations (i.e. rows) for each decision maker - Automatically set based on indivID by default.</li> <li>• seed: Numeric. Seed for random number generation.</li> <li>• weights: Character. Name of column in database containing weights for estimation.</li> </ul> |

- workInLogs: Boolean. TRUE for increased numeric precision in models with panel data - FALSE by default.
- apollo\_HB List. Contains options for Bayesian estimation. See ?RSGHB::doHB for details. Parameters modelName, gVarNamesFixed, gVarNamesNormal, gDIST, svN and FC are automatically set based on the other arguments of this function. Other settings to include are the following.
- constraintNorm: Character vector. Constraints for *random* coefficients in bayesian estimation. Constraints can be written as "b1>b2", "b1<b2", "b1>0", or "b1<0".
  - fixedA: Named numeric vector. Contains the names and fixed mean values of random parameters. For example, c(b1=0) fixes the mean of b1 to zero.
  - fixedD: Named numeric vector. Contains the names and fixed variance of random parameters. For example, c(b1=1) fixes the variance of b1 to zero.
  - gNCREP: Numeric. Number of burn-in iterations to use prior to convergence (default=10^5).
  - gNEREP: Numeric. Number of iterations to keep for averaging after convergence has been reached (default=10^5).
  - gINFOSKIP: Numeric. Number of iterations between printing/plotting information about the iteration process (default=250).
  - hbDist: *Mandatory* setting. A named character vector determining the distribution of each parameter to be estimated. Possible values are as follows.
    - "CN+": Positive censored normal.
    - "CN-": Negative censored normal.
    - "DNE": Parameter kept at its starting value (not estimated).
    - "JSB": Johnson SB.
    - "LN+": Positive log-normal.
    - "LN-": Negative log-normal.
    - "N": Normal.
    - "NR": Fixed (as in non-random) parameter.
- apollo\_draws List of arguments describing the inter and intra individual draws. Required only if apollo\_control\$mixing = TRUE. Unused elements can be omitted.
- interDrawsType: Character. Type of inter-individual draws ('halton', 'mlhs', 'pmc', 'sobel', 'sobelOwen', 'sobelFaureTezuka', 'sobelOwenFaureTezuka' or the name of an object loaded in memory, see manual in <http://www.ApolloChoiceModelling.com> for details).
  - interNDraws: Numeric scalar ( $\geq 0$ ). Number of inter-individual draws per individual. Should be set to 0 if not using them.
  - interNormDraws: Character vector. Names of normally distributed inter-individual draws.
  - interUnifDraws: Character vector. Names of uniform-distributed inter-individual draws.
  - intraDrawsType: Character. Type of intra-individual draws ('halton', 'mlhs', 'pmc', 'sobel', 'sobelOwen', 'sobelOwenFaureTezuka' or the name of an object loaded in memory).
  - intraNDraws: Numeric scalar ( $\geq 0$ ). Number of intra-individual draws per individual. Should be set to 0 if not using them.

|                               |  |
|-------------------------------|--|
|                               | <ul style="list-style-type: none"> <li>• <code>intraUnifDraws</code>: Character vector. Names of uniform-distributed intra-individual draws.</li> <li>• <code>intraNormDraws</code>: Character vector. Names of normally distributed intra-individual draws.</li> </ul>  |
| <code>apollo_randCoeff</code> | <p>Function. Used with mixing models. Constructs the random parameters of a mixing model. Receives two arguments:</p> <ul style="list-style-type: none"> <li>• <code>apollo_beta</code>: Named numeric vector. Names and values of model parameters.</li> <li>• <code>apollo_inputs</code>: The output of this function (<code>apollo_validateInputs</code>).</li> </ul>   |
| <code>apollo_lcPars</code>    | <p>Function. Used with latent class models. Constructs a list of parameters for each latent class. Receives two arguments:</p> <ul style="list-style-type: none"> <li>• <code>apollo_beta</code>: Named numeric vector. Names and values of model parameters.</li> <li>• <code>apollo_inputs</code>: The output of this function (<code>apollo_validateInputs</code>).</li> </ul>  |
| <code>recycle</code>          | <p>Logical. If TRUE, an older version of <code>apollo_inputs</code> is looked for in the calling environment (parent frame), and any element in that old version created by the user is copied into the new <code>apollo_inputs</code> returned by this function. For <code>recycle=TRUE</code> to work, the old version of <code>apollo_inputs</code> <b>must</b> be named "apollo_inputs". If FALSE, nothing is copied from any older version of <code>apollo_inputs</code>. FALSE is the default.</p> |
| <code>silent</code>           | <p>Logical. TRUE to keep the function from printing to the console. Default is FALSE.</p>  |

### Details

All arguments to this function are optional. If the function is called without arguments, then it will look in the user workspace (i.e. the global environment) for variables with the same name as its omitted arguments. We strongly recommend users to visit <http://www.ApolloChoiceModelling.com> for examples on how to use Apollo. In the website, users will also find a detailed manual and a user-group for help and further reference.

### Value

List grouping several required input for model estimation.

---

`apollo_varcov`

*Calculates variance-covariance matrix of an Apollo model*

---

### Description

Calculates the Hessian, variance-covariance matrix and standard errors of an Apollo model as defined by its likelihood function and `apollo_inputs` list of settings. Performs automatic scaling for increased numeric stability.

**Usage**

```
apollo_varcov(apollo_beta, apollo_fixed, varcov_settings)
```

**Arguments**

- apollo\_beta**      Named numeric vector. Names and values of parameters at which to calculate the covariance matrix. Values **must not be scaled**, and they must include any fixed parameter.
- apollo\_fixed**      Character vector. Names of fixed parameters.
- varcov\_settings**  
List of settings defining the behaviour of this function. It must contain at least one of the following: `apollo_logLike`, `apollo_grad` or `apollo_inputs` together with `apollo_probabilities`.
- `apollo_grad`: Function to calculate the gradient of the model, as returned by [apollo\\_makeGrad](#).
  - `apollo_inputs`: List grouping most common inputs. Created by function [apollo\\_validateInputs](#).
  - `apollo_logLike`: Function to calculate the log-likelihood of the model, as returned by [apollo\\_makeLogLike](#).
  - `apollo_probabilities`: `apollo_probabilities` Function. Returns probabilities of the model to be estimated. Must receive three arguments:
    - `apollo_beta`: Named numeric vector. Names and values of model parameters.
    - `apollo_inputs`: List containing options of the model. See [apollo\\_validateInputs](#).
    - `functionality`: Character. Can be either "components", "conditionals", "estimate" (default), "gradient", "output", "prediction", "preprocess", "raw", "report", "shares\_LL", "validate" or "zero\_LL".
  - `hessianRoutine`: Character. Name of routine used to calculate the Hessian. Valid values are "analytic", "numDeriv", "maxLik" or "none" to avoid estimating the Hessian and covariance matrix.
  - `numDeriv_settings`: List. Additional arguments to the Richardson method used by `numDeriv` to calculate the Hessian. See argument `method.args` in [grad](#) for more details.
  - `scaleBeta`: Logical. If TRUE (default), parameters are scaled by their own value before calculating the Hessian to increase numerical stability. However, the output is de-scaled, so they are in the same scale as the `apollo_beta` argument.

**Details**

It calculates the Hessian, variance-covariance, and standard errors at `apollo_beta` values of an estimated model. At least one of the following settings must be provided (ordered by speed of computation): `apollo_grad`, `apollo_logLike`, or (`apollo_probabilities` and `apollo_inputs`). If more than one is provided, then the priority is: `apollo_grad`, `apollo_logLike`, (`apollo_probabilities` and `apollo_inputs`).

**Value**

List with the following elements

- apollo\_beta: Named numerical vector. Parameter estimates (model\$estimate, not scaled).
- corrmatrix: Numerical matrix. Correlation between parameter estimates.
- hessian: Numerical matrix. Hessian of the model at parameter estimates (model\$estimate).
- hessianScaling: Named numeric vector. Scales used on the parameters to calculate the Hessian (non-fixed only).
- methodsAttempted: Character vector. Name of methods attempted to calculate the Hessian.
- methodUsed: Character. Name of method used to calculate the Hessian.
- robccorrmatrix: Numerical matrix. Robust correlation between parameter estimates.
- robse: Named numerical vector. Robust standard errors of parameter estimates.
- robvcov: Numerical matrix. Robust variance-covariance matrix.
- se: Named numerical vector. Standard errors of parameter estimates.
- varcov: Numerical matrix. Variance-covariance matrix.

---

apollo\_varList

*Lists variable names and definitions used inside a function*

---

**Description**

Returns a list containing the names and definitions of variables in `f`, `apollo_randCoeff` and `apollo_lcParams`

**Usage**

```
apollo_varList(f, apollo_inputs)
```

**Arguments**

`f` A function, usually `apollo_probabilities`

`apollo_inputs` List grouping most common inputs. Created by function [apollo\\_validateInputs](#).

**Details**

It looks for variable definitions inside `f`, `apollo_randCoeff`, and `apollo_lcParams`. It returns them in a list.

**Value**

A list of expressions containing all definitions in `f`, `apollo_randCoeff` and `apollo_probabilities`

---

|                  |                        |
|------------------|------------------------|
| apollo_weighting | <i>Applies weights</i> |
|------------------|------------------------|

---

### Description

Applies weights to individual observations in likelihood function.

### Usage

```
apollo_weighting(P, apollo_inputs, functionality)
```

### Arguments

- |               |  |
|---------------|--|
| P             | List of vectors, matrices or 3-dim arrays. Likelihood of the model components.   |
| apollo_inputs | List grouping most common inputs. Created by function <a href="#">apollo_validateInputs</a> .  |
| functionality | Character. Setting instructing Apollo what processing to apply to the likelihood function. This is in general controlled by the functions that call <code>apollo_probabilities</code> , though the user can also call <code>apollo_probabilities</code> manually with a given functionality for testing/debugging. Possible values are: <ul style="list-style-type: none"> <li>"components": For further processing/debugging, produces likelihood for each model component (if multiple components are present), at the level of individual draws and observations.</li> <li>"conditionals": For conditionals, produces likelihood of the full model, at the level of individual inter-individual draws.</li> <li>"estimate": For model estimation, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>"gradient": For model estimation, produces analytical gradients of the likelihood, where possible.</li> <li>"output": Prepares output for post-estimation reporting.</li> <li>"prediction": For model prediction, produces probabilities for individual alternatives and individual model components (if multiple components are present) at the level of an observation, after averaging across draws.</li> <li>"preprocess": Prepares likelihood functions for use in estimation.</li> <li>"raw": For debugging, produces probabilities of all alternatives and individual model components at the level of an observation, at the level of individual draws.</li> <li>"report": Prepares output summarising model and choiceset structure.</li> <li>"shares_LL": Produces overall model likelihood with constants only.</li> <li>"validate": Validates model specification, produces likelihood of the full model, at the level of individual decision-makers, after averaging across draws.</li> <li>"zero_LL": Produces overall model likelihood with all parameters at zero.</li> </ul> |

**Value**

The likelihood (i.e. probability in the case of choice models) of the model in the appropriate form for the given functionality, multiplied by individual-specific weights.

---

|                 |                           |
|-----------------|---------------------------|
| apollo_writeF12 | <i>Writes an F12 file</i> |
|-----------------|---------------------------|

---

**Description**

Writes an F12 file (ALogit format) with the results of a model estimation.

**Usage**

```
apollo_writeF12(model, truncateCoeffNames = TRUE)
```

**Arguments**

|                    |  |
|--------------------|--|
| model              | Model object. Estimated model object as returned by function <a href="#">apollo_estimate</a> . |
| truncateCoeffNames | Boolean. TRUE to truncate parameter names to 10 characters. FALSE by default.                  |

**Value**

Nothing.

---

|                   |  |
|-------------------|--|
| apollo_writeTheta | <i>Writes the vector [beta,ll] to a file called modelname_iterations.csv</i> |
|-------------------|--|

---

**Description**

Writes the vector [beta,ll] to a file called modelname\_iterations.csv

**Usage**

```
apollo_writeTheta(beta, ll, modelName)
```

**Arguments**

|           |  |
|-----------|--|
| beta      | vector of parameters to be written (including fixed ones). |
| ll        | scalar representing the log-likelihood of the whole model. |
| modelName | Character. Name of the model.                              |

**Value**

Nothing.

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